DESIGN A DSM ORIENTED, TIME OF USE (TOU) TARIFF MODEL FOR DOMESTIC CONSUMERS WITH A LOAD RESEARCH

Erandi Heshani Udageachchi

(159379K)

Dissertation submitted in partial fulfillment of the requirements for the Degree Master of Science

Department of Electrical Engineering

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DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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The above candidate has carried out research for the Masters Dissertation under our supervision.

…….

Signature of the supervisor Date:

(Dr. Asanka Rodrigo)

ABSTRACT

The night-time peak demand drives the sector investments and hence has become a major target area for Demand Side Management programs aimed at energy conservation and efficiency improvement. Time Of Use (TOU) Tariffs are perceived as a major tool to curb the peak demand.

Further, with the growth of the usage of electrical vehicles, there is a tendency of increasing the peak demand because of the charging load. The introduction of the TOU tariff will shift the charging load to off peak hours and the domestic consumers will get the opportunity to charge their vehicles at a cheaper rate. If the charging of electric vehicle at the off-peak hours can be encouraged, the valley in the load profile at the off-peak hours can also be filled while clipping the peak demand.

With those intensions, an optional TOU Tariff has been introduced to domestic customers of Sri Lanka in 2015. But the prevailing TOU tariff has not been derived after a load research and it is not attractive to the domestic consumers.

The effectiveness of the existing TOU tariff for domestic consumers was analysed in this study. Further an effective TOU tariff for domestic consumers was proposed and the appropriateness of the proposed TOU tariff for the domestic consumers in each block was identified. The benefits of implementing the proposed TOU tariff were also quantified.

ACKNOWLEDGEMENT

Foremost, I pay my sincere gratitude to Dr. Asanka Rodrigo who encouraged and guided me to conduct this research and on perpetration of final dissertation.

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LIST OF ABBREVIATIONS

Abbreviation	Description
CEB	Ceylon Electricity Board
CPP	Critical Peak-Pricing
DSM	Demand Side Management
EDP	extreme day pricing
GWh	Giga watt hour
kWh	kilo watt hour
LECO	Lanka Electricity Company (Pvt) Ltd.
LKR	Sri Lankan Rupee
Mn	Million
MW	Mega watt
PUCSL	Public Utilities Commission of Sri Lanka
TOU	Time Of Use
USA	United States of America
WPN	Western Province North

CHAPTER 1

1 INTRODUCTION

1.1 Background

The cost of supplying electricity differs with the time of the day. Cost of supplying one unit of electricity during the peak hours is more than that of off-peak hours. The system control center has to dispatch powerplants with higher generation cost due to higher demand. The Time of Use pricing is a mechanism to price the units of electricity depending on the time of its usage and it is also a pricing technique which reflects the cost of supply to a greater extent.

The large investments in the electricity sector are driven by the night-time peak demand. Time Of Use (TOU) pricing is considered as a Demand Side Management program to curb the peak demand.

Time Of Use (TOU) Tariffs provide an indication of network congestion time of the day to the consumers and thus the consumers will willingly shift their loads from peak to off peak hours to get the incentive. The clipping of peak demand reduces the energy cost and in the long run it will lower the investment requirements.

Further, the growth in the usage of electrical vehicles, might contribute to the increase of the peak demand because the consumers are not aware of the network congestion time and they might charge their vehicles at peak hours. Introducing TOU tariff scheme is a solution for the above mentioned issue and it will provide the domestic consumers the opportunity to charge their vehicles at a cheaper rate.

There is another advantage of having a TOU tariff. When there is significant change in costs, adjusting the tariffs would be easier with TOU tariffs, compared to block tariff.

1.2 Objectives Of The Study

The main objective of the study is to design a DSM oriented TOU tariff for domestic consumers with the results of a load research. The existing TOU tariff scheme has not been attractive among the domestic consumers. Studying the effectiveness of the existing TOU tariff and

identify the customers who can be benefited with the existing TOU tariff are also objectives of this study.

After proposing a new TOU tariff, the next objective is to analyse the proposed tariff schemes. The appropriateness of those tariff schemes for the domestic consumers in each block was identified. Then the financial impact of introducing the proposed TOU tariff, on the utilities was studied.

CHAPTER 2

2 LITERATURE REVIEW

2.1 TOU Pricing Models In The World

Time-dependent tariffs are popular in many developed countries. In most of the cases, the TOU tariffs are mandatory for large commercial and industrial customers while they are optional for residential customers. For larger customers, the peak to off-peak ratios are typically high. For example, in Victoria (Australia), the peak to off-peak ratio is in between 2:1 and 3:1 for low voltage customers and for high voltage customers the ratio is in between 3:1 and 5:1. Some countries have gone beyond the traditional TOU pricing by introducing Critical Peak-Pricing (CPP), Extreme Day Pricing (EDP) and Real Time Pricing (RTP).

2.2 How Customers Have Responded To Time Varying Pricing

- Arizona, USA

  Over 20 years, "Arizona Public Service" has enrolled 51% of its customers on an optional TOU rate and "Salt river Project Power and Water" has enrolled about 30% of its customers on an optional TOU rate.
- Oklahoma, USA

  Within three years, "Oklahoma Gas and Electric (OG&E)" was able to enroll 100,000+ customers on TOU pricing. In the near future the number is expected to reach 20% of its customer.
- Australia

  In Australia 20% of AusGrid's (Sydney) residential customers has enrolled on TOU rates
- Ontario, Canada

  About 90% of residential customers have chosen the TOU tariff
- Italy

  In Italy, about 23 million residential and small-medium enterprises are consuming electricity under the TOU rates.
- France

  In France, about one third of customers in Électricité de France (EDF) are on TOU tariff. It is one of the most successful examples of TOU tariff.

2.3 Green Energy UK Has Launched Time-Of-Use Tariff

- Green Energy has introduced a new TOU tariff called "Tide" on 03/01/2017 and it is the second time-of-use tariff to be launched in the United Kingdom. In the first TOU tariff, called the 'Free Time' tariff, electricity was provided without a charge to smart meter customers between 9am and 5pm on weekends.

  Tide is an optional tariff. Green Energy UK has 20,000 customers and around 8,000 customers already have smart meters. If the customers who do not have smart meters, like to shift to TOU tariff, Green Energy UK will install the meters for them.

Table 2-1: TOU Tariff rates at Green Energy UK

Time interval	Rate (p/kWh)
4 pm to 7 pm - 'High Tide'	24.99
11 pm to 6 am - 'Low tide'	4.99
Rest of the time	11.99

Source: [8]

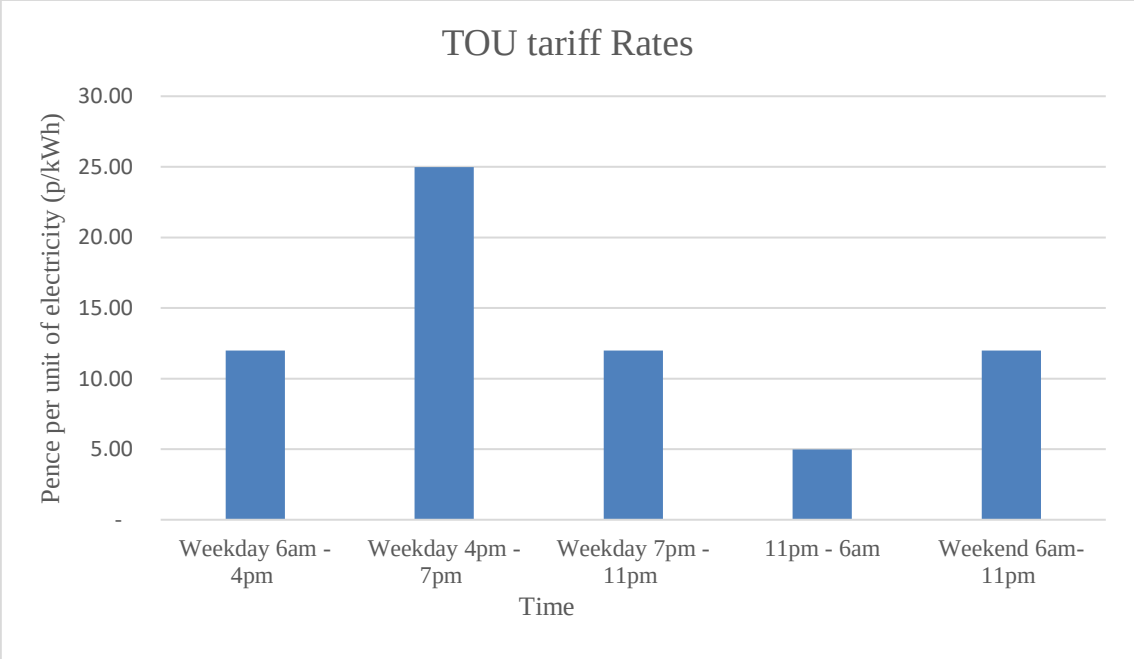

Figure 2-4:TOU Tariff rates at Green Energy UK

Source: [8]

2.4 Australian Time Of Use Pricing

In all regions of Australia, the domestic customers have the capability of moving to optional time-of-use tariffs. On weekends and public holidays, there are no peak rates in most of the areas. In the Northern Territory, Time of Use rates are applied on weekday and public holidays. In South Australia, the time dependent rates are applied only in Summer (from 1st of November to the 31st of March).

The Table 2-2 shows the different time of use rates in different states of Australia.

Table 2-2: Time of use rates in different states of Australia

Region		Off-Peak	Shoulder	Peak
New South Wales	*Time intervals*	*10pm-6:59am*	*7am-1:59pm,8pm-9:59pm*	*2pm-7:59pm*
	Rate	10 cents	18 cents	43 cents
Victoria	*Time intervals*	*10pm-6:59am*	*7am-2:59pm, 9pm-9:59pm*	*3pm-8:59pm*
	Rate	10 cents	17 cents	23.5 cents
Queensland	*Time intervals*	*10pm-6:59am*	*7am-3:59, 8:00pm-9:59pm*	*4pm-7:59pm*
	Rate	18 cents	23 cents	33 cents
Western Australia	*Time intervals*	*9pm-6:59am*	*7am-2:59pm,*	*3pm-8:59pm*
	Rate	13 cents	25 cents	48 cents
South Australia	*Time intervals*	*9pm-3:59pm*	*4pm-8:59pm winter only*	*4pm-8:59pm summer only*
	Rate	20 cents	24 cents	49 cents
Australian Capital Territory	*Time intervals*	*10pm-6:59am*	*9pm-4:59pm, 8pm-9:59pm*	*7am-8:59am, 5pm-7:59pm*
	Rate	10 cents	14 cents	21 cents
Northern Territory	*Time intervals*	*6pm-5:59am*		*6am-5:59pm*
	Rate	23 cents		30 cents

Source: [12]

2.5 Time Of Use Tariff To Residential Customers In Italy

Starting from 1st July 2010, Italian Authority for Electricity and Gas (AEEG) approved a mandatory TOU tariff scheme. There are only two parts in this time of use tariff.

- F1 time slot- Peak hours : 8.00 am to 7.00 pm
- F2 time slot - Off peak hours : remaining hours

There was a transition period up to 31st December 2011 and in that period the variation between the peak and off-peak price was small. From 1st January 2012, regular period started with a relatively large difference between the peak and off-peak price.

Table 2-3: Difference in Energy prices between flat tariff and rates of TOU tariff

Energy price difference	
Difference in Energy prices between flat tariff and Peak rate of ToU tariff	-0.0059 Euro/kWh
Difference in Energy prices difference between flat tariff and off-peak rate of TOU tariff	0.00295 Euro/kWh

Source: [4]

With the introduction of mandatory TOU tariff, only a small shift of consumption from peak hours to off-peak hours was observed. But the usage of energy efficient appliances has increased. Because of the introduction of the mandatory TOU tariff the overall saving during the period of July 2010-June 2012 was 6.75 Million Euro.

2.5.1 Effect Of Tariff Change On The Load Curve

Average energy shifts from peak to off peak hours on average working day in different sessions are stated in the Table 2-3.

Table 2-4: Energy shifts from peak to off peak hours

Winter 2012-2011		Spring 2012-2011		Summer 2012-2011	
Δ peak hours	**Δ off-peak hours**	**Δ peak hours**	**Δ off-peak hours**	**Δ peak hours**	**Δ off-peak hours**
0.39%	-0.39%	0.50%	-0.50%	-0.56%	0.56%

Source: [4]

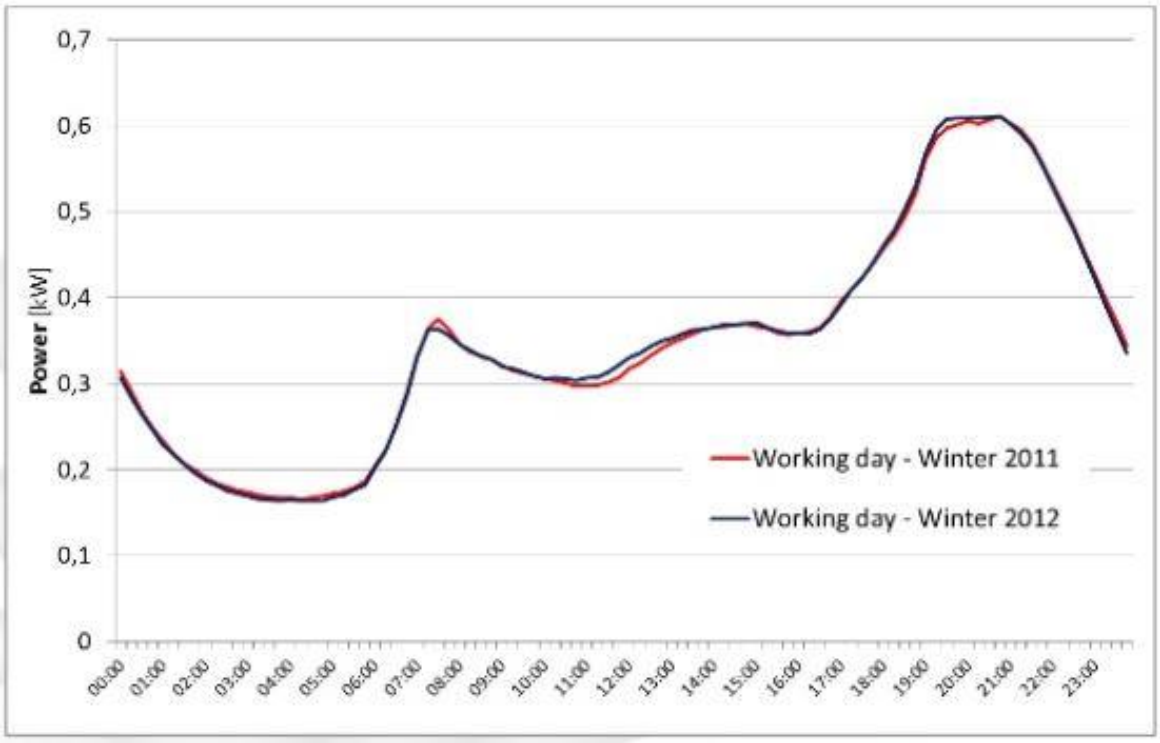

Figure 2-5:Energy shifts from peak to off peak hours in Winter

Source: [4]

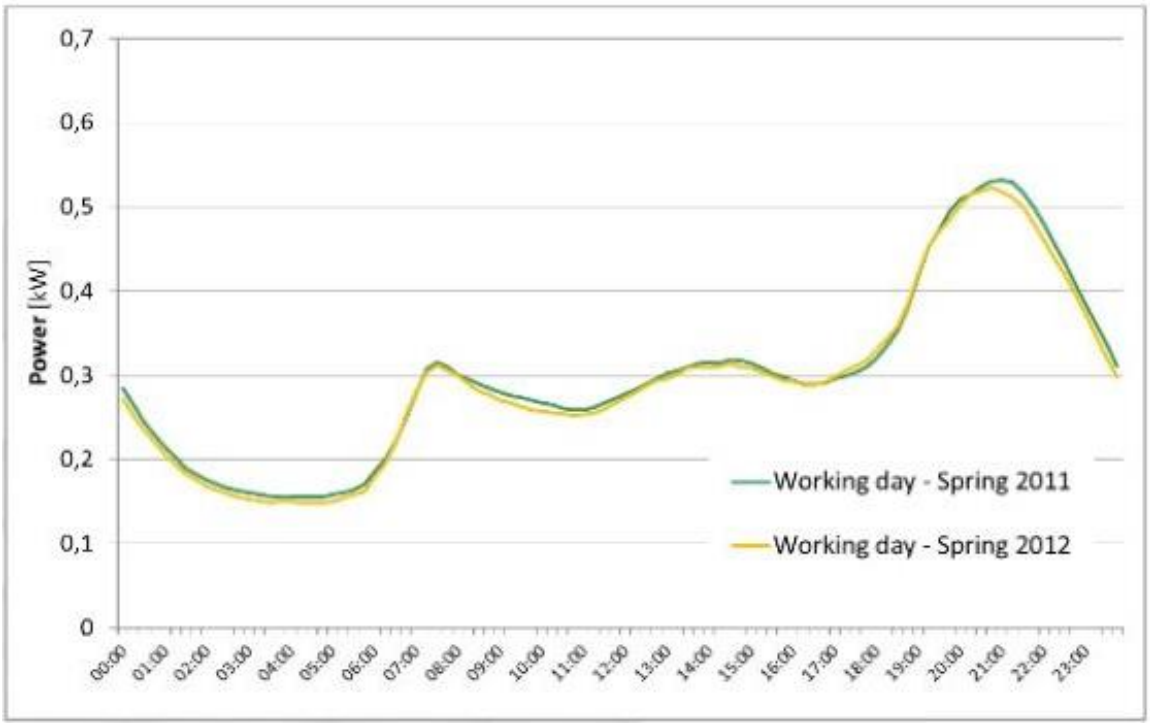

Figure 2-3: Energy shifts from peak to off peak hours in Spring

Source: [4]

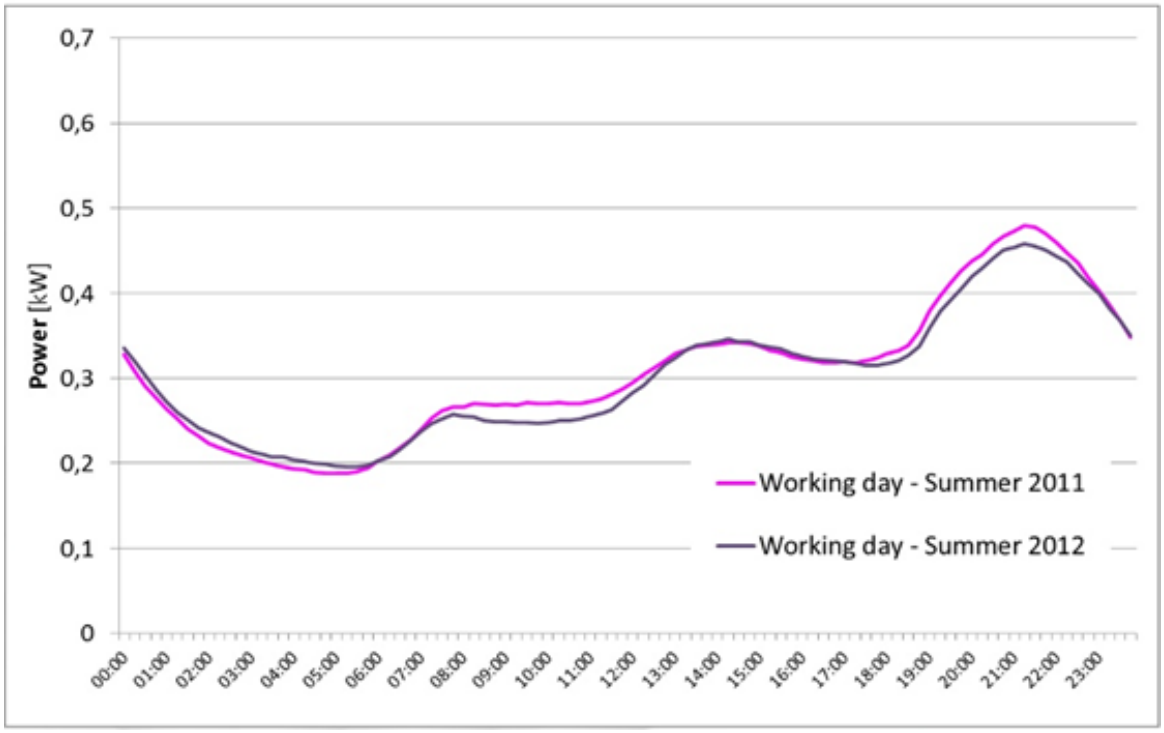

Figure 2-4: Energy shifts from peak to off peak hours in Summer

Source: [4]

They have not experienced a big shift of consumption from peak to off peak because of reasons like weak pricing signal and more than 50% of customers are benefited by TOU tariff even without shifting their loads. The TOU tariff can be made more effective by increasing the pricing signal, revising the allocation of the hours between peak and off-peak hours and also introducing “Critical Peak Pricing”.

2.6 Time Of Use Tariff To Residential Customers In South Africa

- In South Africa “City Power” has introduced a residential optional time-of-use tariff effective from 1st July 2015. Customers who want to shift to TOU tariff, have to install meters with the automatic meter reading capability.
- With the implementation of this program City Power is able to remotely and automatically switch off geysers during the peak periods.
- Customers who shift to the time-of-use tariff are free to choose the appliances which will be switched off during the peak period.
- Peak periods are in weekdays from 7am to 10am and from 6pm to 9pm.

Table 2-5: TOU tariff rates for single phase customers

Supply	**Service Charge R/month**	**Capacity Charge R/month**	**Energy charge (c/kWh)**	
			Summer	**Winter**
Peak	60A:105.29 80A:105.29	60A:310.28 80A:341.06	123.29	294.04
Standard			97.53	117.41
Off-Peak			76.73	82.23

Source: [11]

Table 2-6: TOU tariff rates for three phase customers

Supply	Service Charge R/month	Capacity Charge R/month	Energy charge (c/kWh)	
			Summer	Winter
Peak	60A:105.29 80A:105.29	60A:386.38 80A:424.86	123.29	294.04
Standard			97.53	117.41
Off-Peak			76.73	82.23

Source: [11]

2.7 TOU Tariff For Residential Consumers In Jiangsu Province, China

Jiangsu Province in China has introduced optional TOU in August 2003. The consumers do not have to pay for the meters and utilities bear the cost of installing the meters. About 750,000 families had moved to TOU tariff, by the end of 2003. With the introduction of TOU tariff, 20% of peak load (around 100MW) has been shifted to off peak periods.

Table 2-7: TOU tariff for residential consumers in Jiangsu Province, China

Period	Rate (cents/kWh)
Peak -8:00 am- 9:00 pm	6.7
Off peak - Rest of the hours	3.6

Source: [5]

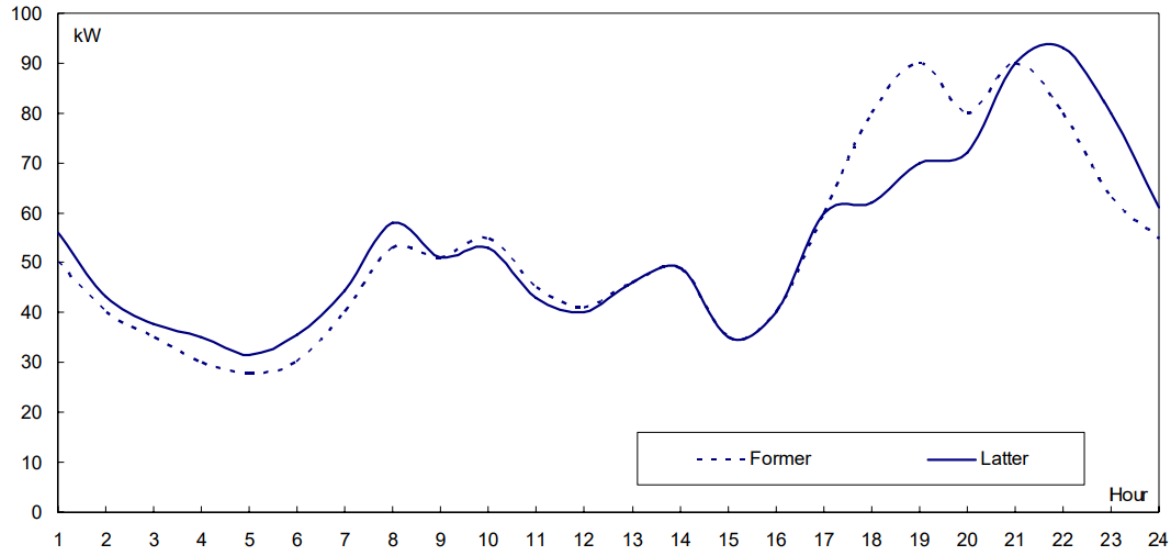

Figure 2-5: The shift of the load curve tariff in the summer (2003), as result of the introduction of TOU tariff

Source: [5]

2.8 Customer's Response To The Time Of Use Pricing

It has been observed that the customers' demand response increases with the increasing peak to off-peak price ratio, but at a diminishing rate.

Table 2-8: Customer response to Time of Use Pricing

Peak to non-peak price ratio	The expected peak reduction in demand
2:1	4.7% to 9.4%
5:1	9.9% to 20.7%

Source: [13]

2.9 Factors For The Success Of TOU Pricing

According to the Literature Review and case studies, it has been noticed that when determining the rates, it is essential to consider two factors. The rates should be good for utilities in terms of achieving reductions in peak loads, at the same time the rates should be good for the customers to reduce their electricity bills. Higher customer acceptance can be obtained by keeping the duration of the peak period as small as possible. The peak to off-peak ratio should

be 2:1 or higher, in order to obtain a significant reduction in peak load and to have a substantial saving in the customer's bill. Further, the impact of the rates should be monitored and the rates should be modified as required to ensure cost-effectiveness and high levels of customer satisfaction. Customers must be well aware of the benefits of TOU tariff, for them to select it over block tariff.

2.10 Electric Vehicles With TOU

From the year 2014 to 2015, registration of electric Motor Cars in Sri Lanka has increased from 90 to 3,238. Approximately 5,000 electric vehicles are currently running on the roads. As the statistic reveals the number of consumers who are using electric vehicle are more than the number of consumers who have moved to existing TOU tariff. That indicates that the electric vehicle owners are charging their vehicles with the normal block tariff at their homes or charging their vehicles at the CEB owned or private charging stations. If the owners are charging the vehicles at their homes without TOU tariff, the charging load may be adding up to the peak because the consumers are not aware of the network congestion time.

The government wants to encourage the usage of electric vehicles and has reduced taxes on them. If an attractive TOU tariff is introduced, people will find it economical to use an electric vehicle because they can charge the vehicle in the off-peak hours at a low charge. Thus the demand for electric vehicles will also go up.

CHAPTER 3

3 LOAD RESEARCH AND SURVEY

3.1 Load Research

Pilot Load Research project was conducted at Western-North Province by CEB with the support of ADB in the year 2016. 500 meters were installed in the houses of domestic consumers. Though 500 meters were installed, data was only downloaded from 446 meters. Samples selected for meter installation are given in the Table 3-1.

Table 3-1: Samples selected

Block	Number of Meters Installed	Percentage	Number of Meters in which the Data has been Downloaded
Below 30	13	2.6%	12
30-60	91	18.2%	81
60-90	160	32.0%	143
90-120	108	21.6%	96
120-180	90	18.0%	80
Above 180	38	7.6%	34
Total	**500**	**100%**	**446**

Source: [1]

3.2 Load Survey

A survey has been conducted not only for the Domestic category, but also for the Commercial (GP1) and Industrial (I1). Around 3,300 retail customers and 2,500 domestic customers were surveyed in different sites of Western-North province. The domestic consumers selected for the survey from each area are mentioned in the Table 3-2.

Table 3-2: Number of household consumers selected for the survey

Area	Number of household consumers
Gampaha	385
Veyangoda	621
Ja-Ela	636
Kelaniya	389
Negombo	99
Divulapitiya	361
Total	2,491

Source: [1]

The key finding of the survey of the domestic consumers were listed below:

- Electricity is used mainly for lighting, televisions, charging of mobile phones, irons, fans, rice cookers and water pumps, in less than 120kWh/m category.
- Refrigerators (1-2 door) and air conditioning loads are considerable components of the category of above 180kWh/m consumption.
- CFL is the mostly used Lighting technology.
- LED lighting contribution is higher in higher tariff categories.
- Photo Voltaic & Solar Thermal system usages are limited

CHAPTER 4

4 EXISTING TOU TARIFF FOR DOMESTIC CONSUMERS IN SRI LANKA

TOU tariff has been introduced in Sri Lanka in 2015 for the consumers who had 3 phase connections and consumptions of 30A or above. Those customers had the capability of shifting to the optional TOU tariff. In May 2017 the same tariff was extended to single phase domestic consumers as an optional tariff. The existing TOU tariff for domestic consumers is stated in the Table 4-1.

Table 4-1: Existing TOU tariff for domestic consumers

Time of use	Energy charge (LKR/kWh)	Fixed charge (LKR/month)
Off Peak (2230-0530 hrs)	13.00	540.00
Day (0530-1830 hrs)	25.00	
Peak (1830-2230 hrs)	54.00	

Total number of domestic consumers in Sri Lanka is more than 5.7 Million. It is around 87% of the total consumers in the country. But the number of customers who have shifted to the existing TOU tariff is around 500. This indicates that the existing TOU tariff is not attractive among the domestic consumers.

As there is a low response from the consumers, the desired outcomes of introducing the TOU tariffs have not been realized.

4.1 Analyzing The Financial Impact Of Shifting To The Existing TOU

The load profiles shown in the Figures 4-1,4-2,4-3,4-4,4-5 and 4-6 are derived by using the survey results and those load profiles were redefined by using data downloaded from the meters. With the available load profiles, the energy consumption of the domestic consumers, with respect to the time, can be obtained.

4.1.1 The load profiles of an average household customer in the block of 0-30 kWh/month

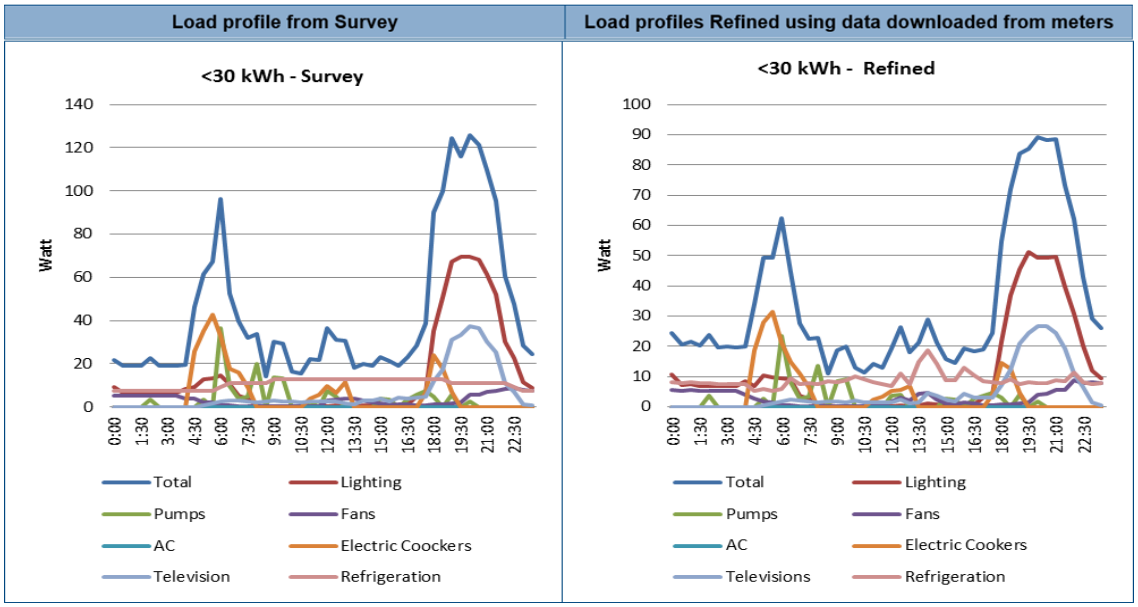

Figure 4-1: The load profiles of an average household customers in the block of 0-30 kWh/month

Source: [1]

In order to validate the effectiveness of the existing TOU tariff, the electricity bill was calculated under the both existing tariffs, TOU and block. It is assumed that the consumption patterns will remain the same, even after the consumers shift to the optional TOU tariff.

The electricity bill calculation for the consumers in the block of 0-30 kWh/month consumption, if they have shifted to the existing TOU tariff was stated in the Table 4-2.

Table 4-2: The electricity bill calculation for the consumers in the block of 0-30 kWh/month

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak (18:30- 22:30)	13.01	54.00	702.68
Day (5:30-18:30)	12.84	25.00	321.00
Off peak (22:30-5:30)	5.45	13.00	70.88
Total Energy Charge			1,094.56
Fixed Charge			540.00
Total bill			1,634.56

Total electricity bill under the existing TOU tariff = LKR 1,634.56

Total electricity bill under the existing Block tariff = LKR 143.00

Similar to this calculation, the electricity bills under the existing TOU tariff were calculated for the customers in each block and were compared with the electricity bills under the existing Block tariff. Those calculations and the comparisons are indicated in the subsections 4.1.2, 4.1.3, 4.1.4, 4.1.5 and 4.1.6.

4.1.2 The load profiles of an average household customer in the block of 31-60 kWh/month

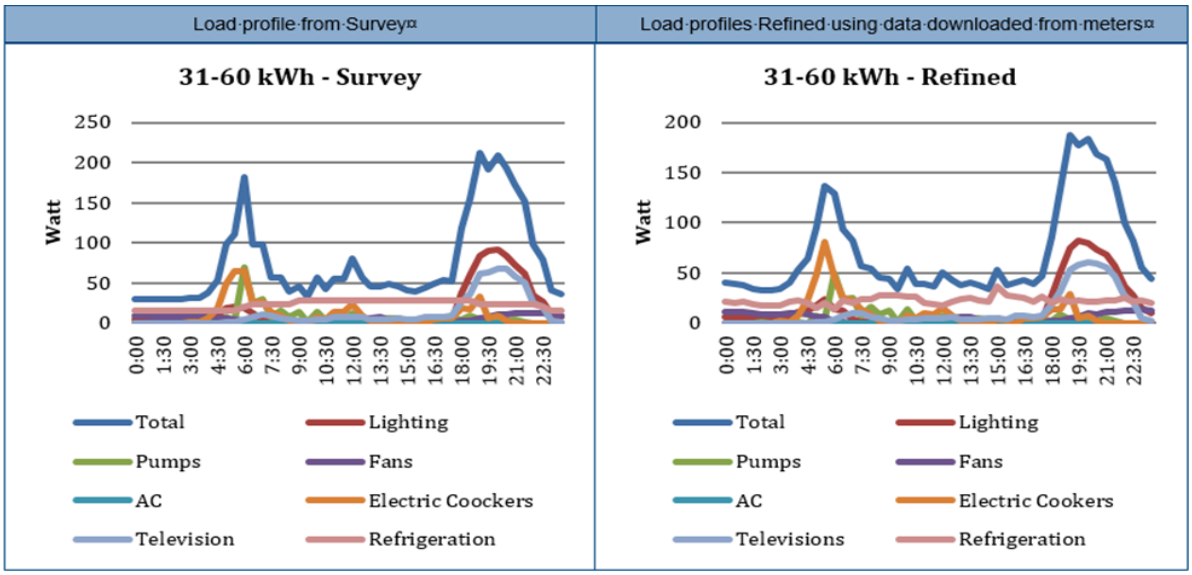

Figure 4-2: The load profiles of an average household customers in the block of 31-60 kWh/month

Source: [1]

Table 4-3: The electricity bill calculation for the consumers in the block of 31-60 kWh/month

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak (18:30- 22:30)	18.79	54.00	1,014.53
Day (5:30-18:30)	21.56	25.00	539.06
Off peak (22:30-5:30)	11.09	13.00	144.20
Total Energy Charge			1,697.79
Fixed Charge			540.00
Total Bill			2,237.79

Total electricity bill under the existing TOU tariff = LKR 2,237.79

Total electricity bill under the existing Block tariff = LKR 239.00

4.1.3 The load profiles of an average household customer in the block of 61-90 kWh/month

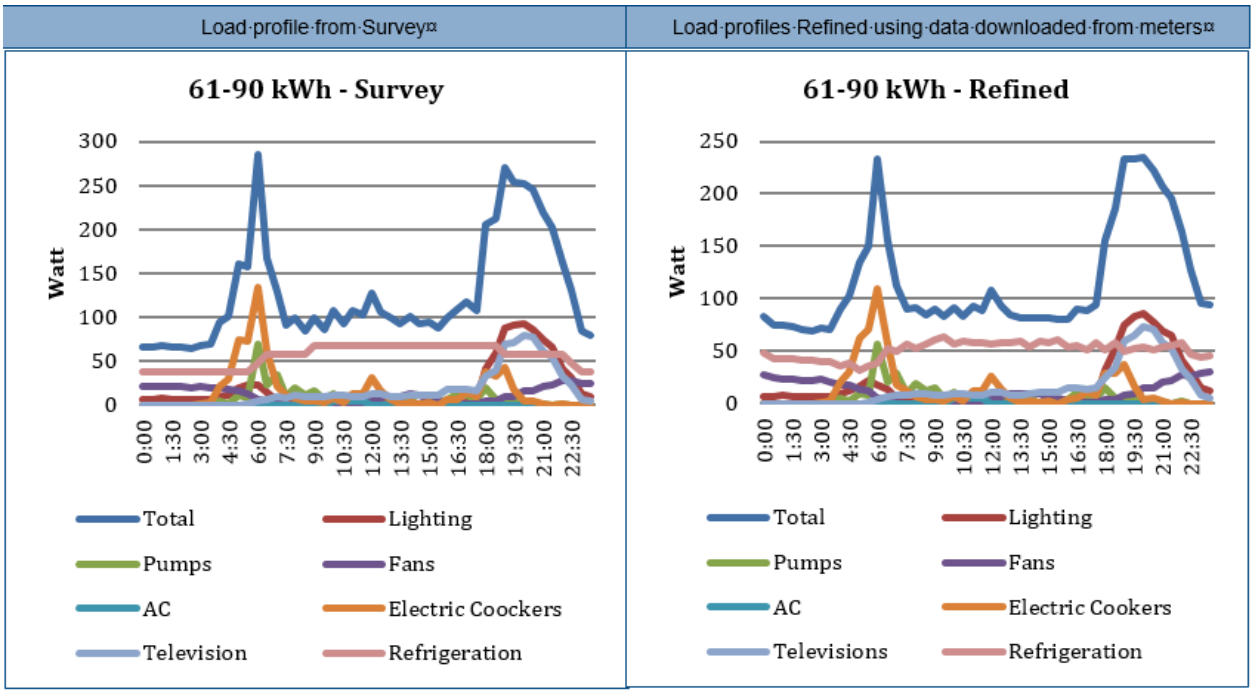

Figure 4-3: The load profiles of an average household customer in the block of 61-90 kWh/month

Source: [1]

Table 4-4: The electricity bill calculation for the consumers in the block of 61-90 kWh/month

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak (18:30- 22:30)	24.59	54.00	1,327.59
Day (5:30-18:30)	39.92	25.00	997.88
Off peak (22:30-5:30)	18.60	13.00	241.80
Total Energy Charge			2,567.27
Fixed Charge			540.00
Total Bill			3,107.27

Total electricity bill under the existing TOU tariff = LKR 3,107.27

Total electricity bill under the existing Block tariff = LKR 792.00

4.1.4 The load profiles of an average household customer in the block of 91-120 kWh/month

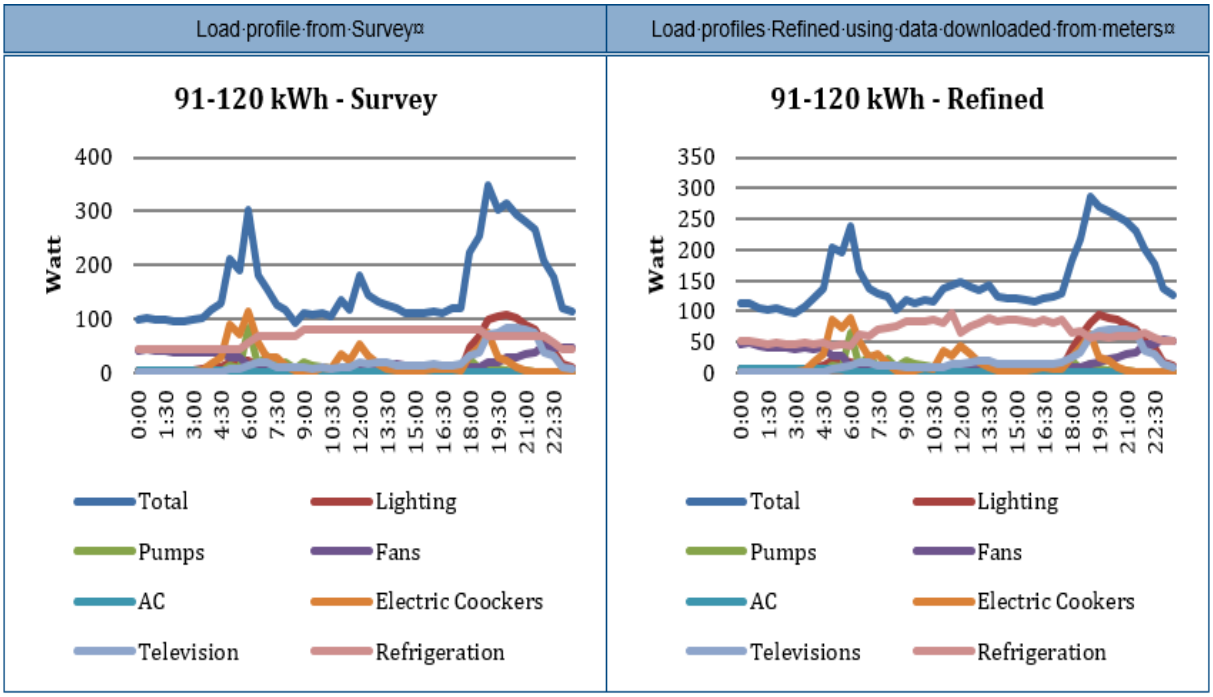

Figure 4-4: The load profiles of an average household customer in the block of 91-120 kWh/month

Source: [1]

Table 4-5: The electricity bill calculation for the consumers in the block of 91-120 kWh/month

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak (18:30- 22:30)	28.73	54.00	1,551.15
Day (5:30-18:30)	53.66	25.00	1,341.56
Off peak (22:30-5:30)	26.03	13.00	338.42
Total Energy Charge			3,231.14
Fixed Charge			540.00
Total Bill			3,771.14

Total electricity bill under the existing TOU tariff = LKR 3,771.14

Total electricity bill under the existing Block tariff = LKR 1,762.16

4.1.5 The load profiles of an average household customer in the block of 121-180 kWh/month

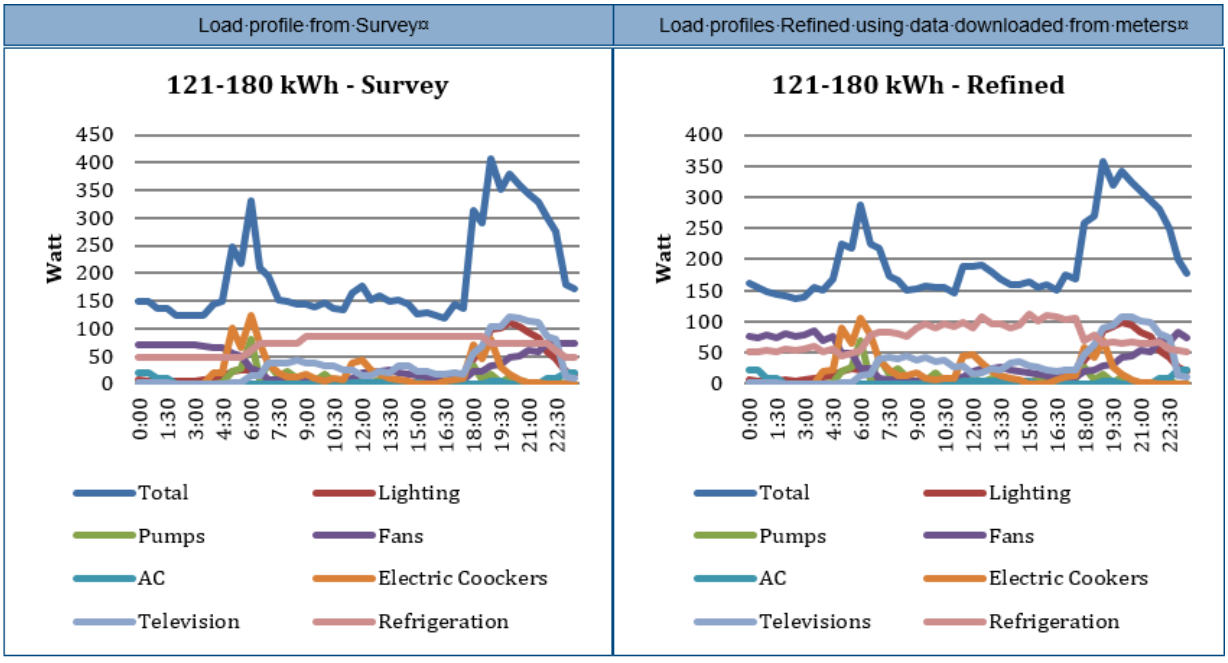

Figure 4-5: The load profiles of an average household customer in the block of 121-180 kWh/month

Source: [1]

Table 4-6: The electricity bill calculation for the consumers in the block of 121-180 kWh/month

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak (18:30- 22:30)	37.19	54.00	2,008.40
Day (5:30-18:30)	68.96	25.00	1,724.06
Off peak (22:30-5:30)	36.86	13.00	479.12
Total Energy Charge			4,211.57
Fixed Charge			540.00
Total Bill			4,751.57

Total electricity bill under the existing TOU tariff = LKR 4,751.57

Total electricity bill under the existing Block tariff = LKR 2,819.82

4.1.6 The load profiles of an average household customer in the block of 180 < kWh/month

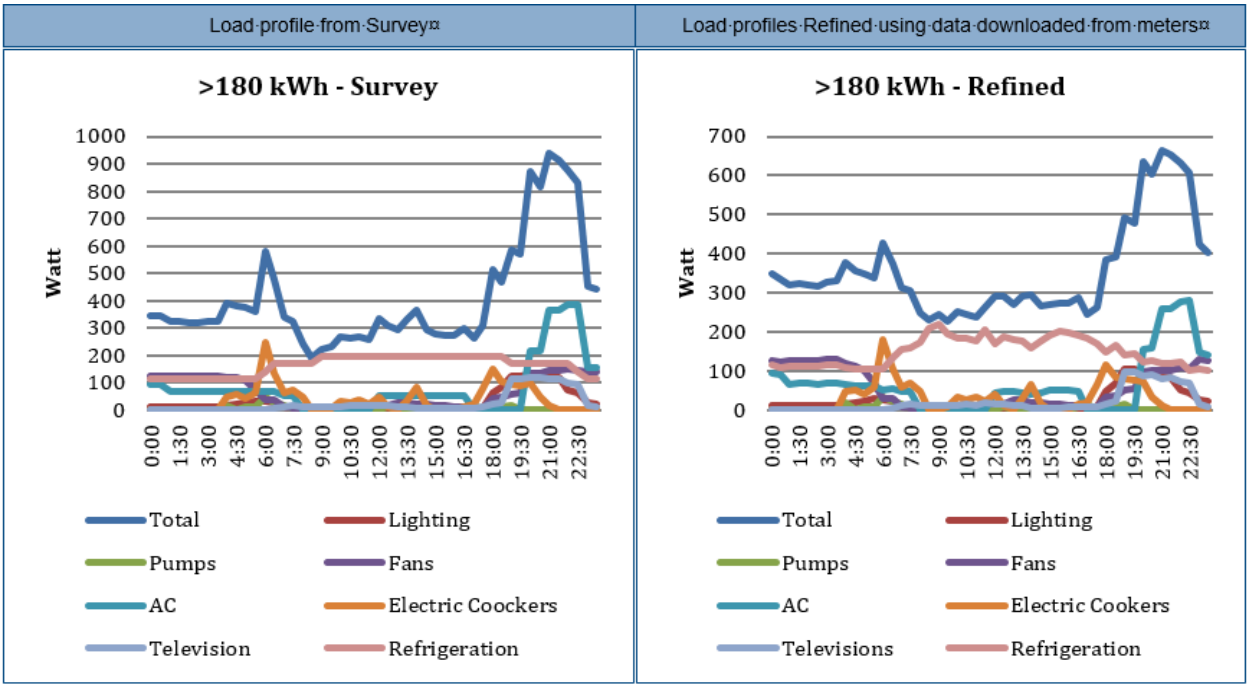

Figure 4-6: The load profiles of an average household customer in the block of 180 < kWh/month

Source: [1]

Table 4-7: The electricity bill calculation for the consumers in the block of 180 < kWh/month

	Energy Units (kWh)	**Rate (LKR/kWh)**	**Charge (LKR)**
Peak (18:30- 22:30)	70.05	54.00	3,782.70
Day (5:30-18:30)	112.20	25.00	2,805.00
Off peak (22:30-5:30)	75.48	13.00	981.24
Total Energy Charge			7,568.94
Fixed Charge			540.00
Total Bill			8,108.94

Total electricity bill under the existing TOU tariff = LKR 8,108.94

Total electricity bill under the existing Block tariff = LKR 7,561.35

As per the calculation above, it is clear that the existing TOU tariff is not attractive to all the domestic consumers. Even for a customer whose consumption is more than 180 kWh per month, the existing TOU tariff is not attractive. Because of that, there is a requirement of preparing an effective TOU tariff for domestic consumers.

CHAPTER 5

5 DETERMINING A COST REFLECTIVE TOU TARIFF

5.1 Energy Charge

The cost of generation varies with the time of the day. In the peak hours the cost of generation is higher compared to the rest of the hours. The cost of generation is at the lowest rate in the off-peak hours. The average energy costs of generation pertaining to the three-time intervals were extracted from the "Decision Document on Bulk Supply Tariff for April- September 2017" and are shown in the Table 5-1.

Table 5-1: The average energy costs of generation under time intervals

Period	Unit	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17
Generation energy cost (E1)	LKR/kWh	13.03	11.72	11.81	10.95	10.96	10.84
Generation energy cost (E2)	LKR/kWh	16.94	15.24	15.36	14.23	14.25	14.09
Generation energy cost (E3)	LKR/kWh	7.82	7.03	7.09	6.57	6.58	6.50

Source: [2]

To calculate the energy charge at the end user level, the above rates are adjusted for losses using the allowed transmission and distribution losses have been used.

- Allowed Transmission loss : 2.41%
- Allowed Distribution losses :

Table 5-2: Allowed Distribution losses of 2017

	DL1	DL2	DL3	DL4	DL5
Allowed Distribution losses-2017	7.41%	8.57%	7.64%	7.92%	4.81%
Forecasted Annual Sales (GWh)-2017	3,616	3,911	2,227	1,733	1,507

Source: [2]

- Weighted average Distribution loss: 7.57%

The transmission and distribution losses also vary with the time interval of the day and peak adjustment factors are used to adjust the loss factors. The peak adjustment factors and adjusted loss factors are mentioned in the Table 5-3.

Table 5-3: The peak adjustment factors and adjusted loss factors

Period	Factor	Transmission loss factor	Distribution loss factor
E1 - Day	1	2.47%	7.57%
E2- Peak	1.3	3.16%	9.83%
E3- Off peak	0.6	1.75%	4.54%

Source: [2]

With the aid of the adjusted loss factors the energy charges at the end user point were calculated for the six months and then the six months average were taken with respect to three time intervals.

Table 5-4: Energy charges for the interval 1(Day)

		Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17
Generation energy cost (E1)	LKR/kWh	13.03	11.72	11.81	10.95	10.96	10.84
Transmission loss factor (E1)	%	2.47%	2.47%	2.47%	2.47%	2.47%	2.47%
Bulk Supply Tariff (E1)	LKR/kWh	13.35	12.01	12.11	11.22	11.24	11.11
Distribution loss factor (E1)	%	7.57%	7.57%	7.57%	7.57%	7.57%	7.57%
End user (E1)	LKR/kWh	14.36	12.92	13.02	12.07	12.09	11.95

Source: [2]

Table 5-5:Energy charges for the interval 2 (Peak)

		Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17
Generation energy cost (E2)	LKR/kWh	16.94	15.24	15.36	14.23	14.25	14.09
Transmission loss factor (E2)	%	3.16%	3.16%	3.16%	3.16%	3.16%	3.16%
Bulk Supply Tariff (E2)	LKR/kWh	16.94	15.24	15.36	14.23	14.25	14.09
Distribution loss factor (E2)	%	9.83%	9.83%	9.83%	9.83%	9.83%	9.83%
End user (E2)	LKR/kWh	19.19	17.27	17.40	16.12	16.15	15.97

Source: [2]

Table 5-6:Energy charges for the interval 3(Off- peak)

		Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17
Generation energy cost (E3)	LKR/kWh	7.82	7.03	7.09	6.57	6.58	6.50
Transmission loss factor (E3)	%	1.75%	1.75%	1.75%	1.75%	1.75%	1.75%
Bulk Supply Tariff (E3)	LKR/kWh	7.95	7.16	7.21	6.68	6.69	6.62
Distribution loss factor (E3)	%	4.54%	4.54%	4.54%	4.54%	4.54%	4.54%
End user (E3)	LKR/kWh	8.32	7.48	7.54	6.99	7.00	6.92

Source: [2]

The average energy charges at the transmission boundary (Bulk supply tariff) and the end user level for the selected six months are calculated and stated in the Table 5-7.

Table 5-7: Calculated Bulk supply tariff and the End user tariff

	Unit	Bulk supply tariff (LKR)	End User tariff (LKR)
(E1) 6-Month weighted average	LKR/kWh	11.82	12.71
(E2) 6-Month weighted average	LKR/kWh	15.47	16.99
(E3) 6-Month weighted average	LKR/kWh	7.04	7.36

Source: [2]

The above mentioned rates have been rounded off to derive the energy charge in the TOU tariff.

Table 5-8: Rounded rates for End user tariff

	Unit	End User tariff (LKR)
(E1) 6-Month weighted average	LKR/kWh	13.00
(E2) 6-Month weighted average	LKR/kWh	17.00
(E3) 6-Month weighted average	LKR/kWh	8.00

5.2 Capacity Charge

The capacity charge is separately calculated for the end users. The Generation capacity cost, Transmission allowed revenue, BSOB allowed revenue, term loan and weighted average Distribution allowed revenue are taken from the "Decision Document on Bulk Supply Tariff for April- September 2017". The monthly figures of the above-mentioned costs are then divided by the System Coincidental Peak demand of the respective month to derive the cost figures in the Table 5-9. Bulk Supply Service cost comprises of the BSOB allowed revenue and the term loan.

Table 5-9: Calculation of capacity charge

	Unit	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17
Generation capacity	LKR/MW	1,733,093.79	1,839,270.85	1,840,728.32	1,817,303.40	1,818,559.87	1,788,896.15
Transmission	LKR/MW	338,440.76	356,562.85	359,459.76	351,926.79	351,533.21	349,715.73
Bulk Supply Service	LKR/MW	382,509.19	402,990.97	406,265.09	397,751.25	397,306.41	395,252.28
Distribution	LKR/MW	329,536.55	347,181.87	350,002.56	342,667.78	342,284.55	340,514.89
Total Capacity Charge	**LKR/MW**	**2,783,580.28**	**2,946,006.54**	**2,956,455.72**	**2,909,649.22**	**2,909,684.03**	**2,874,379.05**

Source: [2]

Table 5-10: Weighted average capacity charge

6-Month weighted average	LKR/MW	**2,895,540.47**
	LKR/kW	**2,895.54**

The capacity charge has also been rounded off to the nearest hundred and the capacity charge under the proposed TOU tariff is 2,900.00 LKR/MW.

5.3 Fixed Charge

When determining the fixed charge, the costs incurred for the retail services were considered. The weighted average retail service price cap of the five distribution licensees was calculated to derive the fixed charge for each customer.

Table 5-11: Calculation of fixed charge

	Unit	DL1	DL2	DL3	DL4	DL5
Forecast customers 2017		1,738,364	2,021,065	1,253,191	1,020,569	553,075
Retail Service Price Cap	LKR/Cust	500.19	463.17	572.21	593.08	950.75

Source: [2]

- Weighted average fixed charge (Annually) = LKR/Cust 554.76

- Weighted average fixed charge per month = LKR/Cust 46.23

The fixed charge has also been rounded off to the nearest ten and the fixed charge under the proposed TOU tariff is 50.00 LKR/customer.

CHAPTER 6

6 ANALYZING THE FINANCIAL IMPACT OF SHIFTING TO THE PROPOSED TOU TARIFF

6.1 The Financial Impact On The Customers

The financial impacts of shifting to the proposed TOU tariff were analyzed, with respect to all the domestic customers under each block.

6.1.1 Analysis of proposed TOU tariff: 0-30 kWh/month household customers

Table 6-1: Energy charge for the consumers in the block of 0-30 kWh/month under the proposed TOU tariff

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak	13.01	17.00	221.21
Day	12.84	13.00	166.92
Off peak	5.45	8.00	43.62
Total Energy Charge			431.75

Table 6-2: Capacity charge for the consumers in the block of 0-30 kWh/month under the proposed TOU tariff

	Maximum Demand (kW)	Rate (LKR/kW)	Charge (LKR)
Capacity Charge	0.126	2900.00	365.40

Fixed Charge = LKR 50.00
Total electricity bill under proposed TOU tariff = LKR 847.15

6.1.2 Analysis of proposed TOU tariff: 31-60 kWh/month household customers

Table 6-3: Energy charge for the consumers in the block of 31-60 kWh/month under the proposed TOU tariff

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak	18.79	17.00	319.39
Day	21.56	13.00	280.31
Off peak	11.09	8.00	88.74
Total Energy Charge			688.44

Table 6-4: Capacity charge for the consumers in the block of 31-60 kWh/month under the proposed TOU tariff

	Maximum Demand (kW)	Rate (LKR/kW)	Charge (LKR)
Capacity Charge	0.188	2900.00	545.20

Fixed Charge = LKR 50.00
Total electricity bill under proposed TOU tariff = LKR 1,283.64

6.1.3 Analysis of proposed TOU tariff: 61-90 kWh/month household customers

Table 6-5: Energy charge for the consumers in the block of 61-90 kWh/month under the proposed TOU tariff

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak	24.59	17.00	417.95
Day	39.92	13.00	518.90
Off peak	18.60	8.00	148.80
Total Energy Charge			1,085.64

Table 6-6: Capacity charge for the consumers in the block of 61-90 kWh/month under the proposed TOU tariff

	Maximum Demand (kW)	Rate (LKR/kW)	Charge (LKR)
Capacity Charge	0.234	2900.00	678.60

Fixed Charge = LKR 50.00
Total electricity bill under proposed TOU tariff = LKR 1814.24

6.1.4 Analysis of proposed TOU tariff: 91-120 kWh/month household customers

Table 6-7: Energy charge for the consumers in the block of 91-120 kWh/month under the proposed TOU tariff

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak	28.7	17.00	488.33
Day	53.7	13.00	697.61
Off peak	26.0	8.00	208.26
Total Energy Charge			1,394.20

Table 6-8: Capacity charge for the consumers in the block of 91-120 kWh/month under the proposed TOU tariff

	Maximum Demand (kW)	Rate (LKR/kW)	Charge (LKR)
Capacity Charge	0.282	2900.00	817.80

Fixed Charge = LKR 50.00
Total electricity bill under proposed TOU tariff = LKR 2,262.00

6.1.5 Analysis of proposed TOU tariff: 121-180 kWh/month household customers

Table 6-9: Energy charge for the consumers in the block of 121-180 kWh/month under the proposed TOU tariff

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak	37.19	17.00	632.27
Day	68.96	13.00	896.51
Off peak	36.86	8.00	294.84
Total Energy Charge			1,823.63

Table 6-10: Capacity charge for the consumers in the block of 121-180 kWh/month under the proposed TOU tariff

	Maximum Demand (kW)	Rate (LKR/kW)	Charge (LKR)
Capacity Charge	0.35	2900.00	1,015.00

Fixed Charge = LKR 50.00
Total electricity bill under proposed TOU tariff = LKR 2,888.63

6.1.6 Analysis of proposed TOU tariff: over 180 kWh/month household customers

Table 6-11: Energy charge for the consumers in the block of over180 kWh/month under the proposed TOU tariff

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak	70.05	17.00	1,190.85
Day	112.20	13.00	1,458.60
Off peak	75.48	8.00	603.84
Total Energy Charge			3,253.29

Table 6-12: Capacity charge for the consumers in the block of over180 kWh/month under the proposed TOU tariff

	Maximum Demand (kW)	Rate (LKR/kW)	Charge (LKR)
Capacity Charge	0.665	2900.00	1,928.50

Fixed Charge = LKR 50.00
Total electricity bill under proposed TOU tariff = LKR 5,231.79

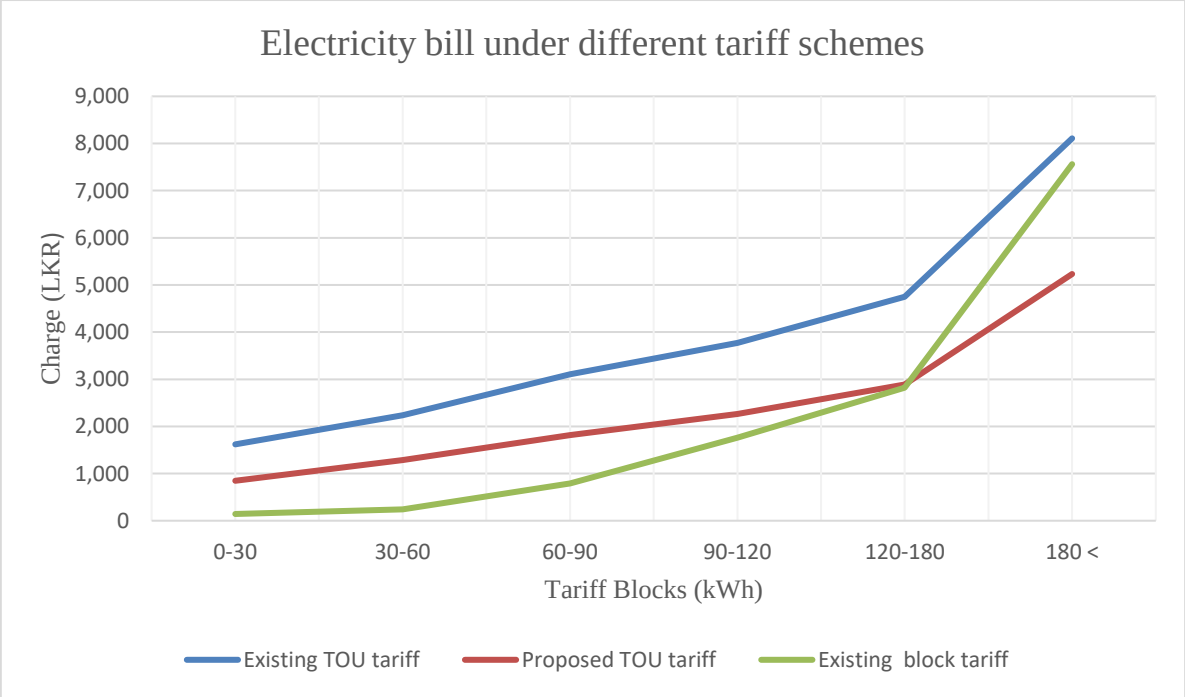

Figure 6-1: Average electricity bill of a customer under different tariff schemes

It can be observed that the consumers who are in the lower consumption blocks will not be benefitted from Time of Use pricing schemes as the initial units under the existing block tariff are highly subsidized. For the consumers whose consumption is approximately lower than 120 kWh units, it is financially beneficial to remain in the block tariff scheme rather than moving to Time of Use pricing schemes.

Considering the consumers who fall into the blocks of 120-180 units and more than 180 units, it can be observed that shifting to proposed Time of Use pricing will be favourable. But the current TOU tariffs are not favourable even for those customers whose consumption is more than 180kWh.

6.2 Financial Impact On The Utilities

6.2.1 Average cost of supplying electricity to the customers

- The total actual cost of generation : LKR Mn 251,707
- The cost of transmission
  (Transmission, BSOB Revenue Cap, term loan) : LKR Mn 17,806
- The cost of distribution
  Distribution Revenue Cap : LKR Mn 41,399
  Retail Cost : LKR Mn 3,654
- The total cost : LKR Mn 314,566
- Sales : 13,222.12 GWh
- Average cost : 23.79 LKR / kWh

- The approximated average cost to supplying electricity is 23.79 LKR / kWh in the year of 2017.
- According to the sales forecast, in the year of 2017 a total energy of 4,616 GWh is supplied to the domestic consumers.
- The total cost of supplying electricity to the domestic consumers, based on the sales forecast of 2017 is LKR Mn 109,821.

6.2.2 Sales revenue of the Utilities under the Block Tariff

The total sales revenues of 2017, generated from the domestic consumer in the different blocks, under the existing Block tariff are mentioned in the Table 6-13.

Table 6-13: Sales revenues of 2017 under the existing Block tariff

Block	Number of consumers	Sales (GWh)	Energy Charge (LKR Mn)	Fixed Charge (LKR Mn)	Total Revenue (LKR Mn)
0-30	1,255,646	225	562.00	452.03	1,014.04
31-60	1,884,582	911	2,823.18	1,356.90	4,180.08
61-90	1,434,347	1,243	10,209.28	1,549.10	11,758.37
91-120	607,033	767	8,712.48	3,496.51	12,208.99
121-180	399,204	698	11,632.85	2,299.41	13,932.26
180<	164,579	772	25,708.91	1,066.47	26,775.38
Total	**5,745,391**	**4,616**	**59,648.70**	**10,220.42**	**69,869.12**

According to the calculation it can be observed that there is a loss of LKR Mn 39,951.81 from the sales of electricity to domestic customers. Normally the loss generated from the domestic customers is cross subsidized by the revenue from the other customer categories.

6.2.3 Sales revenue of the Utilities if the proposed TOU Tariff is made mandatory for all the domestic customers.

The proposed TOU Tariff is a cost reflective tariff. As a result, the Utilities should be able to cover the cost, if the proposed tariff is made mandatory. But when it is optional the customers whose consumption is more than 120 kWh, may shift and others may not shift to the new TOU tariff. Subsequently the utility will adversely be affected as there will not be a cross subsidy.

If the proposed TOU tariff is made mandatory for all the domestic customers, the total revenue of the Utilities is mentioned in the Table 6-14.

Table 6-14: The total revenue of the Utilities if the TOU tariff is made mandatory

Block	Number of consumers	Energy Charge (LKR Mn)	Capacity Charge (LKR Mn)	Fixed Charge (LKR Mn)	Total Revenue (LKR Mn)
0-30	1,255,646	6,505.54	5,505.76	753.39	12,764.68
31-60	1,884,582	15,569.06	12,329.69	1,130.75	29,029.50
61-90	1,434,347	18,686.21	11,680.17	860.61	31,227.00
91-120	607,033	10,155.89	5,957.18	364.22	16,477.29
121-180	399,204	8,735.98	4,862.30	239.52	13,837.81
180<	164,579	6,425.08	3,808.69	98.75	10,332.51
Total	**5,745,391**	**66,077.76**	**44,143.79**	**3,447.23**	**113,668.78**

It can be observed that if the proposed tariff is made mandatory, the Utilities will be able to cover up the cost incurred to supply electricity to the domestic consumers as the total cost of supplying electricity to the domestic consumers is LKR Mn 109,821.

6.2.4 Sales revenue of the utilities if the proposed TOU Tariff is made optional for all the domestic customers.

When the proposed TOU Tariff is made optional, the low-end consumers will not shift to this scheme. Only the high-end consumers whose monthly consumption is more than 120kWh will shift to the proposed TOU tariff. Therefore, when calculating the sales revenue of the Utilities under an optional TOU tariff with the proposed rates, few assumptions were done.

Assumptions:

- The customers whose consumption is less than 120kWh will not shift to optional TOU Tariff. Only the customers in the blocks of “120- 180kWh” and “over 180kWh” will shift to TOU tariff.
- The first comparison was done for the customers who are in the block of “120-180kWh”. It is assumed that. 10%, 25%, 50%, 75% and 100% of those customers will shift to optional TOU Tariff

- The second comparison was done for the customers who are in the block of "120- 180kWh". It is assumed that. 10%, 25%, 50%, 75% and 100% of those customers will shift to optional TOU Tariff

6.2.4.1 First comparison: Difference between the revenue collected under Block Tariff and proposed TOU Tariff – customers in the block of 120-180kWh

Table 6-15: Differences of Revenues (customers in the block of 120-180kWh)

Percentage of customers who are shifting to TOU Tariff	Revenue collected under Block Tariff (LKR Mn)	Revenue to be collected under proposed TOU Tariff (LKR Mn)	Loss of revenue when shifted from Block Tariff to proposed TOU Tariff (LKR Mn)
10%	1,393.23	1,383.78	9.45
25%	3,483.07	3,459.45	23.62
50%	6,966.13	6,918.90	47.23
75%	10,449.20	10,378.36	70.84
100%	13,932.26	13,837.81	94.45

6.2.4.2 Second comparison: Difference between the revenue collected under Block Tariff and proposed TOU Tariff – customers in in the block of over 180kWh

Table 6-16: Differences of Revenues (customers in the block of 120-180kWh)

Percentage of customers who are shifting to TOU Tariff	Revenue collected under Block Tariff (LKR Mn)	Revenue to be collected under TOU Tariff (LKR Mn)	Loss of revenue (LKR Mn)
10%	2,677.54	1,033.25	1,644.29
25%	6,693.84	2,583.13	4,110.71
50%	13,387.69	5,166.26	8,221.43
75%	20,081.53	7,749.38	12,332.15
100%	26,775.38	10,332.51	16,442.87

Depending on the percentage of customers who are shifting to the proposed TOU tariff, the loss to the Utilities will vary.

CHAPTER 7

7 DETERMINING A COST REFLECTIVE TOU-BLOCK TARIFF

When determining the cost reflective TOU -Block tariff, the cost of generation at each time interval was taken for the calculations. As hydro power plants are dispatched at the peak hours the real energy cost at peak hours is low. Therefore taking the actual cost of generation at the relevant time period for the calculation of tariff will not represent the negative impact of having a high demand at the peak hours.

In this calculation a new merit order is assumed which is totally dependent on the unit cost of generation. The unit cost of the generation pertaining to each power plant was taken from the "Bulk Supply Tariff filing for the period from April- September 2017".

Table 7-1: Developed merit order

Power plant	Capacity (MW)	Unit Cost (kWh)
Canyon	60.00	-
Wimalasurendra	50.00	-
Old Laxapana	53.50	-
New Laxapana	116.00	-
Polpitiya	75.00	-
Upper Kotmale	150.00	-
Kotmale	201.00	-
Victoria	210.00	-
Randenigala	122.00	-
Rantambe	49.00	-
Ukuwela	40.00	-
Bowatenna	40.00	-
Samanalawewa	120.00	-
Kukule	70.00	-
Inginiyagala	11.25	-
Udawalawe	6.00	-
Nilambe	3.20	-
LVPS 3	855.00	7.33
Barge	60.00	18.84
Uthuru Janani	26.01	21.33
ACE Matara	20.00	21.66
Sapugaskanda B	69.60	21.74
Westcoast	270.00	22.01
ACE Embilipitiya	100.00	22.06

Sapugaskanda A	69.60	22.96
Emergency Power	60.00	23.95
Sojitz	163.00	24.58
Kelanitissa Combined Cycle	161.00	26.30
Asia Power	50.80	28.66
Kelanitissa- GT7	113.00	69.67
Kelanitissa- Small GTs	65.20	99.11

Power plants do not generate power at their full capacity. Though the total Hydro Capacity is more than 1300MW, they are not fully dispatched. The generated energy of the hydro power plants in the year of 2017 accounts only to 25% of the total capacity. For the hydro power plants there are few constraints which limits the power generation. On average hydro power plants can provide a power of 351.06 MW at a given time. When determining the cost reflective block tariff, it is assumed that the average capacity of the hydro power plants is dispatched first.

All the thermal powers do not operate in their full capacity at a given time. When dispatching the thermal power plants, the capacities are adjusted with the forced outage rate. The Figure 7-1 shows how an average load profile of a day where the power plants are dispatched according to the above mentioned merit order.

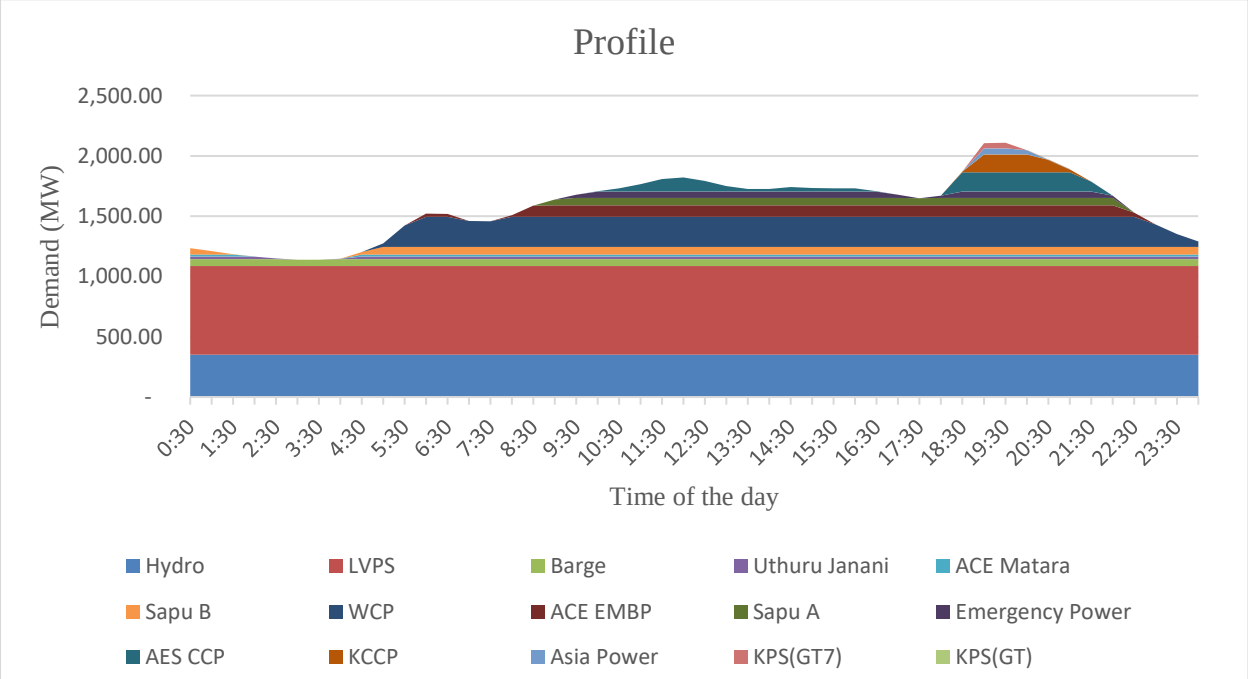

Figure 7-1: An average load profile of a day with the power plants dispatched according to the developed merit order

With the available half-hourly dispatch, the half-hourly energy rate was calculated and it is shown in the Figure 7-2.

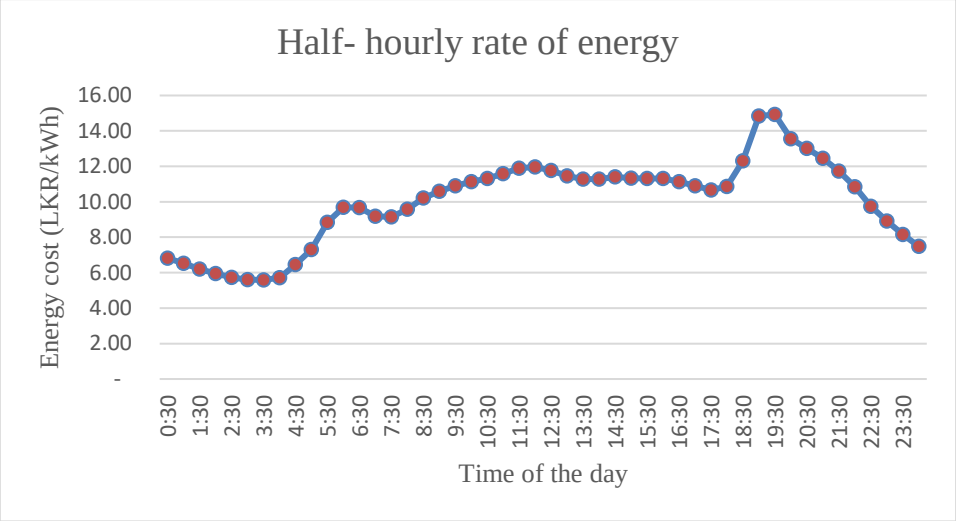

Figure 7-2: Half-hourly energy rate

7.1 Determination Of The Blocks

Four different blocks have been defined for the domestic customers based on the monthly energy consumption (kWh) of each customer. The Table 7-2 shows those four blocks and the number of customers in the respective block.

Table 7-2: Defined blocks

Block	**Monthly energy consumption (kWh)**	**Number of consumers**
1st Block	0-60	3,140,228
2nd Block	61-120	2,041,381
3rd Block	121-180	399,204
4th Block	More than 180	164,579
Total		**5,745,391**

To determine the cost reflective TOU tariff for each block, block-factors were calculated for each time interval. Those block factors are based on the demand contribution of each customer block and the total demand.

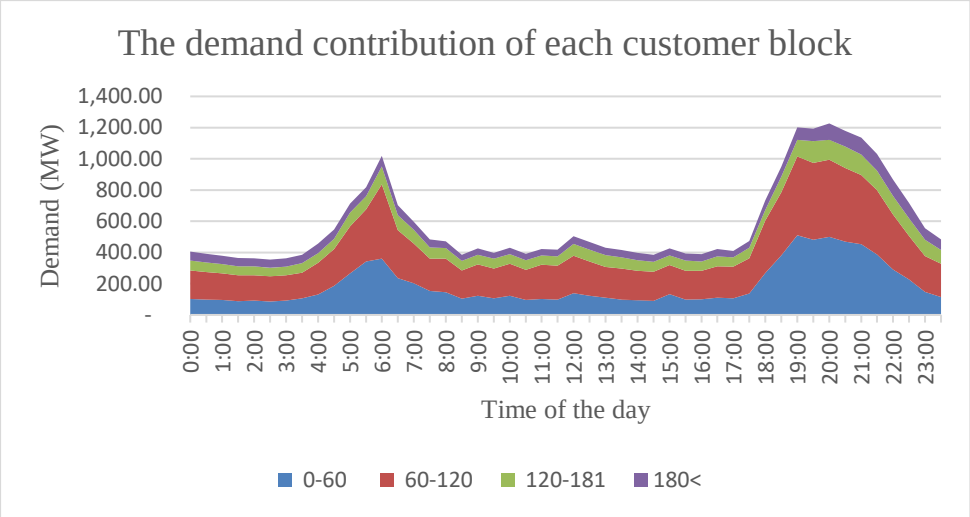

Figure 7-6: The demand contribution of each customer block

7.2 Calculation Of Block Factors

Block factor for Block 1 = $\frac{D1\times4}{4D1+3D2+2D3+D4}$

Block factor for Block 2 = $\frac{(D1+D2)\times4}{4D1+3D2+2D3+D4}$

Block factor for Block 3 = $\frac{(D1+D2+D3)\times4}{4D1+3D2+2D3+D4}$

Block factor for Block 4 = $\frac{(D1+D2+D3+D4)\times4}{4D1+3D2+2D3+D4}$

- D1= Demand contribution of block 1
- D2= Demand contribution of block 2
- D3= Demand contribution of block 3
- D4= Demand contribution of block 4

Block factors were calculated for each time interval. Demand contribution and calculated Block factors for few time intervals are shown in the Table 7-3.

Table 7-3: Demand contribution and calculated block factors

	Demand contribution (MW)				Block Factor			
Time	**1st Block**	**2nd Block**	**3rd Block**	**4th Block**	**1st Block**	**2nd Block**	**3rd Block**	**4th Block**
0:00	103.01	181.52	64.67	57.60	0.360	0.995	1.221	1.423
0:30	97.36	177.22	60.68	55.96	0.355	1.000	1.221	1.425
1:00	96.41	170.10	59.08	52.67	0.362	0.999	1.221	1.418
1:30	87.93	165.41	57.88	53.49	0.346	0.996	1.224	1.434
2:00	91.07	163.76	56.29	52.67	0.357	0.999	1.219	1.425
2:30	86.05	161.11	55.09	52.17	0.348	0.999	1.221	1.432

The relevant block factor is then multiplied by the half- hourly energy rate to determine the energy charge for each block under each time interval. The Table 7-4 shows the block wise energy rate for few time intervals.

Table 7-4: Block wise half- hourly energy rate

Time	**Half-hourly energy rate (kWh)**	**Block Factor**				**Half- hourly energy rate for each block (kWh)**			
		1st Block	**2nd Block**	**3rd Block**	**4th Block**	**1st Block**	**2nd Block**	**3rd Block**	**4th Block**
0:00	7.48	0.360	0.995	1.221	1.423	2.70	7.44	9.14	10.64
0:30	6.82	0.355	1.000	1.221	1.425	2.42	6.82	8.33	9.72
1:00	6.52	0.362	0.999	1.221	1.418	2.36	6.52	7.96	9.25
1:30	6.20	0.346	0.996	1.224	1.434	2.14	6.17	7.58	8.89
2:00	5.95	0.357	0.999	1.219	1.425	2.12	5.94	7.25	8.47
2:30	5.73	0.348	0.999	1.221	1.432	1.99	5.72	7.00	8.21

The half- hourly energy rates were then averaged to obtain the relevant energy rates for the “Peak” , “Day” and “Off- peak”.

Table 7-5: TOU block tariff at the generation boundary

Block	**Rate for Day (LKR/kWh)**	**Rate for Peak (LKR/kWh)**	**Rate for off-peak (LKR/kWh)**
0-60	4.13	6.58	2.65
60-120	11.06	13.36	6.84
120-180	13.24	15.23	8.35
180<	14.72	16.65	9.64

The above mentioned rates are applicable at the generation boundary. The energy charges at the end user level were calculated by incorporating the transmission loss and the distribution loss. The peak adjusted loss factors mentioned in the section 10, were used for the calculation.

Table 7-6: Peak adjusted loss factors

	Transmission loss			**Distribution loss**		
	Day	**Peak**	**Off-peak**	**Day**	**Peak**	**Off-peak**
Loss factors	2.47%	3.16%	1.75%	7.57%	9.66%	5.36%

Table 7-7: Energy charges at the transmission boundary and end user level

	Energy rate at Transmission boundary (LKR/kWh)			**Energy rate at end user level (LKR/kWh)**		
	Day	**Peak**	**Off-peak**	**Day**	**Peak**	**Off-peak**
0-60	4.23	6.78	2.70	4.55	7.44	2.84
60-120	11.33	13.79	6.96	12.19	15.12	7.33
120-180	13.57	15.71	8.49	14.60	17.23	8.95
180<	15.08	17.18	9.81	16.22	18.84	10.34

The above table shows the energy rates of the cost reflective TOU-Block tariff. The capacity charge and the fixed charge are the same charges mentioned in the section 7.2 and 7.3.

CHAPTER 8

8 ANALYZING THE FINANCIAL IMPACT OF SHIFTING TO THE PROPOSED COST REFLECTIVE TOU-BLOCK TARIFF

8.1 Impact on the consumers

Calculation of the Impact on the customers whose monthly consumption is in the range of 0-30 kWh

Table 8-1: The energy charge for the consumers in the block of 0-30 kWh/month under the TOU- Block tariff

	Energy Units (kWh)	Rate (LKR/kWh)	Charge (LKR)
Peak	13.01	7.44	96.81
Day	12.84	4.55	58.48
Off peak	5.45	2.84	15.50
Total Energy Charge			170.79

Table 8-2: The Capacity charge for the consumers in the block of 0-30 kWh/month under the TOU- Block tariff

	Maximum Demand (kW)	Rate (LKR/kW)	Charge (LKR)
Capacity Charge	0.126	2900.00	365.40

Fixed Charge = LKR 50.00
Total electricity bill under the proposed cost reflective TOU -Block tariff = LKR 586.19

Similar calculations were done for the consumers in every block and the respective average electricity bills are mentioned in the table 8-3.

Table 8-3: Average electricity bill under the proposed cost reflective TOU -Block tariff

Existing blocks	Average energy charge for a customer under the cost reflective TOU -Block tariff (LKR)	Average capacity charge for a customer under the cost reflective TOU -Block tariff (LKR)	Average total charge for a customer under the cost reflective TOU -Block tariff (LKR)
0-30 kWh	170.79	365.40	586.19
31-60 kWh	269.52	545.20	864.72
61-90 kWh	994.48	678.60	1,723.08
91-120 kWh	1,279.11	817.80	2,146.91
121-180 kWh	1,977.43	1,015.00	3,042.43
More than 180 kWh	3,920.34	1,928.50	5,898.84

It can be observed that the cost reflective TOU -Block tariff is comparatively advantageous for almost every customer.

Comparisons of the average electricity bill of a consumer in each block, under the existing tariffs and the proposed tariffs are shown in the Table 10-3 and the Figure 10-1.

Table 8-4: Average electricity bill of a consumer under the different tariff schemes

	Electricity bill for the customers					
	Block of 0-30 kWh (LKR)	Block of 31-60 kWh (LKR)	Block of 61-90 kWh (LKR)	Block of 91-120 kWh (LKR)	Block of 121-180 kWh (LKR)	Block of 180< kWh (LKR)
Existing Block tariff	143.00	239.00	792.00	1,762.16	2,819.82	7,561.35
Existing TOU tariff	1,634.56	2,237.79	3,107.27	3,771.14	4,751.57	8,108.94
Proposed TOU tariff	847.15	1,283.64	1,814.24	2,262.00	2,888.63	5,231.79
Proposed TOU- block tariff	586.19	864.72	1,723.08	2,146.91	3,042.43	5,898.84

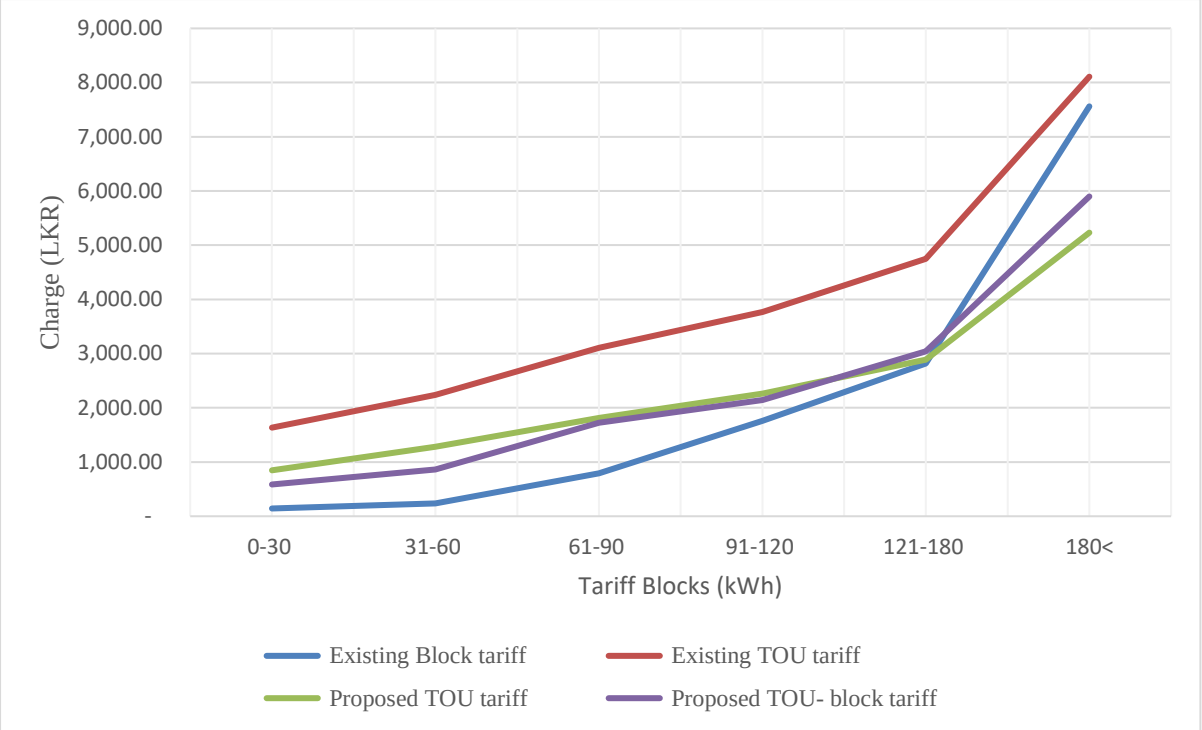

Figure 8-1: Comparison of the electricity bill under the different tariff schemes

When analyzing the above chart, it can be observed that the proposed TOU- Block Tariff is favourable for the customers in every block, compared to the initially proposed TOU tariff. Still the existing block tariff is advantageous for the consumers in the low consumption patterns because of the highly subsidized units.

It can also be observed that the charge for the high-end consumers is comparatively high in the proposed TOU- Block Tariff than initially proposed TOU tariff.

CHAPTER 9

9 FINANCIAL IMPACT ON THE UTILITIES WITH THE PROPOSED TOU- BLOCK TARIFF

As this is a cost reflective TOU- Block Tariff it is assumed that this tariff is made mandatory. The Table 9-1 shows the total annual revenue which can be earned if the proposed TOU- Block Tariff is made mandatory.

Table 9-1: Annual revenue to be earned under the proposed TOU- Block Tariff

Block	Number of consumers	Energy Charge (LKR Mn)	Capacity Charge (LKR Mn)	Fixed Charge (LKR Mn)	Total Revenue (LKR Mn)
0-30	1,255,646	2,573.48	5,505.76	753.39	8,832.62
31-60	1,884,582	6,095.17	12,329.69	1,130.75	19,555.61
61-90	1,434,347	17,117.22	11,680.17	860.61	29,658.00
91-120	607,033	9,317.53	5,957.18	364.22	15,638.93
121-180	399,204	9,472.76	4,862.30	239.52	14,574.58
180<	164,579	7,742.46	3,808.69	98.75	11,649.90
Total	**5,745,391**	**52,318.62**	**44,143.79**	**3,447.23**	**99,909.64**

As mentioned in the section 12, the total annual cost of supplying electricity to the domestic consumers is LKR Mn 109,821. If this TOU tariff is introduced as a mandatory tariff, it will generate a revenue of LKR Mn 99,909.64. There will be a loss of LKR Mn 9,911.36 and this loss is comparably low than the loss of LKR Mn 39,951.81 under the current block tariff. The chart in the Figure 11-1 shows the comparison of cost of supply with the revenues that are generated under each tariff scheme.

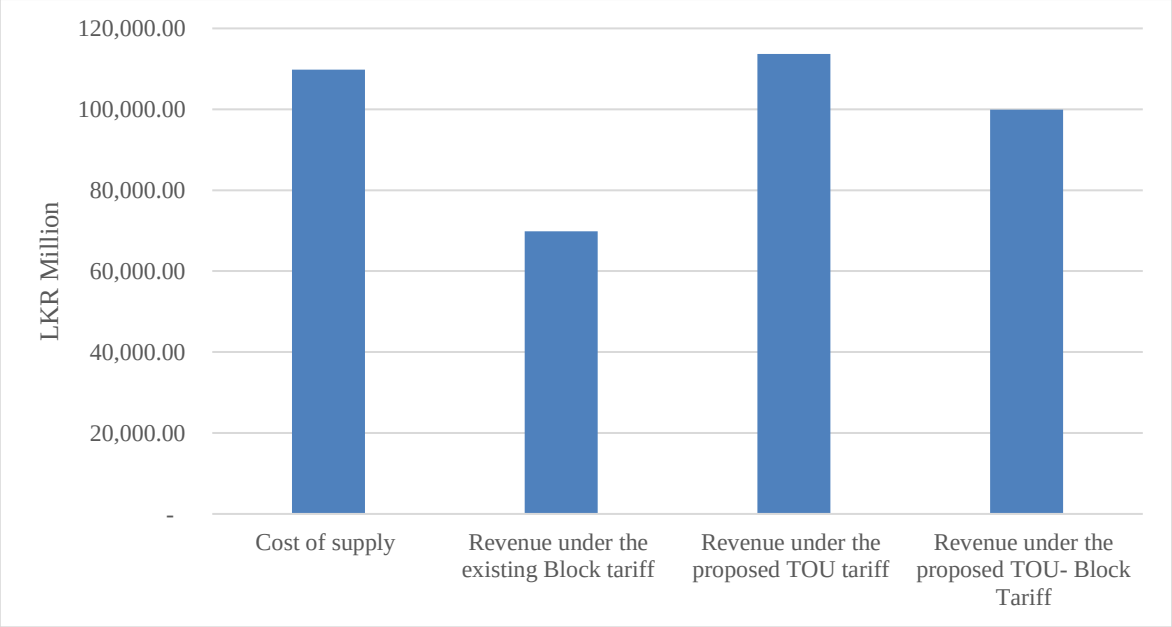

Figure 9-1: Comparison of revenues under each tariff scheme and the cost of supply

When looking at the perspective of utilities proposed TOU tariff is favourable and it covers the cost of supply. Revenue under the proposed TOU- block tariff is also beneficial to the utilities than the existing block tariff. Both those tariff schemes should be made mandatary in order to get the favourable revenue.

CHAPTER 10

10 SHIFTING OF LOADS

Introduction of a TOU tariff scheme will encourage the consumers to shift their loads from peak hours to off-peak hours. But a consumer whose consumption is low, will not be able to shift his/ her loads from peak to off-peak hours. But a high-end consumers will be able to shift his/her work such as ironing, water heating (hot water systems), pumping of water, charging, etc. to off -peak hours.

An analysis was done on the effects of load shifting, by considering the following assumptions.

Assumptions:

- The TOU tariff schemes are made mandatory.
- The customers who consume less than 60kWh, will not be able to shift their loads.
- The percentage shifts of load from peak to off-peak hours and peak to day hours are mentioned in the Table 10-1.

Table 10-1: Shift of loads

Block	**Percentage shift of load from peak to off-peak hours**	**Percentage shift of load from peak to day hours**
61-90kWh	5%	5%
91-120kWh	10%	5%
121-180kWh	20%	10%
More than 180kWh	20%	10%

When the customers shift their loads from peak hours, there will be a reduction in their monthly bill. Reduction in monthly bill under both TOU schemes are analyzed.

Table 10-2: Monthly saving from shifting of load under TOU tariff scheme

Block	Before shifting the loads		After shifting the loads		Total monthly saving (LKR)
	Energy Charge (LKR)	Max Demand Charge (LKR)	Energy Charge (LKR)	Max Demand Charge (LKR)	
61-90kWh	1,085.64	678.60	1,069.66	610.74	83.84
91-120kWh	1,394.20	817.80	1,362.60	695.13	154.27
121-180kWh	1,823.63	1,015.00	1,741.80	710.50	386.33
More than 180kWh	3,253.29	1,928.50	3,099.18	1,349.95	732.66

Table 10-3: Monthly saving from shifting of load under TOU- block tariff scheme

Block	Before shifting the loads		After shifting the loads		Total monthly saving (LKR)
	Energy Charge (LKR)	Max Demand Charge (LKR)	Energy Charge (LKR)	Max Demand Charge (LKR)	
61-90kWh	994.48	678.60	981.31	610.74	81.03
91-120kWh	1,279.11	817.80	1,252.54	695.13	149.24
121-180kWh	1,977.43	1,015.00	1,906.07	710.50	375.86
More than 180kWh	3,920.34	1,928.50	3,782.93	1,349.95	715.96

It can be observed that high-end consumers can get an advantage from the TOU tariff by shifting their loads.

CHAPTER 11

11 DISCUSSION

TOU pricing is popular in developed countries and in most of those countries, it is optional to residential customers. In those cases, it is observed that the peak to off-peak ratio is in between 2:1 and 3:1 for low voltage customers.

The domestic customers have responded positively to the TOU pricing schemes in most of the countries. On average 20% to 30% of residential customers have moved to optional TOU tariff schemes. In Ontario, Canada about 90% of residential customers have chosen the TOU tariff.

Some countries like Italy have observed only a small shift of demand from peak to off-peak hours, after introducing TOU pricing for the residential consumers. But the people have moved to more energy efficient appliances creating a positive impact on the total demand. The countries that have observed a higher demand response are the countries with a high peak to off-peak ratio.

The response of Sri Lankan domestic consumers to the existing TOU tariff is not significant. It was introduced in the year of 2015 for the domestic consumers who had three-phase connections, and was extended to the single-phase consumers in 2017. As of recently, only around 500 consumers have opted to shift to this TOU tariff scheme.

There is a cross subsidy in the existing block tariff scheme and the low-end consumers are highly subsidized in that scheme. Therefore, the domestic consumers do not like to shift to the TOU tariff schemes. Financial impact of shifting to the existing TOU tariff scheme was analysed with respect to the customers in each block. It can be observed that the existing TOU tariff is not favourable than the existing block tariff, to all the customers. Therefore, it is natural for the domestic customers to avoid the existing TOU tariff.

As the existing TOU tariff is not attractive, two TOU tariff schemes have been proposed in this study. One scheme is a TOU tariff which is based on the Bulk Supply Tariff calculation. The average energy costs of generation pertaining to the three-time intervals were extracted from the “Decision Document on Bulk Supply Tariff for April- September 2017” and those rates were loss adjusted to arrive the energy rates at the transmission boundary and the end user level. The respective energy charges are mentioned in the Table 11-1.

Table 11-1: Energy rates for End user tariff

Interval	Unit	End User tariff (LKR)
Day	LKR/kWh	13.00
Peak	LKR/kWh	17.00
Off-peak	LKR/kWh	8.00

The peak to off-peak ratio is 2.125:1 and it is compatible with the peak to off-peak ratio of the TOU tariff schemes in most of the countries.

The capacity charge was separately derived from the Generation capacity cost, Transmission allowed revenue, BSOB allowed revenue, term loan and weighted average Distribution allowed revenue. The fixed charge for each consumer was derived from the weighted average retail service price cap.

Under the financial impact analysis of the proposed TOU tariff, the financial impacts on customers and the utilities were studied. According this analysis, only the consumers who fall into the blocks of 120-180 units and more than 180 units, can be benefited by shifting from existing block tariff to proposed TOU tariff. If the proposed TOU tariff is made mandatory, the financial impact on the utilities will be positive and the utilities will be able to cover up the costs. But if the TOU tariff is made optional the utilities will make a loss because only the high-end consumers will shift to the TOU scheme while the low-end consumers will remain in the block tariff scheme.

Secondly a cost reflective TOU-block tariff was designed considering the cost of the dispatchable power plants. A new merit order was assumed based on the energy cost of the power plants. Ideally the merit order should be based on the marginal cost of energy. The demand was expected to be supplied according to the new merit order. Then the half hourly energy rates were calculated based on the averaged energy charge of the power plants which are dispatched at the time of consideration. When determining the new merit order and calculating the half hourly energy rates, the energy costs of the hydro power plants were assumed to be zero. But there is a value for water which is known as “water value” and it depends on the reservoir level, hydro inflow, the availability of the power plants, etc. Based on the “water value”, even the hydro power plants can be sequenced in the assumed merit order.

Four blocks were defined and the block factors were calculated based on the demand contribution of the consumers in each block. The energy rates were adjusted with the block factors, to derive at the block wise energy rate for each time interval. The energy rates were then adjusted for transmission and distribution losses to get the cost reflective TOU- block tariff scheme.

Table 11-2: The cost reflective TOU- block tariff

	TOU- block tariff (LKR/kWh)			**Peak to off-peak ratio**
	Day	**Peak**	**Off-peak**	
0-60	4.55	7.44	2.84	2.6:1
60-120	12.19	15.12	7.33	2.1:1
120-180	14.60	17.23	8.95	1.9:1
180<	16.22	18.84	10.34	1.8:1

According to the literature review the peak to off-peak ratio should be more than 2:1 and when the ratio is high, the demand response will increase.

In this TOU- block tariff scheme, the peak to off-peak ratios of the first two blocks, are more than 2:1. But the peak to off-peak ratios of the last two blocks are less than the standard ratio of 2:1 and it can be improved further.

The same capacity charge and the fixed charge of the proposed TOU tariff are applicable for this tariff scheme.

The financial impact of shifting to the TOU-block tariff with regards to consumers and the utilities were then studied. The existing block tariff is advantageous than both the TOU tariff schemes, for the consumers with low electricity consumption. But the proposed TOU- Block Tariff is favourable for those low-end consumers than the initially proposed TOU tariff. From the utilities' perspective the proposed TOU tariff is profitable and the proposed TOU- block tariff almost covers up the cost of supply. Therefore, both the TOU schemes are beneficial to the utilities if they are made mandatory.

When analyzing the shifting of loads from peak to off-peak or day hours, it can be observed that people, who are in the high-end consuming blocks, will get an advantage by shifting of loads as their electricity bills can be reduced.

When the peak load is shifted, there are benefits to the utilities. To calculate the financial benefit to the utilities by shifting of loads, the marginal cost of energy should be used.

CHAPTER 12

12 CONCLUSION

It can be observed that both the developed the TOU tariff schemes are favourable to the utilities than the existing block tariff if the TOU tariffs are made mandatory. But the low-end customers have to pay more for the consumed electricity under TOU tariff schemes. They will no longer be subsidized. If the government is going to introduce these TOU tariff schemes as mandatory schemes, the low-end customers should be given another form of subsidy.

When the two proposed tariffs are compared, the TOU- block tariff scheme is comparably favourable for the low-end customers than the TOU tariff scheme.

If those tariff schemes are made optional the utilities will make losses because only the high-end consumers will shift to the TOU tariff schemes as those schemes will reduce their electricity bill. The highly subsidized low-end consumers will remain in the block tariff. Then the utilities will have to supply electricity to those customers at subsidized prices and supply electricity to the high-end consumers at the actual cost reflective tariffs. The cross subsidy will no longer exist and the utilities will be negatively affected.

TOU tariff schemes have been identified as a Demand Side Management initiative to curb the peak demand and fill the valleys in the load profile. The consumers can be benefitted by shifting their loads to the off-peak hours and utilities can gain financial benefits if the peak is clipped due to the shifting of loads to off peak hours. The clipping of peak demand reduces the requirement to dispatch high cost power plants and hence reduces the overall energy cost. In the long run it will lower the investment requirements too. But for this to be successful the customers should be able to respond to the pricing signals. When the customer's consumption is very low, the customer is not able to shift or reduce the load as those loads are essential. The shifting of loads from peak to off-peak hours will happen, if the peak to off-peak ratio is high enough for the consumers to experience the saving.

While shifting the loads, consumers will increase the usage of energy efficient appliances, resulting a reduction in the total demand. People will tend to go for energy storage options with the introduction of TOU tariff as they can used the stored energy at peak hours.

There is an issue with high capacity charge (2,900 LKR/kWh) in the proposed TOU tariff as it may discourage the Domestic category consumers to shift to the proposed TOU tariff.

There are few improvements that can be done with the introduced TOU tariff schemes. The peak to off-peak ratio can be made higher than 2:1. Higher customer response can be obtained by increasing the ratio of peak to off-peak. Further higher customer acceptance can be obtained by keeping the duration of the peak period as short as possible. Two hours or two and half hours will be the ideal period for the peak.

Sri Lanka is facing the problem of not having enough hydro generation in the dry season. Therefore, it is possible to introduce seasonal TOU tariff schemes, encouraging the consumers to conserve electricity in the dry seasons.

REFERENCES

[1] CEB Load Research (LR) Technical Assistance in Sri Lanka

[2] DECISION ON TRANSMISSION AND BULK SUPPLY TARIFFS effective from 1st April 2017

[3] DECISION ON TRANSMISSION AND BULK SUPPLY TARIFFS effective from 1st October 2016

[4] S. Maggiore, M. Gallanti W. Grattieri, and M. Benini, "Impact of the enforcement of a time-of-use tariff to residential customers in Italy," in 22nd International Conference and Exhibition on Electricity Distribution (CIRED 2013), pp. 1-4.

[5] Ahmad Faruqui *et al*., "Applications of dynamic pricing in developing and emerging economies", Charles River Associates, Oakland, CA, May 2005.

[6] Kobus van den Berg. (2008, Aug. 15). *Implementing smart metering and residential time-of-use tariffs in South Africa* [online]. Available: https://www.metering.com/implementing-smart-metering-and-residential-time-of-use-tariffs-in-south-africa/

[7] T. Cousins, *Using Time of Use (TOU) Tariffs in Industrial, Commercial and Residential Applications Effectively*, Sandton: TLC Engineering Solutions, 2010.

[8] Tom Grimwood. (2017 Jan 03). *Green Energy UK launches time-of-use tariff* [online]. Available: http://utilityweek.co.uk/news/green-energy-uk-launches-time-of-use-tariff/1291892#.WTzaTet97IU

[9] Deloitte Access Economics, "Residential electricity tariff review", Deloitte Access Economics, Barton, ACT, Jan 2014.

[10] Ahmad Faruqui. (2015 Jun 23). *A global perspective on time-varying rates (final version)* [online]. Available: http://www.brattle.com/system/publications/pdfs/000/005/183/original/A_global_perspective_on_time-varying_rates_Faruqui_061915.pdf?1436207012

[11] City Power Johannesburg, "Tariff & Charges 2015/2016", City Power Johannesburg, Booysens, 2016

[12] Ronald Brakels. (2016 July 08). *Standard Tariffs Vs Time Of Use Pricing. Which Goes Best With Solar?* [online]. Available: https://www.solarquotes.com.au/blog/time-of-use-pricing/

[13] D. Mah, P. Hills, V.O.K. Li and R. Balme, "Smart Grid Applications and Developments", London, Springer, 2014, pp. 70