A TARIFF FOR REACTIVE POWER IN SRI LANKA

FINAL REPORT

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ABBREVIATIONS

%	Percentage
A	Ampere
ac	alternating current
CEB	Ceylon Electricity Board
h	hour
IRR	Internal Rate of Return
I_s	Total current
kV	kilovolt
kVA	kilovolt ampere
kVar	kilo Volt ampere reactive
kvarh	kilo volt amps reactive hours
kW	kilowatt
kWh	kilowatt-hour
L	Length of the distribution line
LKR	Sri Lankan Rupee
MVA	Megavolt ampere
Mvar	Mega Volt ampere reactive
Mvarh	Megavolt amps reactive hours
MW	Megawatt
MWh	Megawatt-hour
P	Active Power
PF	Power Factor
R	Resistance per unit length
UK	United Kingdom
USA	United State of America
V	Volt
W	Watt
WACC	Weighted Average Cost of Capital

Prepared for	---
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1 REACTIVE POWER AND PRICING PRACTICES

1.1 Introduction to Reactive Power and Power Factor

All ac induction machines and other electromagnetic devices convert electrical energy into mechanical work and heat. This energy is known as active or “wattful” energy. This is the type of energy we measure using a normal energy meter.

To perform this energy conversation, a magnetic field has to be established in the machines. This will draw another type of energy from the system. This energy is known as reactive or “wattless” energy. This draw of reactive energy from the grid causes a draw of a reactive current component from the system is from generators, transmission lines, transformers and distribution lines. It causes additional energy losses in transmission and distribution systems by heating the conductors. Owing to these higher currents, there will be also higher voltage drops across the transmission and distribution lines, which finally affect quality of supply.

Power factor is defined as the ratio between the real power and the apparent power drawn by a customer or device. The value of the power factor ranges from 0 to 1. A power factor close to unity means that the reactive power flow is small compared with the active power flow. If the power factor is close to unity, then the energy losses in the transmission and distribution lines are at their minimum levels, and system voltage levels can be easily maintained at their nominal values. If the power factor is below, that means there is apparent power been drawn, but there is less useful output. This means more reactive power is used to maintain the magnetic fields in various equipment. A power factor of zero means that there is no useful output (such as a motor rotating or a heater producing heat), but the current is simply maintaining a magnetic field.

1.2 Why should there be a Charge for Reactive Power?

Customers need not draw reactive power from the grid; reactive power can be produced in the customers’ premises itself, by fixing a capacitor or a bank of capacitors. Some equipment are fitted with capacitors in the production line itself and the customer buys an equipment which is already “power factor corrected”. However, in most cases, equipment is purchased without power factor correction capacitors. Therefore, the responsibility lies with the customer to measure the reactive power requirement and fix either a capacitor for all equipment, or a capacitor bank at a central location to serve the entire customer’s equipment. A combination of the two options is most often implemented.

If customers draw reactive power from the grid, it unnecessarily ties down the current carrying capacity of a variety of grid equipment. If equipment is operating at their current limits, then reactive power prevents serving more consumers. It also causes additional heating losses. To discourage customers from drawing reactive power from the grid, countries and electric utilities have adopted different methods, principles and measuring techniques.

Reactive power is sometimes called an “ancillary service”. It is not a mainstream service such as providing “real” power, but an additional requirement that has to be fulfilled owing to the principles of physics governing the supply and conversion of electricity to other forms of energy.

1.3 Charges for Reactive Energy in Different Countries

Presently, most countries do not specifically charge electricity customers for reactive power drawn from the grid. Therefore, customers have no desire to implement power factor correction. If there is a charge for reactive power included in the tariff schedule, it will encourage customers to install their own equipment to improve their power factor. However, a few countries have already introduced a charge for reactive power. Some countries have introduced a penalty charge for low power factor. Several countries have changed from a real power (kW) based tariff to a tariff based on apparent power (kVA) to charge for maximum demand. Some utilities penalize consumers if their power factor is below some targeted value. Some countries also grant discounts to customers who have maintain the power factor above a specific target.

Some countries use direct methods to charge for reactive power, whereas several other countries use indirect methods, as described below.

- Direct method: charge for “reactive energy”, measured in kvarh. Some countries have a surcharge or a discount, if the measured reactive energy reflects an average power factor below or above a declared threshold, respectively.
- Indirect method: charging for the maximum apparent power, measured in kVA. A low power factor will have a direct influence on the amount of total measured demand of a customer. A customer with a lower power factor at the time when the demand for real power is the highest will record a higher maximum demand and will therefore be charged more.

Table 1.1 provides a comparison between several countries, on the manner in which they charge for reactive power and maximum demand.

Among the countries compared, the following countries charge for reactive energy from medium and large customers: Austria, Belgium, Germany, Philippines, Portugal, Singapore, UK and USA.

Prices charged vary from the equivalent of 0.015 LKR/kvarh to 6.00 LKR/kvarh. Some countries charge on the basis of a surcharge on the energy bill, which cannot be reflected as a charge per kvarh.

Table 1.1 - Reactive Power Charges in Various Countries

	Country	**Reactive power charge (Direct)**	**Maximum demand charge (Indirect)**	**Target or benchmark power factor**	**Rates**		**Billing Method**	**Descriptions / comments**
					Direct charge	**Indirect charge**		
01	Austria	✓	-	0.95	1kvarh = between LKR 2.90 & LKR 4.00	-	Different billing price depending on months	
02	Australia		✓	All commercial consumers are requested to maintain a minimum pf of 0.78 or better, but this is never enforced.	It is unclear whether there is a direct charge or not.	LKR 1110 per kVA per month	Companies that have a tariff for maximum demand in kVA typically pay monthly	There is a target power factor value mentioned in the tariff announcement. However, there is no penalty or a surcharge for customers who have power factor values below the target value.
03	Bangladesh	-	✓	-	-	LKR 15.00 per kW of sanctioned load for domestic users LKR 52.00 per kW of sanctioned load above 40 kW for small industry users LKR60.00 per kW of measured load for high voltage users	Demand charge per month.	This demand charge does not guide consumers to correct their power factor.
04	Belgium	✓	-	0.95	LKR 0.92 per kvarh for reactive power outside the 0.95 leading/lagging power factor range	-	When the real power is less than 10% of contracted amount, the lower charge applies for reactive power up to 32.9% of real power and the LKR 0.92 per kvarh charge applies if reactive power is above 32.9% of 10%of contracted amount	There is a target power factor value mentioned and this is good for the system. But the tariff is more complicated to implement.
05	Bhutan	-	✓	-	-	LKR194.00 per kVA per month	Demand charge per month for medium and high voltage consumers	Maximum demand charge is significantly low compared to other regional countries
06	China			0.90			tariff policies depending on the City / Region, but usually there are penalties for pf< 0.90 and in certain regions, a bonus for pf> 0.90	Exact values are difficult to find.
07	Germany	✓		0.95	Penalties		Further details not available	Exact rates are difficult to find.
08	India (Kerala)	-	✓	-	-	411-875 LKR per	Demand charges only for	In India electricity charges are

						kVA	high tension supplies. chargers depend on the category	varying with the state. There are different tariffs for different states.
09	India (Maharashtra)	-	✓	-		LKR 375 per kVA	Demand charges only for commercial and industrial customers.	In India electricity charges vary with the state. There are different tariffs for different states.
10	India (Tamil Nadu)	-	✓	-		LKR 310-750 per kVA	Demand charges only for high tension supplies. Charges depend on the consumer category.	In India electricity charges vary with the state. There are different tariffs for different states.
11	Malaysia	-	-	-	-	-	-	For each kilowatt of maximum demand per month during the peak period. This tariff structure does not have any direct or indirect method to charge for the reactive power.
12	Nepal		✓	-	-	LKR 69 to 343 per kVA	Monthly maximum demand charge is depending on the type of the consumer. There is no maximum demand charge for the domestic consumers.	Charging for the Maximum demand can be identified as the most common tariff system. But the rates in Nepal are very low compared to the other regional countries.
13	Philippines	✓	-	0.85 or higher	0.6% surcharge for every percentage point lower than pf=85% or 0.3% discount for every percentage point higher than 85%.	-	These charges and discounts are only for medium and large customers only	This tariff system forced customers to maintain their Power factor at a high level. If the power factor is higher than 0.85, customers get a discount for their electricity bill. This discount will force customers to install their own reactive power compensation equipment.
14	Portugal	✓	-	0.92	LKR 2.45 to LKR 2.86 per kvarh	-	Billing price varies from month to month	
15	Singapore	✓	-	-	Reactive power charge of LKR 0.55 per chargeable kvarh for small and high tension supplies and charge of LKR 0.45 per chargeable kvarh for extra-large high tension supplies	-	Charging for reactive power used only for high tension supplies	This approach would guide customers to install their own reactive power compensation equipment.
16	South Korea	-	-	-	-	-	-	For each kilowatt of maximum demand per month during the

								peak period. This tariff system does not have any direct or indirect method to charge for the reactive power.
17	Spain		-	0.95	LKR 0.015 for 0.95< pf < 0.9 LKR 1.89 for 0.9< pf < 0.85 LKR 4.00 for 0.85< pf < 0.8 LKR 6.00 from 0.8 per kvarh for all customers	-	-	This tariff system enforced the customers to improve their power factor. At higher power factor values reactive power charge will be less
18	Sri Lanka	-		-	-	Rs850 per kVA for medium commercial customers Rs750 per kVA for large commercial customers Rs850 per kVA for medium industrial customers Rs750 per kVA for large & very large industrial customers	Monthly maximum demand for medium and large customers	
19	Thailand		✓	0.85 lagging or better		LKR 51.00 per kvar	If in any monthly billing period which the customer maximum 15 minute's reactive power demand exceeds 61.97% of his maximum 15 minute active power demand.	In Thailand tariff system they charge for the maximum demand of reactive power. This charging method can be taken as an indirect method.
19	UK	✓		0.95 or 0.90, depending on the contract type	Charge is not available. The charge is for kvarh in excess of the allowance for target power factor	A demand charge is applicable per kVA or per kW of maximum demand per month	Monthly	
20	USA	✓		0.9 &0.95			Penalty values vary according to each state. Some states have no penalties	This tariff system forced customers to maintain their Power factor at a high level. Reactive power rates are difficult to find.

Note: All currency figures are shown in equivalent LKR, at the exchange rates prevailing on 1st August 2011

2 CUSTOMER REACTIVE POWER STATUS IN SRI LANKA

An analysis was conducted on the prevailing reactive power and energy demand of medium-scale customers in Sri Lanka. Load profile data of 93 bulk customers of Ceylon Electricity Board (CEB) were used in this analysis. The information was obtained through the remote meter reading facility of CEB, without the knowledge of the customers. The information was recorded on a normal working day. The total active and reactive power load curves of the 93 customers are shown in Figures 2.1 and 2.2.

Figure 2.1 - The Total Active Power Load Curve of 93 Customers

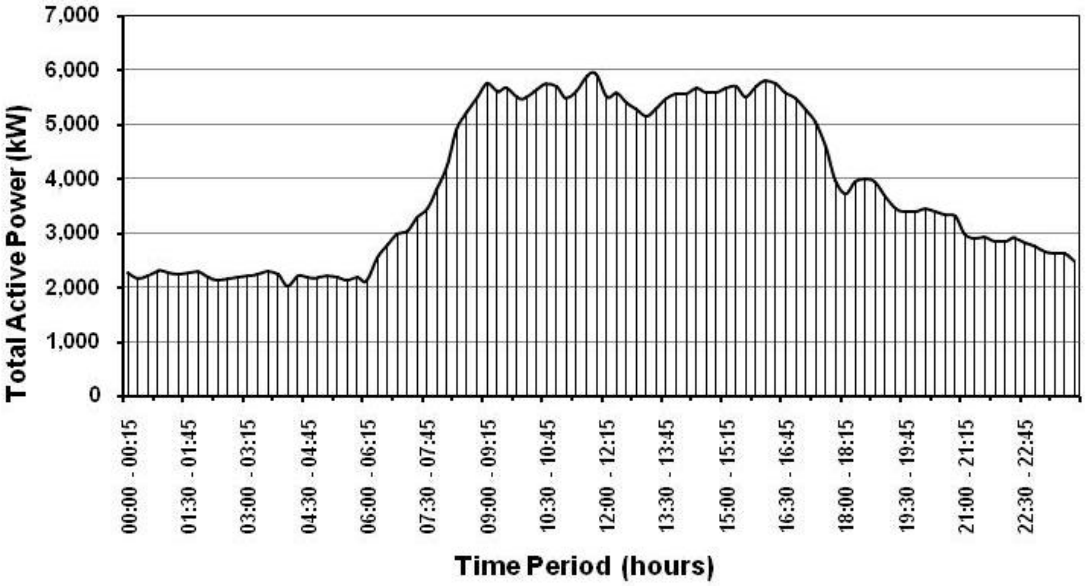
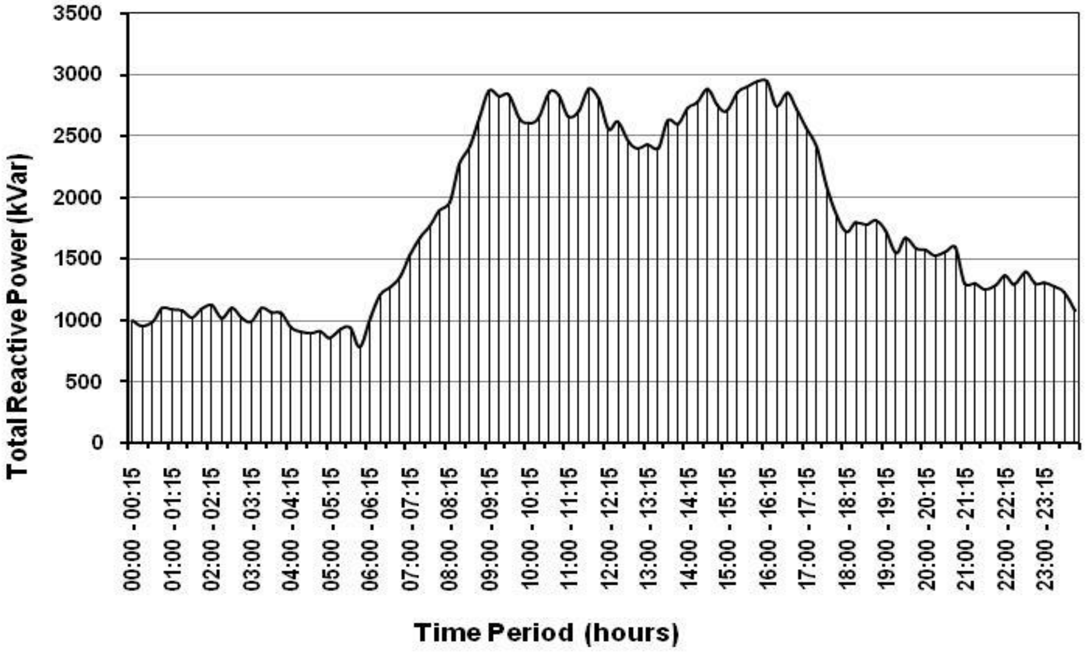


Figure 2.2 - The Total Reactive Power Load Curve of 93 Customers



All the customers in the sample of 93 were from the medium and large commercial and industrial categories, generally referred to as bulk customers. These customers are geographically scattered in the southern suburbs of Colombo. The following comments can be made analysing the Figure 2.1 and Figure 2.2.

(a) The maximum demand for both active and reactive power has occurred during day time.
(b) The maximum active power demand is around 5,924 kW
(c) The maximum reactive power demand is around 2,989 kvar
(d) The real and reactive power maxima are non-coincident, but when the real power maximum demand occurred, the reactive power demand was about 95% of the maximum value of reactive power demand

The maximum real power demand, load factor based on real power demand, average power factor values of each customer in different time periods, calculated using load profile data are shown in Table 2.1.

The calculated average power factor values can be used to assess whether the bulk customers have installed power factor correction equipment or not. According to the load curves, the maximum demand has occurred during the day time. Owing to this reason, the average day time power factor was considered to be the power factor which has to be improved.

For the purpose of classification of customers, the target power factor was taken as 0.95 in this study. Most of the countries that have implemented reactive power charges or power factor related penalties/incentives, preferred 0.95 as the target power factor. The following assumptions were made to assess the status of power factor correction by each customer in the sample of 93 customers.

(a) If the average power factor during the day time interval (0530-1830) was greater than 0.95, the customer was considered to have fixed power factor correction equipment.
(b) If the average power factor during the day time interval (0530-1830) was less than 0.90, the customer was considered not to have fixed any power factor correction equipment.
(c) If the average power factor during the day time interval (0530-1830) was between 0.95 and 0.90, load profile data itself is not sufficient to get a clear idea about power factor correction equipment.

The codes used in Table 2.1 are shown below.

Customer with power factor correction equipment	✓
Customer without power factor correction equipment	X
Customer load profile data is not sufficient to make as assessed	•

Table 2.1 - Average Power Factor Values of Each Customer

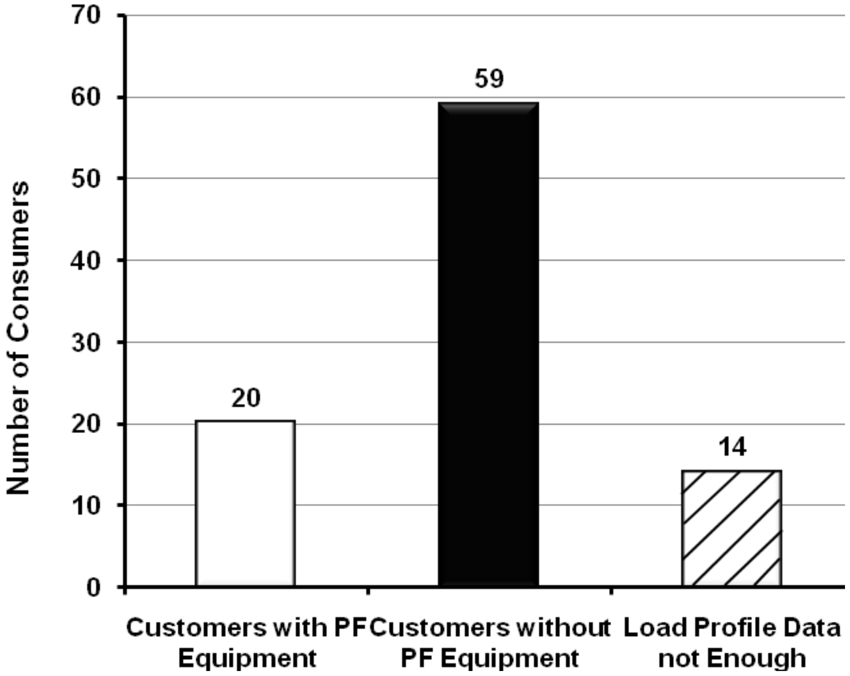
Customer No	Max. Real Power (kW)	Load Factor on Real Power (%)	Avg. Power Factor (Day: 0530 - 1830)	Avg. Power Factor (Peak: 1830-2230)	Avg. Power Factor (Off-Peak: 2230-0530)	Daily Avg. Power Factor
• 01	142	69%	0.94	0.95	0.99	0.96
• 02	6	39%	0.95	0.95	0.93	0.95
✓ 03	22	41%	0.99	0.96	0.73	0.96
• 04	56	41%	0.95	0.81	0.69	0.95
✓ 05	6	24%	0.97	0.82	0.94	0.89
× 06	25	48%	0.67	0.67	0.71	0.69
× 07	41	36%	0.80	0.68	0.69	0.78

× 08	14	33%	0.86	0.96	0.92	0.85
× 09	21	25%	0.62	1.00	0.99	0.60
× 10	30	40%	0.66	0.70	0.87	0.67
× 11	78	46%	0.79	0.72	0.84	0.79
✓ 12	1	53%	1.00	1.00	1.00	1.00
× 13	43	24%	0.88	0.60	0.22	0.78
× 14	6	15%	0.74	1.00	1.00	0.81
✓ 15	492	40%	0.98	0.98	0.94	0.98
× 16	21	36%	0.77	0.65	0.54	0.72
✓ 17	25	25%	0.96	1.00	1.00	0.97
× 18	20	31%	0.86	0.84	0.67	0.84
✓ 19	41	55%	0.98	0.90	0.79	0.94
✓ 20	37	37%	0.99	0.67	0.59	0.99
× 21	16	67%	0.60	0.58	0.58	0.59
× 22	31	83%	0.88	0.90	0.89	0.89
× 23	103	42%	0.89	0.95	0.98	0.91
× 24	127	67%	0.84	0.85	0.88	0.85
× 25	9	45%	0.65	0.59	0.84	0.65
× 26	23	48%	0.62	0.44	0.58	0.58
• 27	36	49%	0.90	0.81	0.62	0.87
× 28	41	72%	0.88	0.82	0.87	0.87
× 29	38	39%	0.77	0.80	0.94	0.79
• 30	46	63%	0.91	0.92	0.92	0.92
× 31	10	32%	0.79	1.00	0.66	0.72
× 32	13	16%	0.86	0.77	0.89	0.86
× 33	44	23%	0.73	0.98	0.95	0.76
× 34	45	61%	0.77	0.75	0.72	0.76
✓ 35	65	70%	0.99	1.00	0.99	1.00
× 36	36	33%	0.69	0.57	1.00	0.67
× 37	18	40%	0.53	0.50	0.65	0.54
× 38	123	62%	0.74	0.65	0.65	0.71
× 39	30	47%	0.65	0.57	0.60	0.62
× 40	85	23%	0.84	0.79	0.61	0.79
× 41	43	35%	0.77	0.76	0.76	0.77
✓ 42	21	86%	0.96	0.97	0.96	0.96
× 43	34	82%	0.70	0.69	0.66	0.69
× 44	17	32%	0.70	0.63	0.65	0.70
× 45	14	45%	0.86	0.74	0.62	0.83
× 46	49	33%	0.64	0.56	0.56	0.63
✓ 47	129	83%	0.97	0.97	0.96	0.97
× 48	52	63%	0.72	0.71	0.69	0.71
• 49	62	73%	0.95	0.97	0.96	0.96
× 50	73	41%	0.89	0.88	1.00	0.89
× 51	123	55%	0.87	0.90	0.93	0.88
× 52	84	38%	0.68	1.00	1.00	0.56
× 53	15	74%	0.76	0.70	0.63	0.72
• 54	9	33%	0.92	0.82	0.86	0.87
× 55	17	33%	0.72	0.86	0.89	0.74
× 56	29	37%	0.55	0.49	0.90	0.55
× 57	35	22%	0.83	0.91	0.90	0.89
× 58	51	92%	0.89	0.87	0.88	0.88
× 59	29	36%	0.65	0.31	1.00	0.50
✓ 60	100	48%	0.97	0.97	0.76	0.96
× 61	22	41%	0.80	0.91	0.79	0.81
× 62	14	12%	0.29	1.00	1.00	0.28
✓ 63	142	36%	1.00	0.98	0.66	1.00
× 64	20	16%	0.48	1.00	1.00	0.41

× 65	38	27%	0.67	0.40	0.45	0.68
✓ 66	50	80%	0.99	0.99	0.99	0.99
✓ 67	44	54%	0.96	0.95	0.98	0.96
● 68	89	41%	0.92	0.71	0.92	0.91
× 69	234	39%	0.85	0.89	0.98	0.85
× 70	54	54%	0.84	0.82	0.74	0.81
× 71	7	48%	0.75	0.68	0.67	0.71
✓ 72	130	76%	0.96	0.96	0.88	0.94
× 73	79	28%	0.87	0.74	0.71	0.86
● 74	42	33%	0.90	0.98	0.89	0.90
× 75	70	40%	0.86	0.84	0.90	0.86
× 76	64	80%	0.82	0.84	0.84	0.83
✓ 77	106	44%	0.97	0.97	0.81	0.97
× 78	4	48%	0.85	0.87	0.79	0.84
× 79	13	54%	0.75	0.78	0.76	0.76
● 80	86	82%	0.90	0.90	0.89	0.90
✓ 81	44	56%	1.00	1.00	0.97	0.99
× 82	38	30%	0.77	0.93	0.96	0.79
× 83	39	65%	0.73	0.76	0.65	0.73
× 84	79	46%	0.72	0.81	0.81	0.74
● 85	178	85%	0.95	0.95	0.97	0.96
● 86	456	44%	0.91	0.95	0.90	0.91
✓ 87	222	53%	0.98	0.98	0.95	0.98
✓ 88	26	24%	0.98	0.99	0.98	0.98
✓ 89	444	71%	0.98	0.99	0.99	0.99
● 90	81	54%	0.93	0.95	0.98	0.94
● 91	468	87%	0.93	0.91	0.94	0.93
× 92	540	61%	0.83	0.84	0.85	0.83
× 93	67	68%	0.70	0.62	0.68	0.69

Results of the assessment of the status of power factor correction are summarized in Figure 2.3.

Figure 2.3 - Assessed Use of Power Factor Correction Equipment



As seen in Figure 2.3, there were only 20 customers out of 93 (22%), who appears to have installed power factor correction equipment. Most of the customers (78%) did not record the targeted power factor of 0.95 during the day time.

Figure 2.4 - The Day Time Average PF Variation Plot of 93 Customers

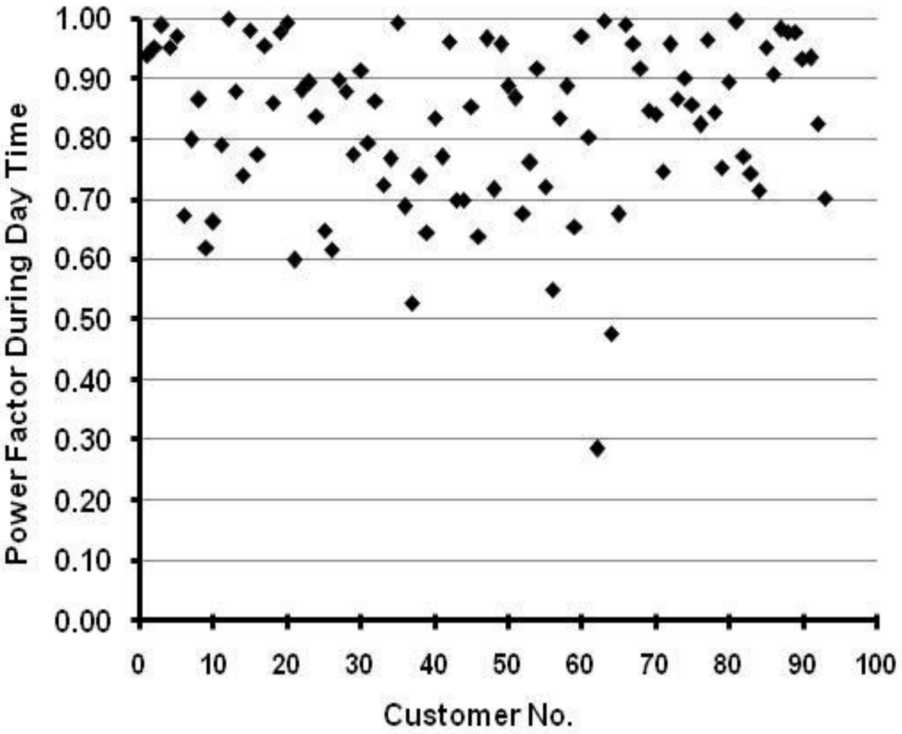
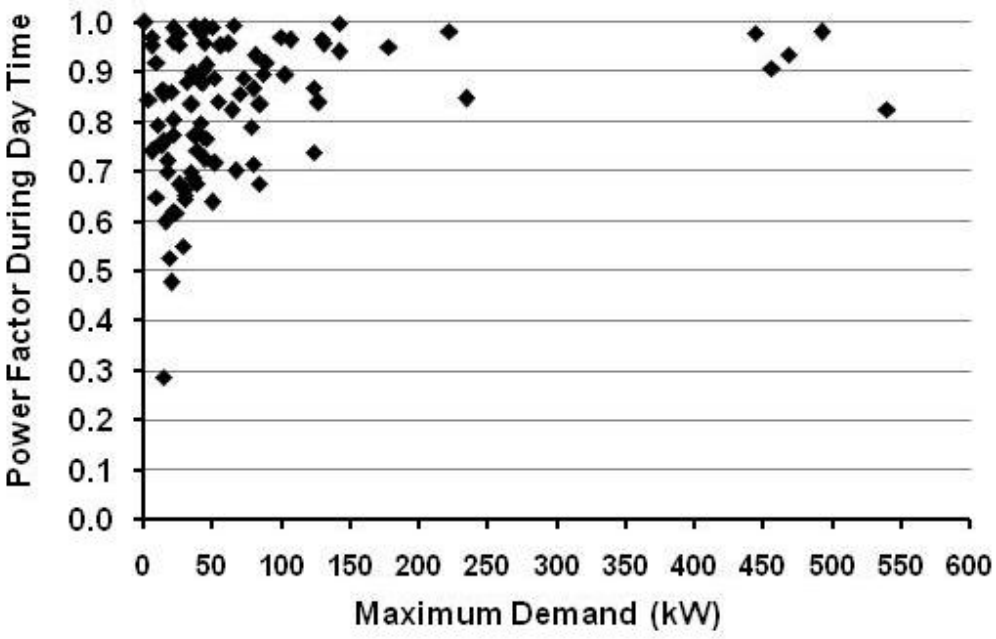


Figure 2.4, shows that the day time average power factor of most of the customers is less than the target power factor value of 0.95. Therefore, it is clear that most of the customers have not installed power factor correction equipment. It is clear from Figure 2.5 that the power factor of four out of the five larger customers (with maximum demand above 400 kW) may have been corrected with compensation equipment. However, among these five large customers, only two appear to have properly corrected their power factor, to remain above 0.95.

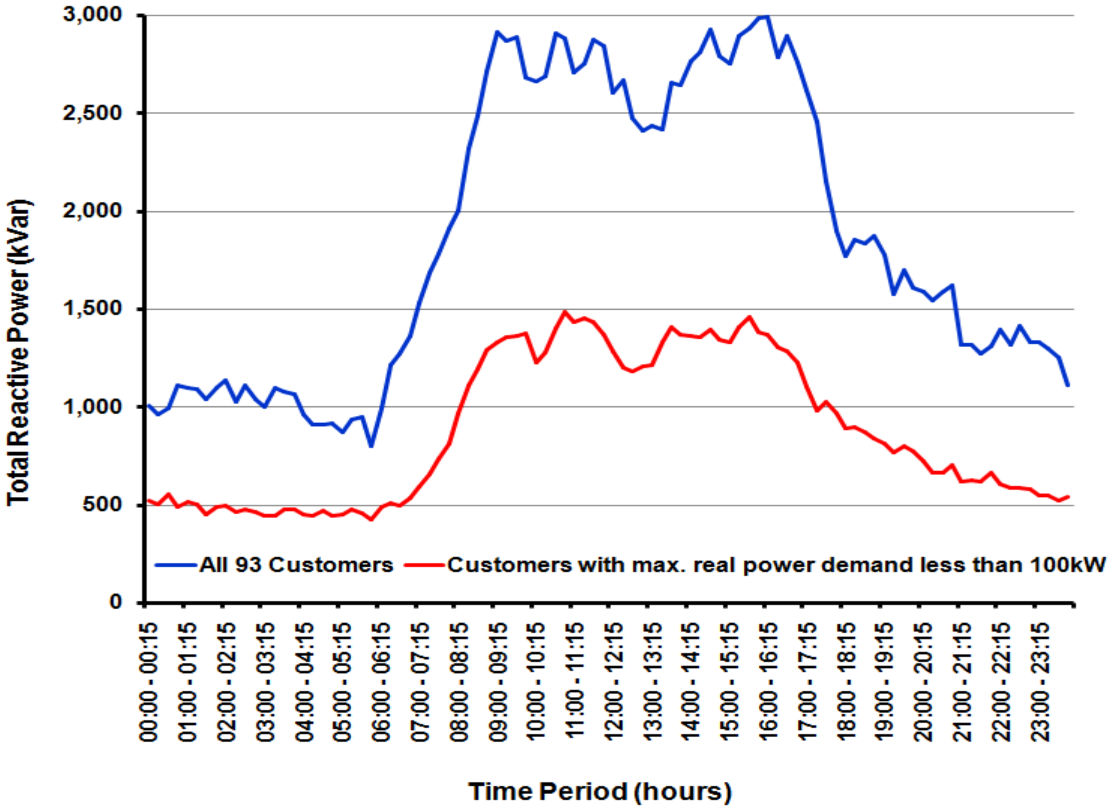
Figure 2.5 - The Day Time Average PF Variation with Respect to Maximum Demand of 93 Customers



It is also clear from Figure 2.5 that although these customers are classified as bulk customers, who have a contract demand of above 42 kVA, 35 customers (38%) actually recorded a demand less than 42 kVA on the date of measurement. Furthermore, bulk customers with poor day time average power factor of less than 0.8, were all recording a maximum demand below 100 kW. Among customers recording a maximum demand of less than 100 kW, 40% had a day time power factor of less than 0.8.

A general conclusion is that bulk customers, who are small, have lesser concern about the need for power factor improvement.

Figure 2.6 - Total Reactive Power Consumption per Day



As shown in the Figure 2.6, nearly 50% of total reactive power consumption is by customers with a maximum real power demand below 100 kW. Out of the 93 customers, 75 had a day-time maximum demand less than 100 kW. Therefore, it is more important to encourage power factor correction by this larger number of small customers, at the same time as encouraging the larger bulk customers.

Table 2.2 - Relationship between Maximum Demand and Day-time Power Factor

Customer maximum demand	Day-Time Average Power Factor	Number of Customers	% of Total
less than 100 kW	less than 0.98	37	40
less than 100 kW	equal to or more than 0.98	38	41
100 kW or more	less than 0.98	14	15
100 kW or more	more than or equal 0.98	4	4
Total		93	100%

3 REACTIVE POWER REQUIREMENTS AT GENERATION LEVEL

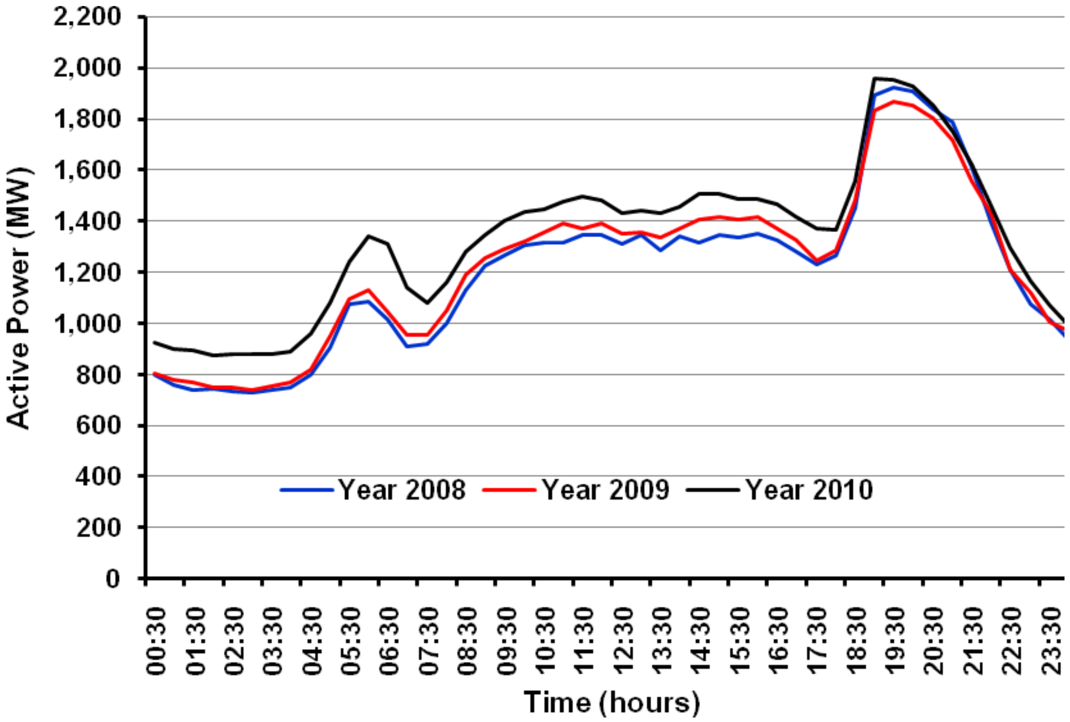
Active and reactive power generation at the system level for the last three years, on the day on which the annual peak demand occurred in each year, obtained from Ceylon Electricity Board is shown in Table 3.1.

Table 3.1 - Active and Reactive Power Generation at System Level

Time	21 May 2008			11 Nov 2009			17 Mar 2010		
	Active power (MW)	Reactive power (Mvar)	Power Factor	Active power (MW)	Reactive power (Mvar)	Power Factor	Active power (MW)	Reactive power (Mvar)	Power Factor
0030	799	141	0.98	799	141	0.98	924	220	0.97
0100	757	144	0.98	776	136	0.98	897	224	0.97
0130	738	143	0.98	767	134	0.99	891	219	0.97
0200	743	129	0.99	748	129	0.99	872	216	0.97
0230	732	122	0.99	744	126	0.99	878	211	0.97
0300	729	125	0.99	736	125	0.99	876	206	0.97
0330	737	125	0.99	751	126	0.99	875	204	0.97
0400	747	131	0.99	766	134	0.98	885	207	0.97
0430	801	137	0.99	816	141	0.99	956	209	0.98
0500	903	159	0.98	947	187	0.98	1,077	234	0.98
0530	1,075	192	0.98	1,091	228	0.98	1,237	325	0.97
0600	1,085	211	0.98	1,127	260	0.97	1,337	377	0.96
0630	1,017	219	0.98	1,044	235	0.98	1,307	380	0.96
0700	911	222	0.97	952	228	0.97	1,136	329	0.96
0730	917	285	0.96	951	293	0.96	1,076	339	0.95
0800	1,001	373	0.94	1,049	384	0.94	1,159	413	0.94
0830	1,132	494	0.92	1,188	527	0.91	1,276	526	0.92
0900	1,227	597	0.90	1,254	586	0.91	1,342	631	0.90
0930	1,265	651	0.89	1,287	627	0.90	1,399	668	0.90
1000	1,306	661	0.89	1,318	638	0.90	1,435	697	0.90
1030	1,313	694	0.88	1,355	679	0.89	1,442	724	0.89
1100	1,313	718	0.88	1,389	700	0.89	1,474	745	0.89
1130	1,347	732	0.88	1,372	726	0.88	1,495	773	0.89
1200	1,348	749	0.87	1,391	727	0.89	1,480	770	0.89
1230	1,308	684	0.89	1,349	674	0.89	1,429	707	0.90
1300	1,347	673	0.89	1,356	669	0.90	1,439	695	0.90
1330	1,288	660	0.89	1,336	664	0.90	1,428	739	0.89
1400	1,343	680	0.89	1,370	685	0.89	1,454	769	0.88
1430	1,314	696	0.88	1,403	727	0.89	1,504	802	0.88
1500	1,344	699	0.89	1,413	749	0.88	1,505	819	0.88
1530	1,335	738	0.88	1,407	734	0.89	1,485	812	0.88
1600	1,348	739	0.88	1,413	730	0.89	1,482	809	0.88
1630	1,328	702	0.88	1,369	687	0.89	1,464	772	0.88
1700	1,279	656	0.89	1,326	622	0.91	1,412	730	0.89
1730	1,229	575	0.91	1,245	543	0.92	1,366	643	0.90
1800	1,268	511	0.93	1,286	487	0.94	1,365	652	0.90
1830	1,450	584	0.93	1,480	602	0.93	1,551	659	0.92
1900	1,893	869	0.91	1,834	762	0.92	1,955	879	0.91
1930	1,922	890	0.91	1,868	795	0.92	1,950	910	0.91
2000	1,906	854	0.91	1,852	793	0.92	1,923	872	0.91
2030	1,837	778	0.92	1,802	760	0.92	1,851	816	0.91
2100	1,785	734	0.92	1,715	686	0.93	1,751	740	0.92
2130	1,613	650	0.93	1,556	592	0.93	1,621	647	0.93
2200	1,395	521	0.94	1,429	490	0.95	1,456	519	0.94
2230	1,210	436	0.94	1,209	381	0.95	1,292	414	0.95
2300	1,074	374	0.94	1,116	325	0.96	1,164	346	0.96
2330	1,017	336	0.95	1,001	251	0.97	1,069	285	0.97
0000	937	303	0.95	966	255	0.97	989	268	0.97
Maximum	**1,922**	**890**	**0.99**	**1,868**	**795**	**0.99**	**1,955**	**910**	**0.98**
Minimum	**729**	**122**	**0.87**	**736**	**125**	**0.88**	**872**	**204**	**0.88**

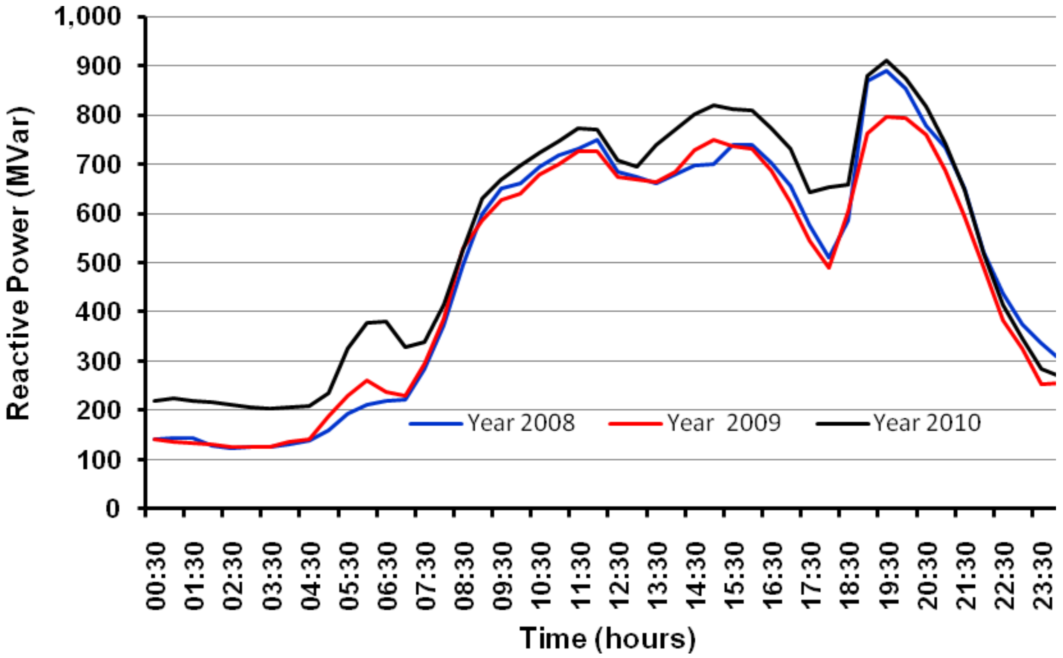
Active and reactive power requirement profiles drawn using the data of Table 3.1 for last three years at the day of peak demand are shown in Figure 3.1 and Figure 3.2.

Figure 3.1 - Active Power Requirement Profile at System Level



Note: Each curve relates to the day on which the system peak occurred in the respective year. 21 May 2008, 11 Nov 2009, 17 Mar 2010. All data exclude the contribution from embedded generation.

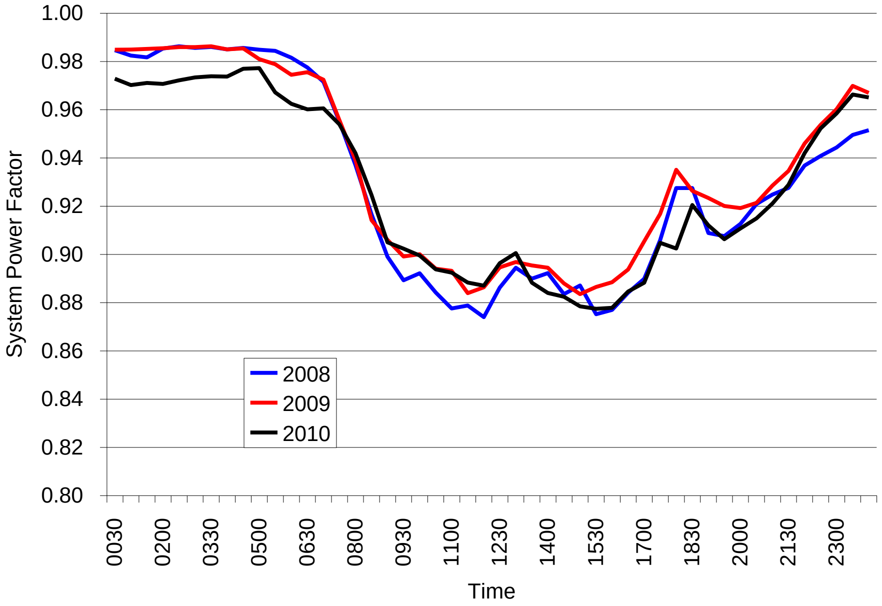
Figure 3.2 - Reactive Power Requirement Profile at System Level



Note: Each curve relates to the day on which the system peak occurred in the respective year. 21 May 2008, 11 Nov 2009, 17 Mar 2010. All data exclude the contribution from embedded generation.

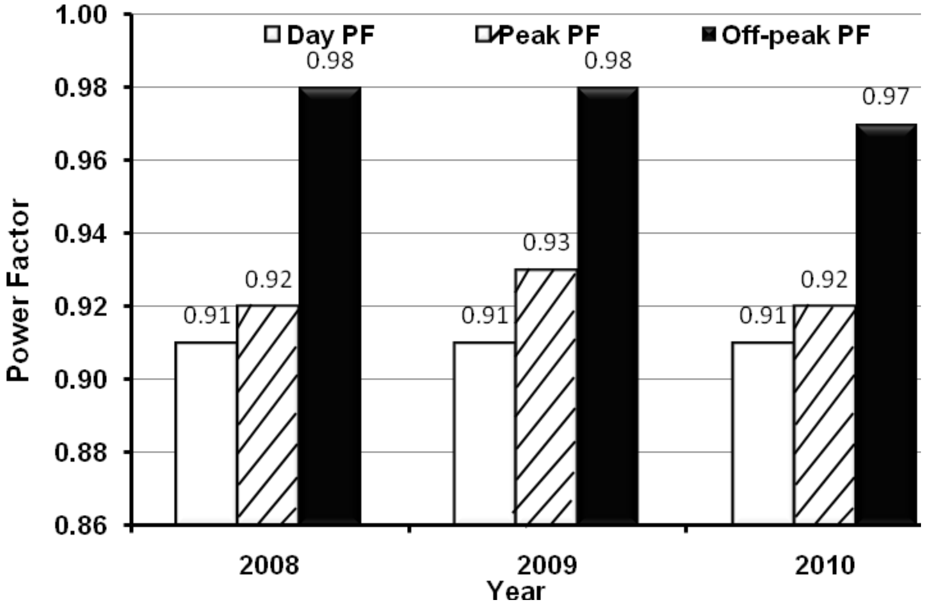
The power factor profiles are shown in Figure 3.3, clearly indicating the lower power factor during the day-time, most likely to be dominated by the bulk customers similar to the sample discussed earlier in this report. System level average power factor values for each time intervals in three years are calculated using data of Table 3.1 and are shown Figure 3.3.

Figure 3.3- Power Factor Profile at Generation Level



Note: Each curve relates to the day on which the system peak occurred in the respective year. 21 May 2008, 11 Nov 2009, 17 Mar 2010. All data exclude the contribution from embedded generation.

Figure 3.4 - System Level Average Power Factor



Note: The average power factor was calculated for each interval, where day: 0530 to 1830, peak: 1830 to 2230 and off-peak 2230 to 0530

As shown in Figure 3.4, it is clear that the power factor is lower during the day time interval than other time intervals, and is also less than the targeted power factor value of 0.95. Therefore it is essential to encourage customers to ensure power factor correction equipment is installed and operational to meet the target power factor. The main requirement is to improve the power factor during day time.

4 POWER LOSS AND REACTIVE POWER CALCULATIONS

The objective of section was to assess the energy loss and reactive power requirement of a typical electricity system serving bulk customers. Load profile data of 93 CEB bulk consumers were used in this calculation. All the 93 bulk customers were assumed to be located on a single 33 kV feeder originating from a grid substation. It was also assumed that there were no distribution substations along this 33 kV feeder.

The load characteristics assessed using load profile data is shown in Table 4.1.

Table 4.1 - Features of the Calculated Combined Load Profile of 93 Customers

Average daily power factor	0.90
Average power factor during peak interval (18.30-22.30)	0.91
Average power factor during off-peak interval (22.30-05.00)	0.90
Average power factor during day time interval (05.30h-18.30h)	0.90
Power factor coincident with the day-time peak at 11:45	0.90
Daily average line current (at 400 V - secondary side) in15 minute intervals	6,190.4 A
Daily average line current (at 33 kV- Primary side) in15 minute intervals	43.32 A
Maximum active power demand at 11:45	5,924.5 kW
Maximum reactive power demand at 16:00	2989.4 kvar
Assuming 25 working days,	
Total active energy delivered to customers per month	2,317.6 MWh
Total reactive energy delivered to customers per month	1,117.0 Mvarh

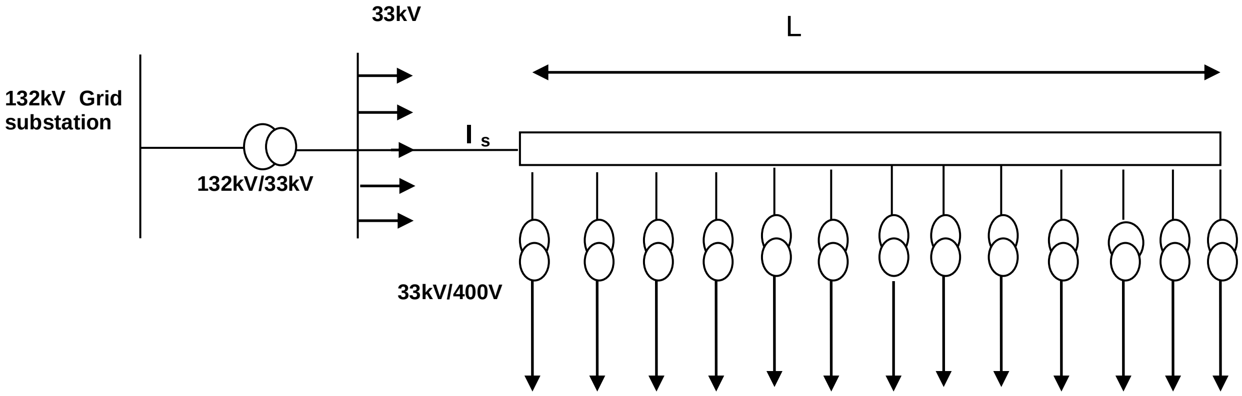
4.1 Line Power Loss Calculation

The following assumptions were made in this calculation.

(a) All the 93 bulk customers are on a single 33 kV feeder from the grid substation.
(b) Each bulk customer is fed through a dedicated transformer (33 kV / 400 V).
(c) The 33 kV feeder is 10 km long, and it is of type “Dog”, a bare conductor of resistance 1.65 Ω/km.
(d) The 93 bulk customers are uniformly distributed along the 33 kV line.

The assumed feeder arrangement to serve these bulk users is illustrated in Figure 4.1.

Figure 4.1 - Distribution Arrangement



For simplicity, the order in which the 93 consumers are placed along the feeder was not specified, but it was assumed that the consumer loads and their physical locations represent a uniformly distributed load. Power loss in a conductor with a uniformly distributed load can be expressed as follows:

$$P_{loss} = \frac{1}{3} I_s^{\,2} RL$$

I_s – Total current

R – Resistance per unit length

L – Length of the distribution line

Calculation was done for values stated in Table 4.1

Line capacitance and inductance were neglected in estimating losses.

Considering the calculated average current of 43.32 A at the sending end of the 33 kV line,

Power loss in one phase a during a 15 minute interval	$= \frac{1}{3} \times (43.32)^2 \times 1.65 \times 10$
	=10.32 kW
Total power loss during a 15 minute interval	=3 x 10.32 kW
	=30.96 kW
Total energy loss during a 15 minute interval	=30.96 x0.25 kWh
	=7.74 kWh

The calculation was done for each 15-minute interval for a whole day and the results are shown in Table 4.2. Working days per month were taken as 25 days.

Table 4.2 - Energy Loss Assessment for the 33 kV Line

	Energy per Day (kWh)	Energy per Month (kWh)
Delivered to 93 customers	92,703.8	2,317,595.6
Loss along the 33 kV line	847.6	21,190.0
Energy input at the grid substation	93,551.4	2,338,785.6
Line loss as a % of input at the grid substation	0.9%	0.9%

4.2 Assessment of Options for Power Factor Improvement

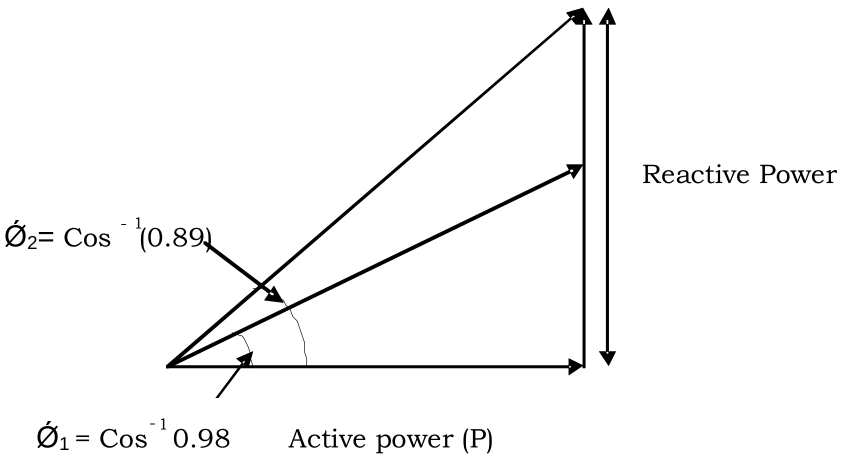
To minimize the reactive power flows in the upstream transmission network, power factor correction can be implemented either collectively by the electricity supplier at the grid substation (Case 1) or individually by each customer (Case 2). As some customers have already implemented power factor correction with different degrees of success, the practical situation will be a combination of Case 1 and Case 2.

4.2.1 Case1: Power Factor Correction on the 33 kV Line at the Grid Substation

The following assumptions were made in this calculation.

(a) Power factor to be improved was taken as the power factor during the 1545 – 1600 time interval (0.89). This is because the maximum demand for reactive power of the group of bulk consumers has occurred during this time interval.
(b) The resulting power factor at the grid substation was assumed to be the power factor during this time interval (0.89). This implies that the 33 kV line inductance and capacitance were neglected.
(c) The target power factor required at the grid substation after improvement was assumed to be 0.98.

The values calculated using load profile data of 93 bulk consumers given in Table 4.1 were used in this calculation.



Total reactive power compensation capacity
required to be installed =P (tanǾ2-tanǾ1)

At the grid substation, the maximum reactive power demand to ensure power factor is maintained at 0.98,

= 5,707.6 x [tan (cos^{-1}(0.89))-tan (cos^{-1}(0.98))]
=1,826.8 kvar
Total reactive energy requirement per year =1,117.0 x12 Mvarh
=13,404.0 Mvarh/year

As the target power factor at the 33 kV busbar is 0.98, the balance reactive power and the corresponding energy has to be provided by the grid, either through further reactive compensation equipment on the 132 kV side or from power plants.

Accordingly, additional reactive energy to be supplied by the grid = 7,756.9 Mvarh/year

4.2.2 Case2 - Power Factor Correction Individually on the Consumer Side

When individual customers correct their power factor, customers invest on and install power factor correction equipment and save on their demand charges, while the line and transformer losses of the electricity supplier will also reduce.

(a) Power Factor Correction by Customer

From the 93 customers, a consumer with a relatively higher demand and low power factor was selected for this calculation. The active power and the reactive power load curves of this customer are shown in Figure 4.2 and Figure 4.3, respectively.

Figure 4.2 - Active Power Load Curve of the Selected Customer

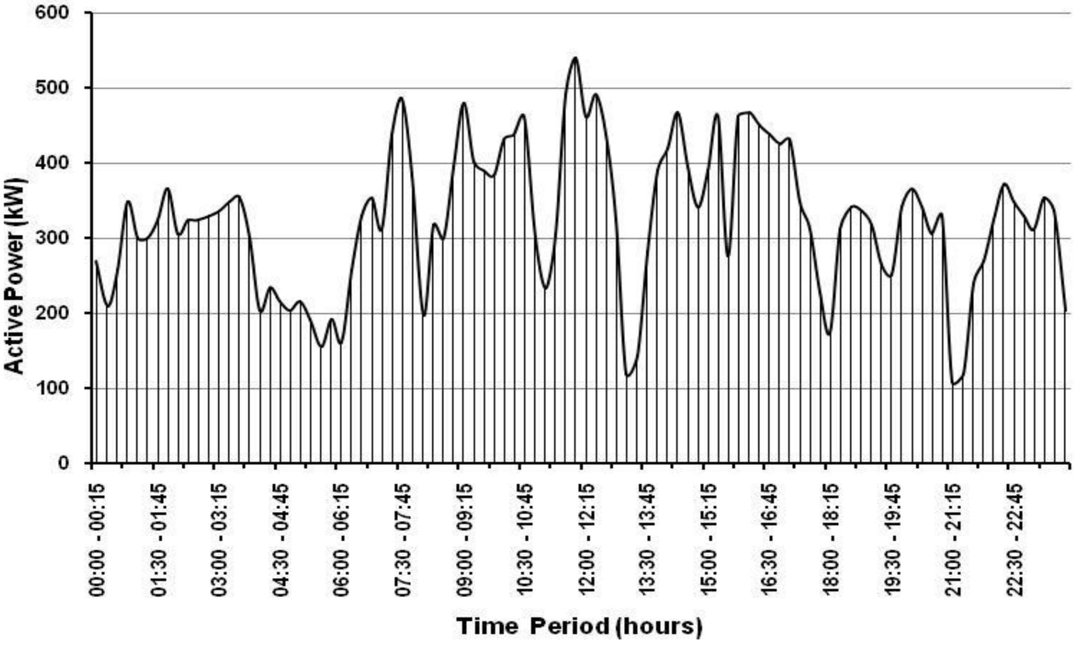
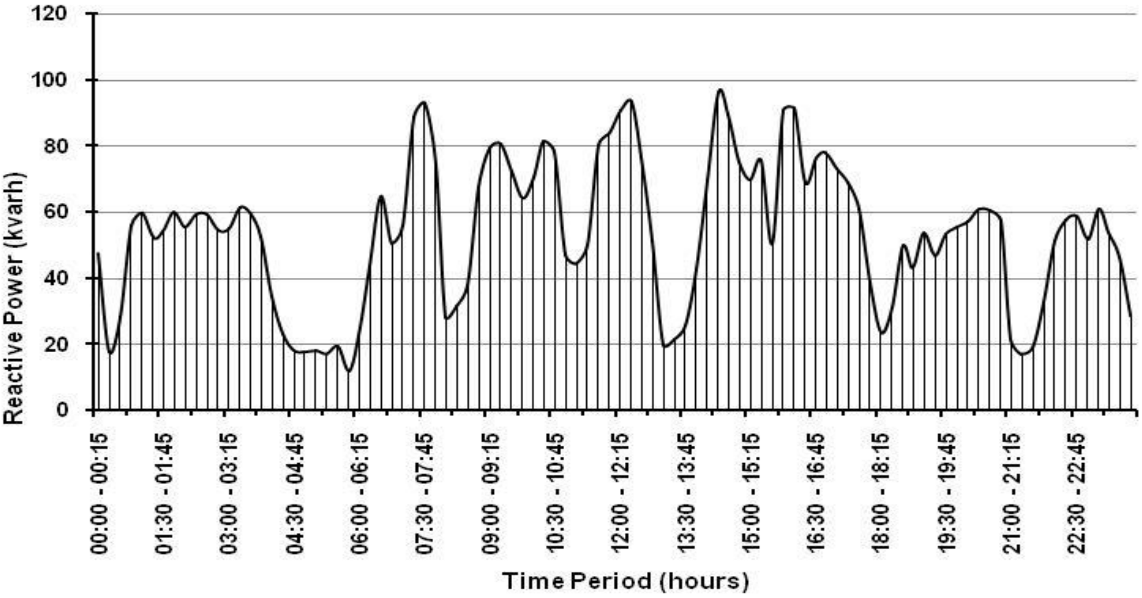


Figure 4.3 - Reactive Power Load Curve of the Selected Customer



The load profile data of the selected consumer is shown in Table 4.3. The highest demand for reactive power occurs during the day time interval.

Table 4.3 - Load Profile Data of the Selected Customer

Maximum Reactive Power Requirement (kvar)	Power Factor when the Reactive Power Demand is at Maximum	Total Reactive Energy Requirement per Month (kvarh)
289.50	0.77	129,485.70

The target power factor of the selected customer after power factor correction was taken as 0.98.

Total reactive energy requirement per year = 129,485.7x12 kvarh
= 1,553.8 Mvarh
Reactive energy from the grid = 1,075.9 Mvarh/year

The reactive energy requirement was calculated to ensure that the customer would maintain a power factor of 0.98 at all times of the day.

Extra reactive energy requirement from power factor correction
equipment fixed by the customer = 477.9 Mvarh/year

(b) Reduction in Power Losses on Lines

If every bulk consumer of the group of 93 consumers could maintain their day time power factor at 0.98 or higher by installing power factor correction equipment, then there will be a significant reduction of power loss in the distribution line. The reduction of power loss in the distribution line can be calculated as follows.

Table 4.4 - Daily Average Line Currents

Daily average total line current (at 400 V - secondary side) in a 15 minute interval	5,689.1 A
Daily average total line current (at 33 kV- Primary side) in a 15 minute interval	39.8 A

Power loss in a single line during a 15 minute interval $= \frac{1}{3} \times (39.8)^2 \times 1.65 \times 10$

= 8.71 kW

Total power loss during a 15 minute interval = 3 x 8.71 kW

= 26.13 kW

Total energy loss during a 15 minute interval = 26.13x0.25 kWh

= 6.53 kWh

The calculation was done for a whole day considering the line currents in each 15 minute interval, and results are shown in Table 4.4. Working days per month were taken as 25 days.

Table 4.5 - Energy Loss after Power Factor Correction at Consumer-End

	Energy per Day (kWh)	**Energy per Month (kWh)**
Delivered to 93 customers	92,703.8	2,317,595.6
Loss along the 33 kV line	713.6	17,840.0
Energy input at grid substation	93,417.4	2,335,435.6
Line loss as a % of input at grid substation	0.8%	0.8%

Therefore, if all customers maintain their day-time power factor at 0.98, and considering the 33 kV line losses without compensation on the customer side given previously in Table 4.2,

Reduction of 33 kV line energy loss per month = 21,190 - 17,840

= 3,350 kWh/month

5 FINANCIAL EVALUATION OF REACTIVE POWER COMPENSATION

To improve the power factor of the system, reactive power requires to be supplied. Reactive power may be supplied at two different locations.

(i) Case 1: Fixing a 33 kV capacitor bank at the grid substation
(ii) Case 2: Fixing capacitor banks by each customer at 400 V

In practice, reactive compensation may be done at both the above locations. However, for the purpose of this analysis targeted towards calculating the cost of reactive power compensation, it was assumed that compensation will be done either at the grid substation or at consumer end.

A financial evaluation was conducted for each of the above cases.

5.1 Capacitor Bank Fixed at the Grid Substation

The following assumptions were made,

(a) The capacitor bank is fixed on the 33 kV line at its origin at the grid substation, and would automatically operate to ensure that the power factor does not drop below 0.98.
(b) Life time of the capacitor bank is 10 years
(c) The all-inclusive cost of installing 1kvar is LKR 5,000
(d) Annual maintenance cost is 2% of capital cost

For the financial evaluation, the Weighted Average Cost of Capital (WACC) was estimated as follows:

WACC = Equity share× Rate of return on equity + Debt share × Interest rate
= 0.3 × 5% + 0.7 × 12%
= 9.9%

Energy loss saved per month = 3,350 kWh
Energy saved per year = 3,350 × 12 = 40,200 kWh

The values taken from the document on Analysis of the Filing, Allowed Revenues and Tariff Calculations published by Public Utilities Commission of Sri Lanka are shown in Table 5.1.

Table 5.1 - Weighted Average Energy Cost at the 33 kV Boundary

	Total Energy Dispatched in 6 Month (GWh)	**6 Month Weighted Average Charge (LKR/kWh)**
Day	3092.4	7.78
Peak	1232.5	10.00
Off peak	1186.8	5.60

Average value of 1kWh of energy saved at 33 kV level;

$$= \frac{3092.4 \times 7.78 + 1232.5 \times 10.00 + 1186.8 \times 5.60}{3092.4 + 1232.5 + 1186.8}$$

= LKR 7.81

Value of energy loss = 40,200 × 7.81

= LKR 313,962

The values calculated using load profile data and Section 3.2.1, were used in this calculation, and are shown in Table 5.2.

Table 5.2 - Reactive Energy Requirement if Capacitor Bank is Fixed at the Grid Substation

Total Reactive Energy Required per Year (kvarh)	**Maximum Reactive Power Requirement (kvar)**	**Value of Energy Loss (LKR/year)**
7,756,933	1,826.8	313,962

5.2 Calculation

Assume that a 2 Mvar capacitor bank is fixed on the 33 kV line at the grid substation to cater to the maximum reactive power requirement.

Total cost of installing the reactive power compensation system

= 5,000 × 2,000

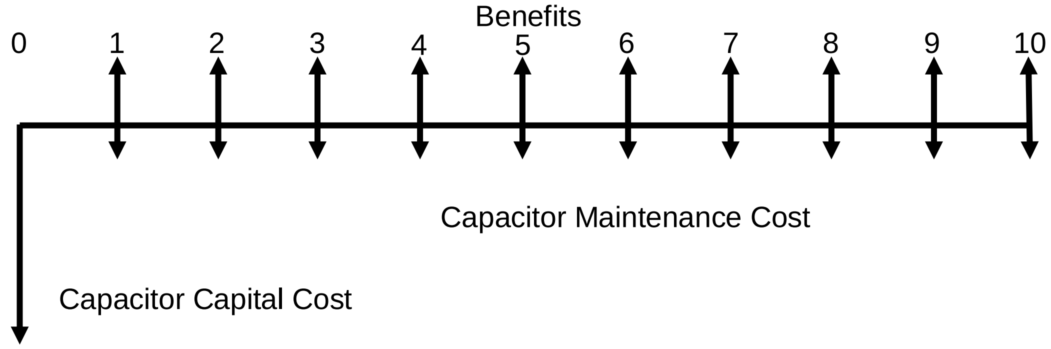
= LKR 10,000,000

Maintenance cost per year =10,000,000 × 0.02

= LKR 200,000

Net annual cash flow is shown in Figure 5.1.

Figure 5.1 - Net Annual Cash Flow



If levelized cost per kvarh is LKR C,

$$\text{PV of Benefits} = \text{PV of Total Cost}$$

$$\text{C} \times \text{PV of kvarh generated} = \text{Capital Cost} + \text{PV of Maintenance Cost} + \text{PV of Energy Losses}$$

$$\text{C} \times \sum_{x=1}^{10} \frac{7{,}756{,}933}{(1+0.099)^{x}} = 10{,}000{,}000 + \sum_{x=1}^{10} \frac{200{,}000}{(1+0.099)^{x}} + \sum_{x=1}^{10} \frac{313{,}962}{(1+0.099)^{x}}$$

$$\text{C} = \text{LKR } 0.28 \text{ per kvarh}$$

5.3 Capacitor Banks Fixed at Customer End

A customer who is consuming more reactive power without any power factor correction equipment was considered for this analysis. This is the same customer considered previously in Section 3.2.2 of this report.

The following assumptions were made.

(a) Life time of the capacitor bank is 5 years
(b) Annual maintenance cost is 2% of capital cost
(c) Cost of installing 1 kvar is LKR 3,000

Weighted average cost of capital (WACC) was estimated as follows:

WACC = Equity × Rate of return on equity + Debt × Interest rate
= 0.3 × 20% + 0.7 × 12%
= 14.4%

The values calculated using load profile data and Section 3.2.2, used in this calculation are shown in Table 5.3.

Table 5.3 - Reactive Energy Requirement if Capacitor Bank Fixed at the Customer End

Total Reactive Energy Required per Year (kvarh)	Maximum Reactive Power Required (kvar)
477,898	289.5

5.4 Calculations

Assume that a 300 kvar capacitor bank is fixed to cater to the maximum reactive power requirement. This is fixed at the customer end.

Total cost of installing reactive power required = 3,000 × 300

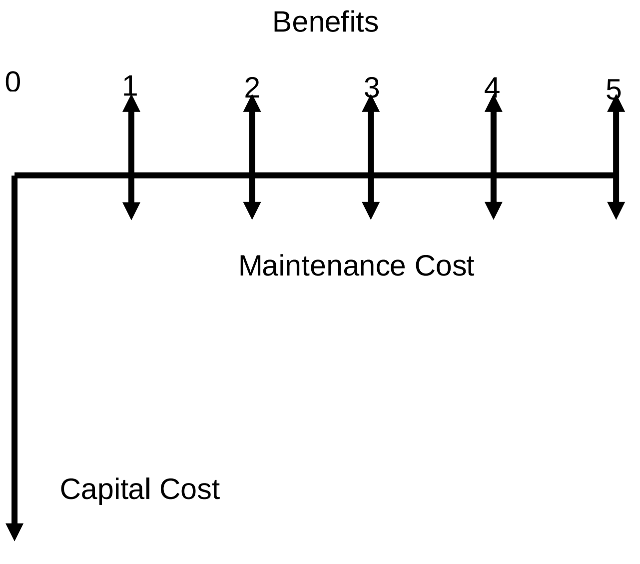
= LKR 900,000

Maintenance cost per year = 900,000 × 0.02

= LKR 18,000

Net annual cash flow is shown in Figure 5.2.

Figure 5.2 - Net Annual Cash Flow



PV of Benefits = PV of Total Cost

C × PV of kvarh generated = Capital Cost + PV of Maintanence Cost

$$C \times \sum_{x=1}^{5} \frac{477{,}898}{(1+0.144)^{x}} = 900{,}000 + \sum_{x=1}^{5} \frac{18{,}000}{(1+0.144)^{x}}$$

C = LKR 0.59 per kvarh

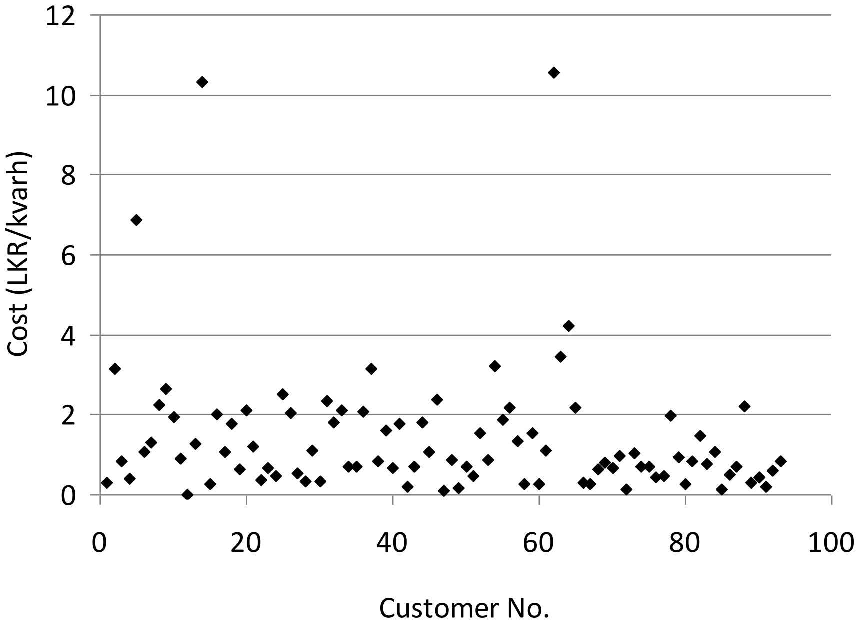
The above calculation was done for 93 customers and the results are shown in Table 5.4.

Table 5.4 - Levelized Cost of “reactive energy” for 93 Customers

Customer No.	Max. Reactive Power Required (kvar)	Capital Cost (LKR)	PV of Maintenance Cost (LKR)	PV of Total Cost (LKR)	PV of Total Reactive Energy Required (kvarh)	Cost per kvarh (LKR)
1	40	120,000	8,160	128,160	432,161	0.30
2	5	15,000	1,020	16,020	5,095	3.14
3	5	15,000	1,020	16,020	18,765	0.85
4	15	45,000	3,060	48,060	114,848	0.42
5	5	15,000	1,020	16,020	2,330	6.88
6	20	60,000	4,080	64,080	59,651	1.07
7	30	90,000	6,120	96,120	73,258	1.31
8	10	30,000	2,040	32,040	14,343	2.23
9	20	60,000	4,080	64,080	24,285	2.64
10	35	105,000	7,140	112,140	58,066	1.93
11	50	150,000	10,200	160,200	178,641	0.90
12	0	0	0	0	0	0
13	20	60,000	4,080	64,080	49,895	1.28
14	5	15,000	1,020	16,020	1,553	10.31
15	40	120,000	8,160	128,160	484,660	0.26
16	20	60,000	4,080	64,080	32,000	2.00
17	5	15,000	1,020	16,020	15,037	1.07
18	15	45,000	3,060	48,060	27,133	1.77
19	15	45,000	3,060	48,060	75,868	0.63
20	5	15,000	1,020	16,020	7,612	2.10
21	20	60,000	4,080	64,080	52,867	1.21
22	15	45,000	3,060	48,060	129,119	0.37
23	40	120,000	8,160	128,160	187,288	0.68
24	60	180,000	12,240	192,240	423,042	0.45
25	15	45,000	3,060	48,060	19,076	2.52
26	35	105,000	7,140	112,140	55,177	2.03
27	15	45,000	3,060	48,060	87,829	0.55
28	15	45,000	3,060	48,060	145,988	0.33
29	25	75,000	5,100	80,100	71,891	1.11
30	15	45,000	3,060	48,060	143,658	0.33
31	10	30,000	2,040	32,040	13,732	2.33
32	5	15,000	1,020	16,020	8,792	1.82
33	30	90,000	6,120	96,120	45,204	2.13
34	30	90,000	6,120	96,120	136,632	0.70
35	10	30,000	2,040	32,040	44,676	0.72
36	35	105,000	7,140	112,140	54,058	2.07
37	35	105,000	7,140	112,140	35,417	3.17
38	100	300,000	20,400	320,400	379,133	0.85
39	35	105,000	7,140	112,140	69,805	1.61
40	20	60,000	4,080	64,080	96,777	0.66
41	40	120,000	8,160	128,160	71,612	1.79
42	5	15,000	1,020	16,020	81,274	0.20
43	30	90,000	6,120	96,120	137,383	0.70
44	15	45,000	3,060	48,060	26,589	1.81
45	10	30,000	2,040	32,040	30,322	1.06
46	60	180,000	12,240	192,240	80,373	2.39
47	15	45,000	3,060	48,060	499,003	0.10
48	45	135,000	9,180	144,180	163,935	0.88
49	10	30,000	2,040	32,040	206,851	0.15
50	30	90,000	6,120	96,120	138,781	0.69

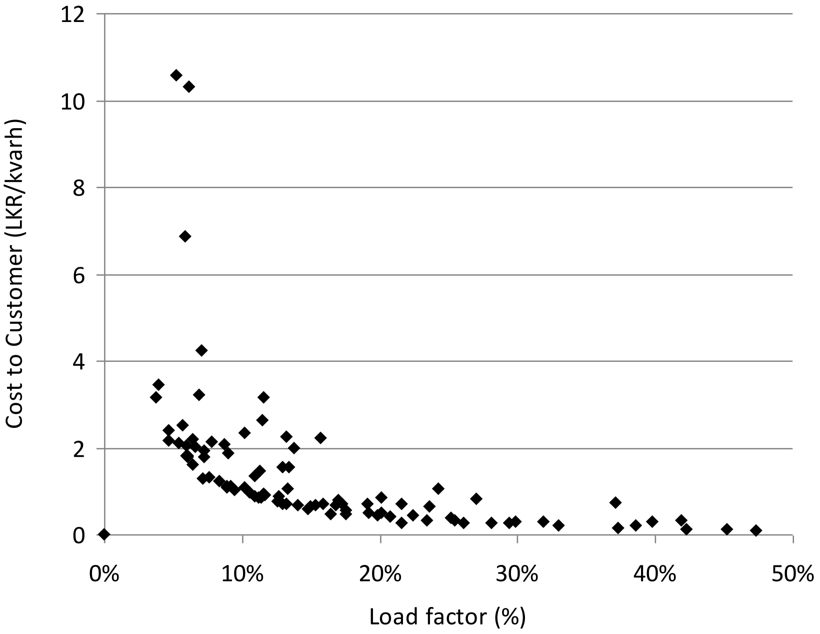
51	50	150,000	10,200	160,200	334,499	0.48
52	75	225,000	15,300	240,300	156,013	1.54
53	15	45,000	3,060	48,060	54,680	0.88
54	10	30,000	2,040	32,040	10,004	3.20
55	15	45,000	3,060	48,060	25,724	1.87
56	35	105,000	7,140	112,140	51,262	2.19
57	15	45,000	3,060	48,060	35,666	1.35
58	20	60,000	4,080	64,080	234,045	0.27
59	25	75,000	5,100	80,100	52,070	1.54
60	15	45,000	3,060	48,060	182,089	0.26
61	15	45,000	3,060	48,060	43,790	1.10
62	25	75,000	5,100	80,100	7,581	10.57
63	10	30,000	2,040	32,040	9,320	3.44
64	20	60,000	4,080	64,080	15,130	4.24
65	35	105,000	7,140	112,140	51,744	2.17
66	10	30,000	2,040	32,040	101,074	0.32
67	10	30,000	2,040	32,040	113,367	0.28
68	35	105,000	7,140	112,140	175,829	0.64
69	110	330,000	22,440	352,440	440,855	0.80
70	30	90,000	6,120	96,120	145,616	0.66
71	5	15,000	1,020	16,020	16,684	0.96
72	20	60,000	4,080	64,080	488,699	0.13
73	35	105,000	7,140	112,140	108,583	1.03
74	15	45,000	3,060	48,060	67,381	0.71
75	30	90,000	6,120	96,120	134,628	0.71
76	35	105,000	7,140	112,140	253,582	0.44
77	25	75,000	5,100	80,100	166,007	0.48
78	5	15,000	1,020	16,020	8,098	1.98
79	10	30,000	2,040	32,040	33,895	0.95
80	30	90,000	6,120	96,120	350,757	0.27
81	5	15,000	1,020	16,020	19,449	0.82
82	25	75,000	5,100	80,100	54,804	1.46
83	30	90,000	6,120	96,120	124,272	0.77
84	60	180,000	12,240	192,240	178,434	1.08
85	30	90,000	6,120	96,120	737,295	0.13
86	150	450,000	30,600	480,600	968,389	0.50
87	50	150,000	10,200	160,200	232,337	0.69
88	10	30,000	2,040	32,040	14,447	2.22
89	60	180,000	12,240	192,240	668,583	0.29
90	25	75,000	5,100	80,100	180,039	0.44
91	125	375,000	25,500	400,500	2,026,564	0.20
92	300	900,000	61,200	961,200	1,624,855	0.59
93	60	180,000	12,240	192,240	226,123	0.85
Total for all customers	2,900	8,700,000	591,600	9,291,600	16,235,747	0.57

Figure 5.3 - Levelized Cost of "reactive energy" for 93 Customers



In these calculations, it was assumed that up to 0.98 power factor, reactive energy is provided by the grid, free of charge. The extra reactive energy requirement to raise the power factor throughout the day from the present level to 0.98 is fulfilled by installing power factor correction equipment at each customer end.

Figure 5.4 - Variation of Levelized Cost per kvarh with Customer Load Factor



Note: Load factor has been calculated on the basis of reactive energy requirement and reactive power demand

As shown in Figure 5.4, the levelized cost per kvarh varies between 0.10 and 10.57 LKR. Furthermore, customers with lower existing “reactive” load factor have to spend more than the customers with a higher “reactive” load factor. This is because of the usage of power factor correction equipment is greater for high load factor customers.

Although the investment for installing power factor correction equipment is high at the grid substation, the levelized cost per kvarh for the selected customer at the customer-end is 0.59 LKR. This is high when compared with the cost at the grid substation 0.28 LKR. This is because the centralized usage of power factor correction equipment at the grid substation end is higher that when individual customers use their own reactive power compensation equipment at different time intervals.

As a group, if each customer installs power factor correction equipment to ensure the power factor is maintained at least at 0.98 at all times, the collective investment would be for 2.9 Mvar of capacitors. The levelized cost of a kvar for the entire group would be 0.57, as seen in Table 5.4. The present value of the investment and maintenance costs is estimated to be LKR 16.2 million (discount rate = 14.4%).

In contrast, the option to install power factor correction equipment at the grid substation has a present value of LKR 13.2 million (discount rate = 9.9%) or LKR 12.6 million (discount rate = 14.4%).

6 CONCLUSIONS

Most of the western countries covered in this study have a reactive power charge in their tariff schedules. Most countries announced 0.95 as the target power factor value. However, most of the Asian countries analysed use the maximum demand charge for apparent power as an indirect method to charge for the reactive power.

Most CEB bulk consumers analysed in the study had average power factors well below the desired range. Most of the consumers (78%) did not have targeted power of 0.95 during day time.

Average daily power factor	0.90
Average power factor at peak interval (18.30h-22.30h)	0.91
Average power factor at off-peak interval (22.30h-05.00h)	0.90
Average power factor at daytime interval (05.30h-18.30h)	0.90

Total reactive power required to be installed at the grid substation	=1,826.8 kvar
Total reactive energy requirement for the consumers per year	=13,404 Mvarh

Levelized cost per kvarh is LKR 0.28 if the power factor is corrected on the system side, by fixing reactive power compensation equipment on the system side at 33 kV, located at the grid substation.

If the customers individually install power factor correction equipment, the total reactive power compensation equipment to be installed will be 2496.8 kvar, to enable each customer to maintain the peak-time power factor at 0.98.

Levelized cost per kvarh is LKR 0.59 if the power factor is corrected by a typical customer considered in these calculations. The range of levelized costs when this calculation is done separately for each one of the 93 customers is between 0.10 and 10.57 LKR/kWh. In general, customers with a high load factor would experience lower levelized costs, meaning that their investment on reactive power compensation equipment would be used well.

The load factor in the reactive power curve (1826.8 kvar) was 50% for all customers at the grid substation, while for the individual customer selected, who is considered for calculations, the load factor was 15%. This causes improved economics of centralized correction, in spite of the fact that 33 kV capacitors are more expensive to install and would also continue to cause additional 33 kV network losses.

7 DESIGN CONSIDERATIONS OF A TARIFF TO CHARGE FOR REACTIVE POWER

As described in chapter 1, it is becoming an increasingly common practice to impose a charge for reactive power to encourage customers to improve their power factor, to assist the electricity supplier maintain a lower level of reactive power circulating in the network to minimize network losses and losses in generation, and to assist in voltage regulation in the network.

The foregoing analysis in this report indicated the following:

<u>The status of reactive power requirements</u>

(a) Sri Lanka generation system has a significantly lower power factor in the daytime.

(b) The bulk customers as well as the retail customers would be contributing to this situation. In the evening, with lower industrial and commercial loads, the power factor improves. Inclusive of the assistance from the available reactive power compensation equipment, the system power factor on the generation bus bar increases to about 0.98 in the early hours each day.

(c) The sample of bulk customers analysed in this study clearly indicated that the power factor is low during the day-time interval. The group power factor reached the lowest level of 0.88 at 1530. The generating system power factor too indicated similar levels of about 0.875 between the period 1100 to 1530. It should be noted that reactive power compensation is available at several grid substations.

<u>Assessment of costs of reactive power compensation</u>

(d) For the sample of customers analysed in the study, it would be financially more beneficial for reactive power compensation equipment be installed at the grid substation, when compared with each customer individually installing such compensation equipment. The main reason for this, in spite of the additional line losses that would be incurred if power factor is corrected centrally at the grid substation, is the improved utilization of compensating equipment when installed centrally. In addition, such centrally installed compensation equipment would be able to cater to the needs of other customers, when the bulk customers impose a lower reactive power demand in the system.

(e) The estimated levelized cost of a unit of “reactive energy” is as follows, to maintain a minimum target power factor of 0.98:

If installed centrally at the grid substation (to serve the sample of customers)
= 0.28 LKR/kvarh
If installed by individual customers, average of the sample = 0.57 LKR/kvarh

The costs of both the above options are on the basis of a unit of “reactive energy” (kvarh) delivered to customers.

Should there be a tariff for "reactive energy" in Sri Lanka ?

If decided, the tariff for reactive power can only be applied for bulk customers, owing to the fact that reactive power metering is presently not available for retail customers. Similarly, a corresponding reactive power tariff may also be charged for inter-licensee transfers ie generation to transmission, transmission to distribution and between distribution licensees.

Arguments supporting a tariff for reactive energy

(f) Presently, the maximum demand charge (for kVA) indirectly reflects the poor power factor at the time when the individual customer's peak demand occurs. However, experience indicates that the charge or the maximum demand does not adequately encourage customers to ensure power factor correction. This is likely to be because,

   i. complete lack of concern (insensitive to electricity costs)
   ii. lack of understanding of how the maximum demand and power factor are interrelated
   iii. inability of the maximum apparent power demand charge to adequately compensate the costs of supplying reactive power.

(g) In spite of a recurrent problem of lower power factor in the network, adequate efforts have not been made by the Licensees to study the problem and install compensation equipment.

(h) Introduction of a tariff for "reactive energy" for bulk customers is therefore likely to,

   i. convey a clear message to the customers, because the charge will appear as a penalty in the monthly electricity bill (an incentive too to be considered for good performers)
   ii. enable each Distribution Licensee (DL) to collect adequate funds to finance compensation equipment to serve the target group of customers and maintain the power factor at the required levels
   iii. clearly separate out the cost of serving reactive power

As the charge on measured reactive energy can only be introduced for bulk customers, the corresponding charge for retail customers would have to be included in the tariff for "real power".

(i) The flow of reactive power in the network can therefore be measured and charged for from generation up to the end-use customer.

Arguments against a tariff for reactive energy

(j) There will be an additional reading to be taken and charged for, in the case of bulk customers. As the distribution licensees have already been advised to read the reactive energy use by bulk customers in each of the three intervals[1] and the same information about transfers from transmission and distribution, the issue of taking an additional reading does not arise.

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[1] See section 8.3, "Decision on Electricity Tariffs Jan to June 2011", PUCSL, July 2011.

(k) If the maximum demand charge based on apparent power (kVA) is retained, then a new charge for reactive energy is effectively double counting the cost of providing reactive power to customers.

Should customers be compelled to improve their power factor ?

(l) As seen in these calculations, the levelized cost of reactive power as well as the present value of the cost of reactive power compensation equipment individually by each customer, is higher than that for fixing equipment on the system side. Therefore, the rational approach will be to provide the full information to customers, and allow the customer to make a decision, whether to purchase reactive power from the grid or to fix compensation equipment in-house.

Should distribution licensees be compelled to fix compensation equipment ?

(m) Similar to customers, distribution licensees too can be given the option of either purchasing reactive power from the grid or to fix capacitors on the distribution network.

What if the customers who operate between 0.98 and 1.00 be provided with a bonus ?

(n) If the benchmark average power factor is fixed at 0.98 lagging, customers operating at power factors between 0.98 and 1.00 may be provided an incentive. This means, a credit will be provided to such customers for the high power factor maintained. However, operation at leading power factor may not be allowed.

8 RECOMMENDATIONS FOR A REACTIVE POWER TARIFF

From the foregoing analyses, it is clear that Sri Lanka power transmission and distribution network has a power factor well below the desired level of 0.98, especially during the day-time. The customers who dominate the day time are the bulk customers, who display a poor power factor during day time. The indications are that the smaller customer within the bulk customer groups have poor power factor, compared with the larger ones.

This is also an indication that the retail industrial and commercial customers, who use less than 42 kVA (ie 3-phase 60 A), are also most likely to have a poor power factor. However, with no metering for reactive power, it is not possible to assess the power factor of such customers.

Based on the issues analysed in chapter 7, the following is proposed:

(a) For MV and LV bulk customers (which include all customers with a contract demand of 42 kVA or more, introduce a <u>charge</u> (or an <u>incentive</u>, as the case may be) for "reactive energy" from January 2012.

(b) A nominal fee, representing only the cost of supply of reactive power by a distribution licensee, will be charged. The proposed fee is 0.25 LKR/kvarh. The amount of reactive energy to which the charge is applied will be calculated as follows:

In a billing month,
Active energy recorded = E_a
Reactive energy recorded = E_r
Chargeable amount of reactive energy, on the basis of an average
power factor of 0.98 lagging = $E_r - E_a \times \tan(\cos^{-1} 0.98)$

The chargeable reactive energy will be –ve, if the customer's power factor is between 0.98 and 1.00, in which case, the customer will be provided with a credit, which will be an incentive for maintaining a high power factor.

Accordingly, the customer bills for two specific customers will be as follows. These estimates have been done on the basis that the daily profiles described previously occur for 25 days in a month. The tariffs are the presently (September 2011) applicable tariffs.

Customer with a high power factor receiving an incentive

Customer number		Meter reading	Rate (Rs)	Charge (Rs)	Surcharge (-discount) as a share of the bill
35	Maximum demand (kVA)	65	850	55,250.00	
Good reactive Power Management	Energy use (kWh)			-	
	Day	16,800	10.45	175,560.00	
	Peak	6180	13.6	84,048.00	
	Off-peak	5,778	7.35	42,468.30	
	Reactive energy use (kvarh)	2,628			
	Reactive energy entitled (kvarh)	5,840			
	Chargeable reactive energy (kvarh)	(3,212)	0.25	(803.00)	
	Fixed charge			3,000.00	
	TOTAL MONTHLY BILL			**359,523.30**	-0.22%

Note: This customer is a real customer, included in the survey

A customer with a low power factor surcharged

52	Maximum demand (kVA)	120	850	102,000.00		Surcharge (-discount) as a share of the bill
Poor reactive Power Management	Energy use (kWh)			-		
	Day	34,835	10.45	364,025.75		
	Peak	375	13.6	5,100.00		
	Off-peak	515	7.35	3,785.25		
	Reactive energy use (kvarh)	27,882				
	Reactive energy entitled (kvarh)	7,255				
	Chargeable reactive energy (kvarh)	20,627	0.25	5,156.75		
	Fixed charge			3,000.00		
	TOTAL MONTHLY BILL			**483,067.75**		1.08%

Note: This customer is a real customer, included in the survey

(c) There will be no change in the policy of charging for maximum demand in kVA and the methodology for determining the rates.

(d) Funds collected as "reactive energy charges" should be separately accounted for by each distribution licensee, and invested on reactive power compensation equipment and their maintenance. If the distribution licensee does not improve the power factor, such funds will flow to the transmission licensee, to install power factor correction equipment on the transmission network. This will be implemented by measuring the reactive energy flow from transmission to distribution licensees, and charging (at the same rate as 0.25 LKR/kvarh) with a free allowance reflecting a monthly average power factor of 0.98.

(e) The transmission licensee is also required to maintain a mandatory monthly average power factor of 0.98 on the transmission network, as measured on the generation busbar. PUCSL may, at a later date, impose a penalty on the transmission licensee, if the power factor is not maintained higher than 0.98 lagging.

(f) Customers will not receive credits for operating their facilities at leading power factor. Meters will ensure such operation at leading power factor is recorded but not counted as –ve reactive power drawn from the system.