END-USE CHARACTERISTICS OF THE ELECTRICITY DEMAND IN SRI LANKA

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ABSTRACT

Although much analysis has been done on the seasonal and periodic variations of the daily demand curve of Sri Lankan power system, very little information is available on the constituent components of the electricity demand curve. A knowledge of these components is very important as it provides a wealth of information essential to several key utility functions such as distribution system planning and operation, Load forecasts, demand-side management planning and tariff structure design.

Ceylon Electricity Board has an ongoing load research study program, under which it collects and analyses customer electricity use characteristics. Load shape information on provincial / area-wise, sector-wise, segment-wise and end use-wise have been developed under these studies. This information could now be used for many applications such as design of demand-side management programs, to optimise the loading on distribution transformers or feeders in a particular area, and also more efficiently meet future load growth.

Load research studies may be conducted either based on customer data ("bottom-up" approach) or based on substation data ("top-down" approach) or in a combination of the two. The study described in this paper has been done using the bottom-up approach. In developing individual load profiles in the study, metering data and market survey data for the samples have been statistically consolidated. At the end, the information collected have been consolidated and verified to be in close correlation with the data available from the grid substations and billing records.

This paper describes the load research study methodology, the results and potential uses of the load profiles developed.

INTRODUCTION

Electricity utilities have traditionally depended on expanding the system capacity (including generation, transmission and distribution) to meet the growing electricity demand. However, the focus now is towards a more balanced and symmetrical approach, where the improvement of end-use efficiency is becoming a key feature. Load research is an activity, which provides a wealth of information related to end-use profile of electricity consumption in a particular system. For an electricity utility, a reliable load research database can be used to support some of its key functions such as system planning and operation, load forecasts, demand-side management planning and tariff design. The importance of regular updating of these databases needs no elaboration.

1. LOAD RESEARCH

Load Research is primarily aimed at analysing and understanding the utility's system load profile. This entails breakdown of the system load profile into various sub components. Therefore, the main objectives of the load research can be identified as follows:

- To develop load shapes at the system, regional, and customer sector level
- To develop a load shape database by major end-uses within customer sectors

It will be evident that these objectives are quite flexible to accommodate any sub system of the main network and to analyse any sub-categories of end uses.

Load research may either be conducted by starting from customer end use to build and develop the total system load shape ("Bottom-up" approach), or by starting from the total system load shape and breaking it down to customer end-use ("Top-down" approach). It may well be a combination of the two.

Both approaches require primary and secondary data collection and are generally accomplished through a combination of the following data collection methods:

- Metering
- Customer load surveys
- Statistical methods
- Using engineering models
- By analysing other data

Figure 1 shows the conceptual approach that was used in the Load research of the CEB system. It has used the Bottom-up approach, with a combination of data collection by metering, customer surveys and using other recorded load data. A list of customer sectors, segments and the end uses, which were analysed, is given in Annex 1.

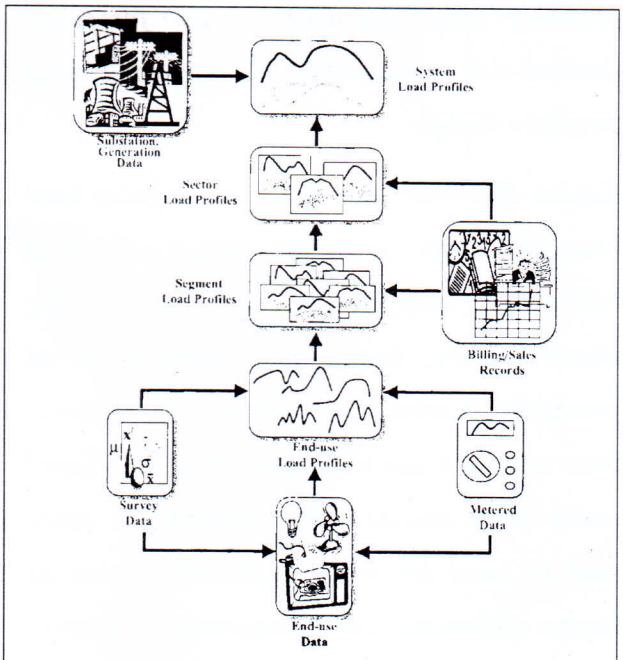

Figure 1 - Conceptual approach to Load Research

2. LOAD RESEARCH DATA SOURCES

2.1 Metering

Metering of customers is the most direct and accurate method of collecting load research data. Metering surveys are used to understand customer electricity use and develop customer load shapes, and where practical, end-use load shapes. Given the prohibitive cost of customer metering, utilities generally survey a subset of customers and use the metering study results to validate the results from the analysis based on market surveys and other data sources. The sample for metering surveys comprise of a sub-sample of the main sample for market research survey.

In this study each customer's installation has been metered for a period of 14 days continuously to capture electricity consumption data.

In the bottom-up approach, a vast amount of such data is required depending on the bottom-most level of analysis required. In CEB's case, it meant data related to end-uses of electricity and end-use technologies. (For example, in the residential segment, 10 major end-uses and the whole of the household were individually metered using electronic data loggers to establish the average (over one year) end-use and whole household load profiles.) It was aggregated from this level to produce system profiles. In other words, the total system load profile was segregated to the level of end-use technologies.

However, as it is impractical to meter all customers to that level, statistically representative samples of customers are selected for data collection purposes. In order to reduce (even remove) certain degree of error associated with statistical analysis techniques, data from established sources are used for validation and cross validation of results (load profiles) at various intermediate stages. Developing a reliable load research database, however, requires considerable time and monetary resources. It is thus important to try and obtain as much information as possible from secondary sources within the utility, as described later.

In order to ensure that the customers selected for the metering sample represents the actual segment population, their energy consumption from their metered load profiles is compared with their historical billing records and the average electricity consumption by an average customer in that segment from utility's billing data. Large deviations here would indicate that the representativeness of sample is doubtful. Therefore, such customers were not considered for the sample.

2.2 Market survey

Development of a reliable load research database requires knowledge of key customer characteristics such as basic demographic information, energy and equipment usage patterns, saturation of equipment and other appliances in the marketplace, etc. While some of this information can possibly be obtained from national statistics, it is usually necessary to conduct questionnaire-based customer surveys to develop this primary data on customer electricity use.

2.2.1 Developing Questionnaires

The design of the questionnaire is the most important component of a customer survey.

This needs to be designed to extract information that precisely explains attributes of customer under focus.

2.2.2 Identifying Customer Sectors and Segments

The load profile is a reflection of a customer's "energy activity". For domestic customers it is a reflection of their lifestyle i.e. what type of energy related activities that are carried out during an ordinary day e.g. cooking, entertainment, washing, etc. For commercial and industrial customers it is a reflection of their business activity i.e. what type of energy related activities are carried during an ordinary day e.g. machining, conveying, steam production, water pumping, chilling, processing etc.

A list of customer sectors, segments and the end uses, which were analysed, is given in Annex 1.

2.3 Sub-Station Logbook Data

Routine records of operational data of primary and secondary distribution sub-stations provide valuable load research information. In CEB, this data is recorded hourly and, where meters are available and operational, the parameters normally recorded are voltage, current, power and power factor. The data from logbooks can thus directly be used to develop load shapes at the feeder level.

2.4 System Control Centre Data

The System Control Centre monitors and directs power flow from all generation sources to customer load centres. It maintains a comprehensive database of hourly load flows for each generation source and of the overall customer demand in Sri Lanka. The most reliable system load shape is thus available from the System Control Centre.

2.5 Sales and Billing data

Historic sales and billing records are essential for establishing checks and balances that can be used to verify the accuracy and reliability of the estimated load shapes and other customer attributes.

3. SAMPLE SIZE

In a previous study done in 1997 the sampling plans for Load Research has been determined. The degree to which one can ascribe the characteristics of the sample to the entire population is measured in terms of the accuracy and the confidence of sample results. i.e. a typical goal in sampling for load research may be to estimate energy usage patterns with an accuracy of ±10% at the 90% confidence level. For a given sample study, less accuracy means higher confidence level and vice versa.

In practice, the sample size is constrained by the survey budget. But, increasing the sample size beyond a certain limit yields diminishing marginal returns in terms of include accuracy and confidence.

A minimum sample size of 30 is commonly assumed for survey work, primarily because for a Poisson approximation of binomially distributed event, there is a 95% probability that in a sample of 30, it will include at least one example of a characteristic occurring in at least 10% of the population.

In this study it was found that a total sample size of 2604 would be a statistical representative sample size at accuracy of ±30% of the population mean at least 90% confidence.

However, in the present study much larger sample sizes were used where 1500 customer surveys in the residential sector, 325 surveys in the large industrial & commercial sector and 800 surveys in the small commercial & industrial sector were done. In each of the sectors, the minimum sample size was used for each tariff segment. Larger sample sizes were used for sectors and segments where the population is smaller.

Therefore the accuracy obtained in this study is better than the design accuracy of ±30% of the population mean. To verify the accuracy, the study compared the results obtained from the bottom-up approach with the total load profile. It was found that the profiles obtained by the two means differed only by average 5.9%.

3.1 Sampling process

Determining the sample size of customers to be surveyed is a function of the required geographical coverage, the level of accuracy desired, the available human and the monetary resources. To preserve the reliability of the database, it is very essential that sample be drawn as random as possible.

4. RESULTS

Final results of the Load Research Project consisted of the following load profiles and the associated data for the CEB network.

1. CEB System
2. Provincial load profiles
3. System load profiles by sectors
4. Domestic sector by segments
5. End use load profiles
    - Domestic
    - Domestic (by lighting technology)
    - Small commercial & industrial
    - Large Industrial & Commercial (Bulk) customers

Annex 2 shows some of these load profiles developed.

5. APPLICATIONS FOR LOAD RESEARCH DATA

5.1 Demand-side Management

Demand-side Management (DSM) objectives of a utility can normally be categorised into Load Shape and Non-Load Shape objectives as described below.

5.1.1 Load Shape Objectives

DSM activities in Sri Lanka cannot considered to be an alternative to supply-side options available for power system capacity expansion. But some load shape objectives of demand-side management could effectively complement the supply side options. In general, the DSM options address the specific load shape objectives depicted in Figure 2.

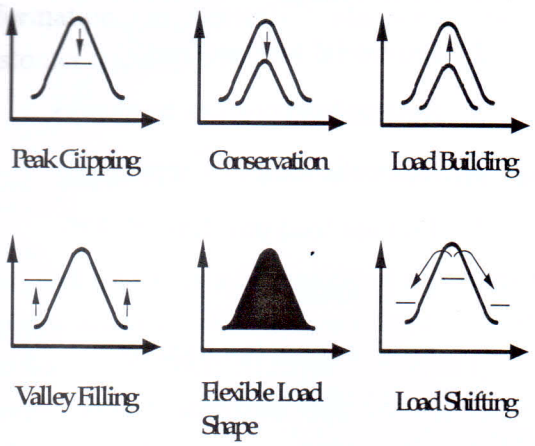

Figure 2 - Load shape objectives

The knowledge available from load research regarding the composition of the load shape is of valuable to design any of these DSM activities and to forecast their impacts. Through subsequent load research, i.e. after implementing the DSM measures, the utility would also be able to evaluate and monitor the impacts of such measures.

5.1.2 DSM Program Options

The breakdown of domestic load profile by segments and by end-use confirms that that lighting is the major contributor to the evening peak. (Annex 2 – Profile 5) Though this was common knowledge, now a quantification of the lighting peak is available, Province-wise and Area wise. Further breakdown of lighting load reveals the contribution of incandescent lamps to the total lighting load and consequently to the system peak in the evening. It is also observed that the Incandescent lamps contribute significantly to the morning peak of the load profile for domestic sector. Such findings can be used to design more focussed DSM programs to replace incandescent lamps with fluorescent or compact fluorescent lamps.

In the Bulk Consumer sector, since a mix of manufacturing and service-based industry dominates it, the dominant end-uses for this sector are observed to be the motive load, air conditioning and lighting. This provides opportunities to design DSM and load management programs aiming the control and efficiency improvement of motive load and promoting efficient air conditioning and lighting systems. For example promoting high efficiency motors, installing variable speed drives on variable loads etc.

These load profiles also provide insight to next focuses of DSM activities. For example, the next highest energy use in the domestic sector is for fans. Therefore, awareness and promotion of efficient fans could be targeted.

5.1.2 Non-Load Shape Related Objectives

Usual operational and management objectives of a utility would include improving power quality and reliability, minimizing pilferage, reducing system losses, improving the distribution network, upgrading sub-stations, high revenue collection efficiency, improving customer service etc. Load research could also provide inputs to any of these.

Non-load shape related applications of load research are not confined to utility operations. Such applications could even be found in advertising and equipment marketing fields.

Three major applications related to electricity utilities are described below.

a. Transmission & distribution planning

Load research data at the Province and customer-sector levels provides key inputs for transmission and distribution planning activities. The planners are now provided with a choice whether to continue with system augmentation in a particular area or to delay the investment by adopting certain DSM measures in the interim. Once, the problem is quantified through a load research confined to the locality, the planners are able to take an informed decision.

b. Developing load forecasts

Load research determines the customer electricity consumption patterns load characteristics and load profiles more accurately than any other conventional way. This information in conjunction with other demographic and socio-economic indicators is invaluable in forecasting regional and sector demand.

c. Tariff design

Load research has many applications in tariff design in a regulated power sector, operating on commercial principles. For example, precise information on revenue potential of a distribution region could be found through load research and tariff could be designed in such a way to recover the costs from the relevant customer segments. The Regulatory Commission also may have its own load research to verify any claims submitted by the sector entities for determination.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

1. Ceylon Electricity Board. "Load Research and DSM Program Design: Final Report", Nov. 2001
2. Ceylon Electricity Board. "Design of a Load Research Program: Final Report", Mar. 1997

Annexes

1. A list of customer sectors, segments and the end uses, which were analysed
2. Load Profiles

Annex 1

A list of customer sectors & segments used for analysis

A. DOMESTIC SECTOR

Segments used for Domestic sector

1. Domestic Small (Electricity consumption: 0-90 units per month)
2. Domestic Medium (Electricity consumption: 91-180 units per month)
3. Domestic Large (Electricity consumption: more than 180 units per month)

B. SMALL COMMERCIAL & INDUSTRIAL

Segments used for small commercial & industrial sector

1. Offices
2. Retail sales
3. Retail foods
4. Restaurants
5. Industries
6. Others

C. LARGE COMMERCIAL & INDUSTRIAL SECTOR

Segments used for large commercial & industrial sector

1. Food, beverage & tobacco
2. Textile
3. Wood Products, Pulp & Paper
4. Chemicals
5. Metals & Metal Fabrication
6. Telecom
7. Water Supply
8. Tea
9. Super Markets, Shopping malls
10. Hotels
11. Office Building and institution
12. Cement
13. Agricultural & livestock
14. Rubber
15. Asbestos, Tile, Ceramic & Granite
16. Other

Annex 2

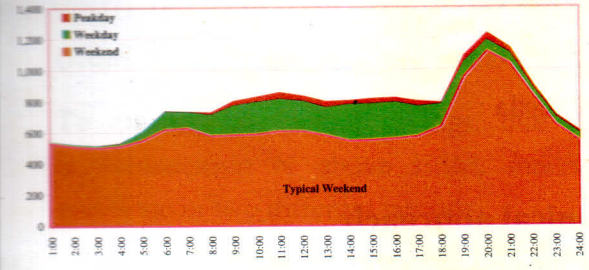
CEB Total System Profile 1999/2000

Average Load Factor = 54.4%

Average Peak on a Typical Peakday = 1,240 MW

Average Peak on a Typical Weekday = 1,191 MW

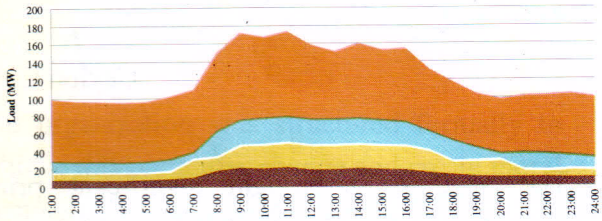
Average Peak on a Typical Weekend = 1,117 MW



Profile 1

CEB Load Profiles
Bulk consumption by end-use

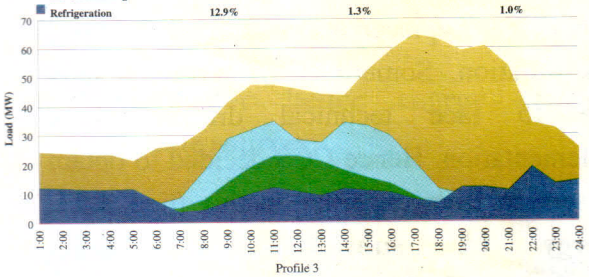
	% Sector kWh	% System kWh	Contrib to Day Peak
Air Conditioning	19.8%	06.4%	03.0%
Lighting	11.9%	03.9%	02.4%
Motive Load	49.9%	16.1%	08.2%
Process Equipment	05.3%	01.7%	00.8%



Profile 2

CEB Load Profiles
Small Commercial & Industry by end-use

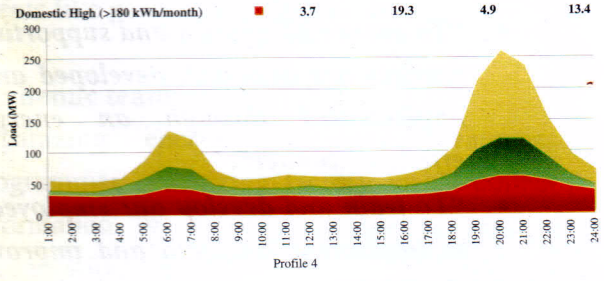
	% Sector kWh	% System kWh	Contrib to System Peak
Lighting	52.2%	5.3%	5.1%
Fan	9.6%	1.0%	0.1%
Air Conditioning	16.9%	1.7%	0.1%
Refrigeration	12.9%	1.3%	1.0%



Profile 3

CEB Load Profiles
Domestic customers by segment

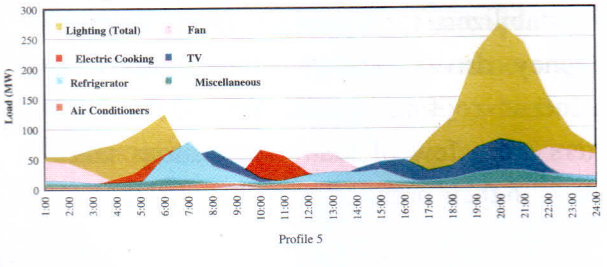
	% Population	% kWh	% Contribution System Peak	% Contribution Sector Peak
Domestic Small (1-90 kWh/month)	74.5	50.5	21.5	59.5
Domestic Medium (90-180 kWh/month)	16.1	30.3	9.8	27.2
Domestic High (>180 kWh/month)	3.7	19.3	4.9	13.4



Profile 4

CEB Load Profiles
Domestic customers by end-use

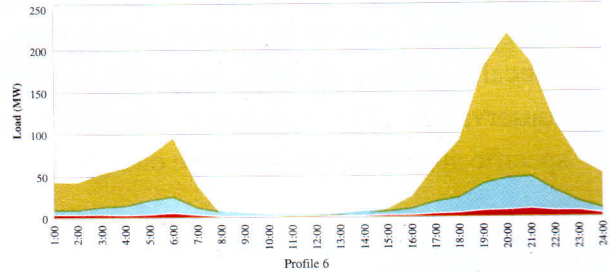
	% Sector kWh	% System kWh	Contribution to System Peak
Lighting	42.3%	10.5%	22.8%
TV	14.9%	3.7%	6.6%
Fan (Ventilation)	14.9%	3.7%	2.9%
Refrigeration	10.7%	2.7%	1.4%



Profile 5

Domestic Lighting Technologies

	% Sector kWh	% System kWh	Contrib to System Peak
Incandescent	32.7%	8.1%	18.4%
Fluorescent	8.2%	2.0%	3.8%
CFL	1.4%	0.3%	0.6%



Profile 6