ELECTRICAL ENERGY: CAPACITY PLANNING, AND DISTRIBUTION MANAGEMENT

BY

SIBANSHU SEKHAR BASU

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TO MY GURUDEV

CERTIFICATE

It is certified that the thesis entitled, "ELECTRICAL ENERGY: CAPACITY PLANNING AND DISTRIBUTION MANAGEMENT" submitted by Sibanshu Sekhar Basu is worthy of consideration for the award of the degree of Doctor of Philosophy and is a record of the original bona fide research work carried out by him under my guidance and supervision. The results contained in the thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

M. S. Sodha
(M.S. SODHA)
Professor
Centre for Energy Studies
Indian Institute of Technology, Delhi
New Delhi-110016

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(S.S. BASU)

PREFACE

SYNOPSIS

ELECTRICAL ENERGY: CAPACITY PLANNING, AND DISTRIBUTION MANAGEMENT

CHAPTER -1

INTRODUCTION:

In recent years, there has been a growing concern over the rapid depletion of natural energy resources. There are basically two types of energy resources - (a) Energy Capital (such as fossil fuels, nuclear fuels and hydro electric power, (b) Recurrent energy supplies (such as energy from deep within the earth, solar energy and wind energy) which are renewable. If the current consumption pattern continues, the present fossil fuel resources will be depleted by the year 2000 (Multan, Morgan & Murray 1976). This fuel shortage (along with the increasing expenses involved in generating energy from fuel) has resulted in an energy crisis.

At a survival level, human beings require approximately 2000 Kcal per day of food energy. But food energy represents only a small fraction of personal energy consumption in the developed world. Total energy use for the average citizen of USA amounts to 250,000 Kcal per day. This represents a 100 fold increase over the subsistence rate. During recent years, however, energy consumption in the industrialised world has not increased as rapidly as in previous years. This is due to several factors:

a conscious effort at conservation by the general public;

Significant increases in energy prices;

Government efficiency regulations and guidelines;

Saturation of markets (when a household has one washing machine, it is unlikely to purchase a second one);

Frequent recessions and economic downturns in the late and early, 1980s.

The per capita consumption of primary energy in the world has remained constant more or less in last five years. But the share of liquids in the consumption pattern had a gradual decline. The share of solid, gases and electricity had an increasing trend. The share of energy requirement met by the traditional fuels has been around 6.5-6.7% of the total energy requirement met in the world.

In India, specifically, the share of energy requirement met through electricity has increased considerably, 13% in the fifties to 30% in the eighties. The electrical power has played an important role in the planned development of India. The electrical power installed capacity has risen from about 2000 MW at the time of independence to about 50000 MW now.

CHAPTERS - 2 & 3

INDIAN ENERGY SCENE AND POWER DEVELOPMENT IN INDIA

The review chapters include Indian energy scene comprising trends in energy consumption, long term projections of commercial energy demand, energy resources, progress in energy production sector, energy conservation, productivity, strategies, targets, outlays and achievements, social aspects of energy like health, quality of life, standard of living and energy use, social impact of energy technologies, energy and life expectancy, energy and transportation, population growth and energy uses. The review & analysis chapters also include power development in India, The extent of coverage is as follows:

Beginning, progress under the plans, programme in the current five year plan, investment in power sector, organisation structure, technology development. The long term perspective is analysed for the power sector and includes discussion on technology options with reference to coal quality, plant factors, T&D losses, auxiliary consumption, unit maintenance time, coal transportation, coal consumption in power plants and gestation periods for the power plants. The industrial commission which reviewed the industrial development of the country during 1916-18 stressed the importance of power development in the country and emphasised the need for a detailed hydro-electric survey to enable systematic development of water - power resources. The most impressive power development scheme implemented in the period prior to the first world war was the 50MW Kopili hydro-electric scheme of Tatas to provide power supply to the Bombay area. The period between the two world wars witnessed development of the Pykara, the Mettur and the Papanasanam projects in Madras, the Shivasamudram project in Mysore etc. Development of thermal power continued in all important urban centres as a close preserve of private enterprises.

Planned development of power was initiated in 1951 to improve the power availability rapidly. The installed generating capacity which stood at 2.3 Million KW at the beginning of the first plan in 1951 has been steadily increasing and stands at around 50 Million KW at present (1987-49,548MW).

Programme in the Seventh five year plan (1985-90)

The Seventh Plan proposes concerted effort to be made at various levels to ensure that there are no slippages in terms of capacity benefits as planned. The project planning and design capabilities of the State Electricity Boards would be strengthened. Detailed pre-planning of the construction activities and extensive use of modern management techniques are emphasised. Ensuring timely fund flow is recommended to avoid the time and cost overruns. The Plan also lays emphasis on static full load operation of the newly commissioned thermal plants bringing down the outage rates and improving availability right from the beginning. Highest priority is laid to maximise the capacity utilisation. Centrally sponsored modernisation and renovation activities are given additional thrust. Setting up of reasonably sized captive power plants is being encouraged.

The targets and outlays for VII Plan are given below:

ENERGY SECTOR

Power Sector	Targets	Outlays
	22245 MW	34273 crores
		Generation 21302 crore
		Transmission and Distribution 9198 crores
		Rural Electrification 2108 crs
		Renovation & Modernisation 972 crs.
Coal & Lignite	226 MT	7401 crores
Petroleum		
Crude Production	34.53 MT)	
Gas Production	41 MCM/day)	12628 crores
	14.918 CM)	
Renewable & new energy schemes		520 crores

Long Term Perspectives

The projected total installed capacity till the year 2005 will be 160,000 MW as projected by various Government agencies. With the technological improvements in the next 15-20 years, it should be possible to attain a thermal PLF of about 65% by the year 2005. The power consumption for station auxiliaries is likely to be reduced from the present average 10.5% to 7% (for thermal stations) and 12% to 10% (for nuclear stations) by improved motors, drives, pumps, fans, etc. The transmission and distribution losses in the country are in the range of 21%, which is very high. However, technologies are available for reducing T&D losses, some of which are already in operation on a limited scale. The T&D losses by the year 2005 would be no more than 15%. It is estimated that the avoidable loss of 5% due to poor design of motors, pumps, etc. would be reduced to zero by the year 2005.

A number of technologies such as co-generation, waste heat recovery system are also emerging in India. Such measures would result in an additional generation/conservation of about 500MW by the year 2005. Non-conventional sources of energy are the long term solution for meeting the rural energy needs of India. Decentralised energy systems for rural areas in particular are the best encouraged, as this can make the villages self-sufficient in their energy needs with minimum gestation periods and cost effective technologies.

NCES (solar, wind, biomass etc.) is likely to contribute about 1000MW of electrical power, either by generation or as an alternative to electricity to consumers in the country by the year 2005.

CHAPTER - 4

ELECTRICAL GENERATION CAPACITY PLANNING AND DEMAND SUPPLY MANGEMENT

The studies conducted for the generation capacity planning in Central Indian and Eastern Indian States, distribution system management exercise in North and South Indian States, and the supplementation of electrical energy needs of remote areas is reported in detail in the main body of the report. The work reported herein is an attempt which deals with specific areas of electrical energy demand and supply management. A particular reference to electrical power demand and supply management in the Indian context has been chosen for the study. The factors affecting the electrical generating capacity installation are studied and reported. Other studies include electrical distribution system losses and the electrical energy supply for rural areas.

As compared to a very high level of energy consumption per capita in the Western world, the per capita energy consumption in India is as low as 200kg. of coal equivalent. Coal and electricity have been most important sources of commercial energy for the Indians. The three most important issues that India faces today specifically in the electrical energy, are the following:

1. Availability of the thermal power plants. Higher outage rates. Higher consumption in the station auxiliaries.
2. Very high (21%) losses in the T&D system;
3. Meeting the energy needs of the remote areas, which are very difficult to be connected to the state or national grid.

Considering the importance of these issues in the Indian perspective, they have been chosen for the detailed study.

Studies

The following studies have been conducted and reported in the thesis:

1. Electrical Generation Capacity Planning
2. Electrical distribution system management
3. Meeting electrical energy needs for remote areas.

It may be noted that the studies have been conducted for the practical systems in operation in India and that these studies do not represent any hypothetical data. For the purpose of generation planning, States in Central and Eastern India have been chosen. The studies reported for distribution system management are for the operating state electricity board systems in Northern India. The cases considered in the rural energy supplementation exercise relate to villages chosen from the North and Southern India.

Statistical methods, computer algorithms and analytical models used are standard and have been taken from the published literature. The purpose of this work was not to develop a new algorithms but to study the utility of already developed theoretical models for the Indian conditions while carrying out the energy planning and management exercise. It will be appreciated that data requirement for conducting such exercise is enormous. Normally, when the algorithms are established and reported in the literature, they are evaluated using the test systems data which is considered to be internationally acceptable. But when these algorithms are to be applied to the practical system, a large amount of data is required from the experience of years of operation. Invariably the Indian utilities are not yet fully geared and organised to collect and compile this data, on line or off line. Therefore, it becomes essential to gather this data through questionnaires, interviews and detailed discussions. Procedure adopted in the case studies reported in this thesis is as follows:

a) Detailed questionnaires were circulated to the states chosen for the case studies.

b) Field visits and discussions on the data gathered.

c) Detailed discussions with various senior level officials in the Government and the utilities after thorough analysis of the data gathered through primary interviews. The following paragraphs give the data which has been gathered through this process. It may be noted that the data gathered and reported in this thesis is relevant and typical for Indian conditions only. The analysis conducted and the results obtained show the variation in the Indian conditions as compared to those in Western Europe and in America.

Data

Generation Capacity Planning Exercise

The decision regarding setting generation reserves are made using past experience as a guide. The operational performance today of earlier planned reserves is not available with most of the utilities in India. The only information that is available is that the planned reserves have not been adequate at all and subsequently have resulted into situations of massive power cuts. For generation planning, the following data was compiled through primary research.

a) Load Model Data

Load Model Data required and collected includes the relative magnitude of the peak loads and load distributions associated with each maintenance interval. The peak load pattern over the year i.e. the monthly peak load as a percentage of yearly peak load are derived. Three load levels to consider the distribution of load in any month are worked out. The load levels considered are 100%, 95% and 90% of the monthly peak. The number of days in a month when peak load is 100%, 95% and 90% of the monthly peak are tabulated from the detailed past data obtained through primary methods. The other information that is gathered and utilised includes monthly consumption of energy, monthly peak load, peak load power cuts and the load shedding. The average monthly energy consumption has a percentage of total yearly consumption are computed based on past data.

b) <u>Capacity Model Data</u>

Three basic data inputs for capacity model collected are unit ratings, forced outage rates and plant maintenance requirements. The unit ratings of the available units varies on a day to day basis due to numerous factors. Single rating for the capacity of the generating unit approximates the real condition. The station auxiliaries consumption is evaluated for thermal and hydro units. The formula for arriving at derating of the old units is worked out from the past data of operational availability of these units. The forced outage rates of the generating units depends on the size, type of the boiler or fuel used, the design and number of years of service. Suitable multiplying factors for the newly commissioned units to obtain immature forced outage rates have been derived from the primary data collected. The primary data also have been utilised to work out the partial outage rates of the generating units due to malfunction of electrical and mechanical auxiliary equipment. The forced outage rates and partial outage rates for various generating stations and types of units are worked out for several years in the past. The rates obtained in this manner are then utilised for the capacity model data. Maintenance requirements for generating units utilised in the study are number of days of planned maintenance to be scheduled in a year. These requirements depend on size of unit, fuel type and number of years of continuous operations i.e. last major maintenance. An attempt has been made to rationalise the scheduled maintenance taking into account the monthly variations in the system peak load and hydro availability with a view to ensure equal availability and gross operating reserve in each month. The past data of maintenance of the units has been taken into account and the need to modify the schedule was felt. The modified schedules were discussed with utility officials and were accepted. It may be noted that the data obtained for capacity model is typical to the Indian conditions as the forced outage rates, maintenance time and auxiliary consumption etc. are not identical through out the world and vary considerably.

Distribution System Management

Various data elements for the study that have been gathered from electricity boards distribution division include voltages at the consumer end, voltages at the grid substation, transformer tap settings, voltage regulation of transmission and distribution lines, the tap settings and regulation of HT & LT distribution transformers. An area equivalent to a district was chosen and the monitored data was recorded.

CONCLUSION OF STUDIES

Capacity Planning

The requirements of generating capacity have been worked out, utilising the operating data for past seven years.

In the planning stage, choice of a high standard of reliability would accommodate minor slippages, which otherwise could jeopardise the plan badly. Following criterion have been used in the present study.

Generation in the system will be such that the peak system load will be met successfully on at least 364 days of the year, taking into account maintenance outages and seasonal and daily peak load variations. In other words, the plan shall ensure a Loss of Load Probability (LOLP) index of 1 day/year.

The past operating experiences are utilised to derive system data base. Suitable data formats are designed and data of last 7 operating years is collected to obtain the following:

i) Monthly peak load as percent of yearly peak load.

ii) Monthly energy consumption as per cent of yearly energy consumption.

iii) Number of days in a month when the load levels of 100%, 95% and 90% are expected.

iv) Number of days of maintenance of operating units.

v) Forced and partial outage rates of operating units.

Following observations from the field data have been utilised:

i) Derating of all thermal units (upto 62.5MW) at the rate of half percent per year from 1978 onwards;

ii) Total outage time of hydro units as 12.5%;

iii) Maintenance time for all the thermal units (upto 120MW) is taken as 30 days;

iv) LOLP indices to be evaluated for 3 different maintenance durations (30 days, 45 days and 60 days) for 200MW and 500MW unit for each scenario;

v) Mature FOR of 16% and 18% for new 200MW and 500MW thermal units and 5% for hydro units.

vi) Uncertainty in unit addition time and the operation of units in initial stages, to be accounted for through immature outage rate multipliers ranging from 2.74 (in the first year) to 1 (in the fifth year of unit's operation).

Results and the conclusions drawn therefrom are presented in detail in the main report. However, important results and observations are reiterated here. They are as follows:

i) From the past data, it has been observed that the yearly peak load in the system occurs in the month of January. The minimum peak load is about 86% of the annual peak load and occurs in the month of July. The monthly peak loads above

90% of the annual peak load are observed in the months from October to May. Monthly peak load is about 95% of yearly peak load in the months from November to March. The average growth rate of energy consumption over the years is about 8.86%. The growth figures would have been much higher, but for power shortage existing in the State for the last seven years. The consumption in industrial sector is about 79% of the total yearly consumption.

ii) Analysis of past outage data for unit sizes ranging from 10MW to 200MW reveals an average Forced Outage Rate (FOR) of 8.85% and Partial Outage Rate (POR) of 2.79%.

iii) For an installed capacity of about 3835 MW and 5545 MW and a load of 2500MW and a load of 4000MW, reliability runs show an LOLP index of 10 days/year. With an installed capacity of 4200MW and 6260MW for peak load levels of 2500MW and 4000MW respectively, LOLP of about 5-6 days/year is observed. However, with installed generating capacity of 4685MW (from 57 units) and 7320MW (from 81 units) for peak load levels of 2500MW and 4000MW respectively, desired LOLP index of 1 day/year is obtained.

iv) From iii) above, it is observed that a reserve of 45% to 55% has to be kept in each month upto the second scenario, if desired LOLP index (or system reliability) has to be achieved.

Such high value of reserve is found to be necessary due to the fact that major unit additions in the system upto second scenario are thermal. These units, due to their higher forced outage rates (higher

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mature FOR as well as higher immature multipliers), long maintenance time (60 days) and sharing by other states, do not provide much benefit from the consideration of system reliability. However, if the maintenance time of thermal units (200MW and 500MW size) is reduced from 60 days to 30 days and more hydro units (instead of thermal) are added by over-expediting the hydro installations, the same reliability standard (LOLP index) could be achieved with less reserve margin. Study results of third scenario, corresponding to peak load level of 7000MW substantiate this observation.

For an installed capacity of 12,360MW and a load of 7000MW (corresponding to third scenario), reliability runs show an LOLP index much lower than 1 day/year. Even with reduced installed capacity of 11,300MW (from 130 units) and a load of 7000MW, LOLP index is lower than 1 day/year. This is explained by the following:

i) Higher number (51) of hydro units addition in the period between second and third scenario. (The hydro units have lower FOR and need less maintenance time)

ii) Thermal units added upto second scenario would complete 5 years and would mature, resulting in a lower overall outage time.

Distribution System Management

Most of the rural consumers take supply at 415 volts. The quantum of current to be distributed by LT network is much more than that on HT side of the network. Total length of LT lines is also more than that of HT lines. So a considerable amount of losses occur in the LT Lines. If the secondary system is not properly planned then this loss becomes high thereby increasing overall system losses.

Excessive losses in the secondary system are due to the following reasons:

i) Inadequate conductor size

ii) Improper location of distribution transformer

iii) Poor power factor, and

iv) Lower utilisation factor of the distribution transformers.

Inadequate conductor size for the lengthy feeder cause excessive voltage drop at the tail end of the feeder which in turn results in more line losses. In such cases either the conductor has to be strengthened or the tail end loads have to be transferred to another transformer.

If the transformer is not located in the load centre, then some of the feeders are much longer than others, and one feeder may be very much overloaded while the other are lightly loaded. Loss being proportional to the square of the current, this uneven distribution of current results in overall higher losses. By shifting the transformer to the load centre, secondary feeder losses are reduced to a great extent. But shifting of transformer involves huge expenditure and may be resorted to only when the load growth in the area has reached its saturation points. In an undeveloped or under developed areas where load is at the growing stage, the load centre will always be changing. In such cases the shifting of transformer is not the proper solution; and new loads need to be connected in such a way that the location of the transformer becomes the load centre of the area.

Poor load power factor is one of the main reasons for higher line losses. At low power factor the loads draw heavy reactive current which increases I^2R loss in the lines. To improve the power factor means to reduce this reactive current and hence reduction of losses. Power factor in the secondary circuit is improved through:

i) Installation of high power factor motor

ii) Installation of capacitor at the terminal of the low power factor motor, or

iii) Installation of capacitor at some convenient point on the LT feeder.

Depending on the local condition, any of the above methods is adopted. Improvement of power factor has its effect not only in the secondary but in the entire system.

Lower utilisation factor is another reason for higher losses. To reduce the constant losses in the distribution transformers, the ratio between the peak load and sum of distribution transformer capacity in the area is made nearly equal to unity.

CHAPTER - 5

EXPERIENCES IN RURAL AREAS

Preceding the experiences of the supplementation of electrical energy needs in rural areas in the northern India, Status of non-conventional energy system technologies, is discussed with reference to India.

The conclusions and observations on the basis of studies and experiences are reported in the concluding summary Chapter.

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