REPORT REPORT REPORT REPORT

Distribution of Electrical Power

D P SEN GUPTA

NATIONAL INSTITUTE OF ADVANCED STUDIES
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Foreword

This report by Prof D P Sen Gupta is the third in the series associated with the ongoing NIAS-Carnegie Mellon collaborative project on options of Electric Power Technology.

Transmission and distribution have unfortunately not received the attention that generation has in India. As a consequence, the evacuation of power, ensuring grid reliability and supply of quality energy to consumers have all suffered. The entirely justifiable objective of providing energy to far flung areas as quickly as possible, has unfortunately led to the neglect of establishing well-planned distribution networks, resulting in haphazard line connectivity and poor quality in energy supply.

This report highlights the problems of distribution networks and describes possible solutions. We acknowledge with thanks the financial support provided by the Carnegie Mellon University for this project.

Roddam Narasimha
Director, NIAS

Abstract

This paper highlights some of the major problems of power distribution in India. Resulting mostly from an unplanned growth with inadequate investment, the distribution network, especially for rural power distribution, with large losses, with poor terminal voltages and frequent interruptions. Generally, poor metering and metering and no metering of agricultural loads, make energy accounting virtually impossible. Urban power supply is also plagued by outages and random load shedding due to peak power shortage.

A tariff system based on subsidies and cross-subsidization results in massive losses in revenue which stall programmes of systems improvement.

This paper suggests some methods to rationalize the distribution system, within the constraints of funds.

Emphasis is laid on:

1. Systems improvement
2. Improving data system to facilitate energy accounting

Softwares developed for (i) restoring power supply in metropolitan cities following cable faults and (ii) short term load forecasting for demand side management and generation scheduling to avoid load shedding are discussed. The proposals are not particularly new. But implementing these in a funds-constrained, poorly managed, sprawling distribution system calls for an innovative approach using appropriate technologies that are affordable.

1.0 Introduction

The total installed capacity in India was 1700 MW in 1950. The generated electricity mainly served the metropolitan cities. Only 3000 villages out of 0.56 million villages had electricity and only 18000 pump sets had been energized. The use of electricity in the urban areas and the associated losses accounted for nearly 95% of the energy generated. As the demand of electricity grew over the decades the installed capacity increased and is around 90,000 MW at present. Nearly 0.5 million villages have been electrified and about 12 million pump sets have been energized. Hydroelectric power generation dominated in early years. Thermal power generation has been subsequently increased for providing base power. Hydroelectric power was reduced to about 35% by the 60s. It has further come down to about 25% of the total power generated.

The transmission system has also grown for evacuating and transmitting the power generated. The most widely used transmission voltages in India are 400 kV and 220kV. High-voltage DC transmission (HVDC) is being used in certain areas. The sub-transmission system is generally comprised 132, 110, 66 and 33 kV.

Distribution of power for urban and rural transmission is made primarily by 11kV radial feeders. The voltage is further stepped down to 430 volts for 3-phase, 4-wire distribution. Table 1 gives the Transmission and Distribution [T&D] network in India at different voltage levels.

TABLE 1

All India length of T&D network at various voltages				
Voltage	**Length of the lines [Ckt Kms.]**			Percentage annual growth
Year	1991-92	1992-93	1995-96	
HVDC	1630	1667	1667	0
400 kV	23085	23886	32256	11.60
230/220kV	65967	68688	76403	3.75
132/110/90 kV	89506	88186	97200	3.40
78/66 kV	35712	36020	37700	1.55
33/22 kV	218070	224685	251400	3.96
15/11/6.6/3.3/2.2 kV	1385113	1434367	1551000	2.71
Distribution lines up to 500 Volts	2755114	2848195	3036500	2.20

Source: Annual Report on the working of SEBs, by Planning Commission (1997)

The percentage annual growth rate of electrical power has been about 9% and it is imperative that Transmission and Distribution should grow correspondingly in order to evacuate the additional power and distribute it efficiently. The growth in T&D has not kept pace with the increase in installed capacity for generation. The Rajadhyaksha Committee [Government of India 1980] recommended that 50% of the total outlay for power sector should be earmarked for T&D facilities. Instead, only 38% and 33% of the total plan resources were spent on T&D. The achievements in commissioning 400 kV fell short by 10% whereas at 220 kV, there was a shortfall of 28% during the period of 1980-81 to 1993-94.

It is well known that T&D losses in India are very large. Distribution of power to far-flung villages to meet agricultural load adds substantially to these losses. It may also be seen from Table 2 that agricultural load has been increasing significantly. Apart from the problem that most State Electricity Boards [SEBs] face, in having to provide virtually free electricity to the agricultural sector, the distribution losses have been increasing since large amounts of power are being transmitted across long distances at relatively low voltages of 11 kV and 430 volts.

TABLE 2

Percentage consumption by major consumer segments			
Year	1984-85	1989-90	1996-97
AGRICULTURE	18.4	26	32.6
DOMESTIC	9	13	16.24
INDUSTRY	50.6	41.8	33

Source: Annual Report on the working of SEBs, by Planning Commission [1997]

Supply to villages is often severely restricted to avert peaking problems in a state. This results in local peaks since all pump sets connected to a particular feeder are switched on by the farmers whenever 3-phase supply is available. As a result, distribution transformers are over-loaded and damaged. [30% of 100 kVA distribution transformers in Karnataka are damaged every year.] Distorted loading patterns aggravate distribution losses.

Average T&D losses in India are estimated to be around 22% (Fig. 1, Table 3). It is however, difficult to assign a number to this, mainly because of a very inadequate metering and meter reading system that prevail and unauthorised use of energy that takes place. In fact energy accounting is not carried out properly in most states.

Take Karnataka State for example. Agricultural consumption in Karnataka is said to exceed 45% of the total consumption, but the basis of this estimate is not very credible. There are 1.2 million irrigation pump sets but none of these is metered. The only means available for estimating the energy consumed in the agricultural sector is from the readings of energy measured at the sub-stations from which the 11kV feeders are drawn radially. Electro-mechanical energy meters are read to record sending-end energy and the readings are entered into books. Ammeter readings recorded every hour are multiplied by 15 [$\sqrt{3}$x11(kV)x0.8(pf)] to estimate power and are also entered into the same book. The meters are often faulty and the readings recorded and entered casually are not very dependable. As a result, a comprehensive estimate of energy is difficult to make. Since receiving end energy of the agricultural sector is never measured, the distribution losses are at best poor guesstimates.

Add to this the "commercial loss" due to the energy thefts, faulty billing and metering [Fig. 6]. Certain steps proposed in a later section would alleviate this problem to some extent. Inadequate metering makes it difficult to detect thefts of energy which are significantly large in certain parts of the country and no realistic estimate of commercial losses [thefts, faulty metering etc.] seems to have been made so far. Static meters which are almost tamper-proof and simultaneously register energy, power [active reactive] voltages, currents etc. at desired intervals and over desired periods are being introduced at various parts of the country. The recorded data are to be downloaded into computers and can provide almost all the necessary information.

It is not only the operations data that are necessary for energy accounting and planning operations, but systems data that provide details of the system to carry out systems improvement need to be procured and stored. It is not an easy task and needs to be carried out using latest technologies.

Interruptions in power supply are fairly common in urban areas also. These may be accidental, due to faults of various kinds, or intentional, due to load shedding. Inadequate availability of both power and energy, and large losses in Transmission and Distribution make it difficult to meet the power/energy demand. Load shedding in towns and cities and restricted supply to the rural areas are the means resorted to by SEBs to avoid a grid collapse.

Acute shortage of funds is one of the major impediments to rationalizing the power systems in the country. Tariff systems in most states of India desperately need revision. Controlled by the Government, the Boards have little say in determining a tariff system that would at least meet the expenses of the Electricity Boards. Agriculturists enjoy almost free supply of electricity. Industries and commercial organizations on the other hand are charged heavily to cross-subsidize for farmers and to a certain extent for the domestic sector. As a result, and in view of supply interruptions, a number of industries resort to captive diesel generation. This leads to loss of revenue for the Boards and inefficient utilization of diesel by industries in an oil-importing country.

It is widely believed that privatization of power distribution will rectify the ills outlined in the above paragraphs. The proposal to privatize the Electricity Boards in a country where rural load comprises more than 35% of energy and is provided free of cost, may not be an easy proposition. The required system modifications, whether they are undertaken by the SEBs or by Private Organisations, *need to utilize modern methods and technologies with the constraints of funds and resources.*

A highly cost effective computer aided method for systems improvement, appropriate for India and other developing countries, developed in the Indian Institute of Science, Bangalore, is briefly outlined.

Suitable software for data acquisition, data base management and transmission is presently being developed. It is intended to draw upon techniques already prevalent in some of the developed countries.

A new algorithm developed for supply restoration in a manually controlled switching system that exists in the country is briefly described (Appendix III).

A proposal for peak power control based on short term load prediction based on modified Kalman filtering is also presented briefly (Appendix IV).

2.0 Distribution Losses: Systems improvement

Large Transmission and Distribution losses [T&D losses] are a major problem of the Indian Power Sector. It will be presently shown that the distribution networks [at 11kV and 430 V] are generally the major sources of power/energy loss. In urban areas, the LT lines [430 V] result in relatively larger losses whereas in the rural sector, the long 11 kV feeders also cause significant losses. For both urban and rural areas, losses also occur due to multiple stages of voltage transformation.

Altering the distribution network in the built-up urban areas to reduce losses tends to be relatively difficult and expensive. Data on connected load and the layout of networks are often unavailable for urban and rural systems and make systems improvement difficult. The Computer Aided Power Systems Improvement (CAPSI) method described in this section is applicable to all types of networks provided, of course, adequate data are available.

Fig. 1 shows that T&D losses in India have remained almost constant at around 22%. This is much too high. Fig 2 represents the T&D losses in different countries and it is evident that these losses can and should be contained within 10%. Fig. 3 shows how T&D losses in South Korea have been brought down significantly from about 35% to 6.5%. Although Rajadhyaksha Committee report had recommended that efforts should be made to bring down T&D losses in India to about 15%, this has not been achieved in about 20 years since the presentation of this report.

TABLE 3

Region and state	Transmission and distribution losses including unaccounted commercial losses						
	1980-81	1985-86	1990-91	1991-92	1992-93	1993-94	1997-98
NORTH :							
Haryana	22.6	20.1	27.5	26.8	26.8	25.0	33
Himachal Pradesh	19.3	22.4	21.0	19.2	20.0	18.8	18.5
Jammu & Kashmir	48.1	39.0	43.0	50.1	48.1	46.4	48
Punjab	19.6	18.3	19.3	21.8	19.6	19.7	18
Rajasthan	26.6	26.2	25.8	23.1	22.7	24.9	23.1
Uttar Pradesh	15.6	21.2	27.1	26.1	24.7	24.4	25.5
WEST :							
Gujarat	19.8	25.1	23.4	23.6	22.2	20.8	19.8
Madhya Pradesh	22.3	19.6	18.0	25.8	22.5	21.8	19.1
Maharashtra	16.2	15.7	18.3	18.6	18.5	17.8	14.8
Goa	[?]	20.1@	25.0	23.8	21.9	24.5	-
Daman and Diu	[?]	0.0	16.9	15.9	15.7	22.3	-
SOUTH :							
Andhra Pradesh	22.6	22.3	22.9	20.3	20.7	20.2	32+
Karnataka	24.6	24.2	20.2	19.3	19.6	19.5	18.5
Kerala	14.9	25.8	22.4	22.5	22.8	20.5	19
Tamil Nadu	19.1	18.5	18.0	18.4	17.3	17.0	16.9
Lakshadweep	[?]	20.0	18.6	17.4	18.7	17.0	–
EAST :							
Bihar	22.1	15.8	16.5	18.3	17.2	15.1	23
Orissa	19.2	24.0	25.8	25.3	25.9	23.1	46.9+
Sikkim	[?]	[?]	24.5	25.9	22.6	22.6	–
West Bengal	13.7	19.3	17.7	19.7	17.5	16.0	17.9
NORTH-EAST :							
Assam	19.3	24.3	24.1	22.7	21.4	22.4	23.2
Manipur	[?]	51.5	28.0	24.4	22.4	23.9	–
Meghalaya*	9.1	10.7	11.5	11.7	11.6	17.9	17.9
Nagaland	[?]	15.9	26.1	23.1	27.3	33.5	–
Tripura	[?]	30.5	29.6	32.0	30.6	30.5	–
Mizoram	[?]	43.7	29.6	34.9	29.0	31.9	–
Arunachal Pradesh	[?]	34.1	20.0	28.2	32.3	42.0	–
ALL INDIA [utilities]	**[?]**	**21.7**	**22.9**	**22.8**	**21.8**	**21.4**	–

* The lower transmission and distribution losses in Meghalaya are due to bulk sale of energy at HT [high-tension] level to neighbouring states.
@ Also included Daman and Diu. These figures are in sharp contrast with those from previous years but are more likely to be true.
Source: Central Electricity Authority [CEA] 1995. Public Electricity Supply, All India Statistics, General Review, 1993/94, p.117, New Delhi: CEA.214pp
Power Line: May 1999, p.61 for the data in the last column.

Table 3 presents, State-wise, T&D losses. Fig. 4 gives the T&D losses in some of the major cities in India. The actual losses are likely to be significantly higher. Take for example the Karnataka Electricity Board's claim of 18.5% being the T&D losses. This figure is not dependable for the simple reason that agricultural load in Karnataka State is not metered and there is no way to estimate T&D losses unless both sending and receiving end energy are metered. Since according to KEB estimates, agricultural load in Karnataka State comprises more than 45% of the total load in the State, T&D losses in the rural network cannot be ignored. On the other hand, these losses are not measured and therefore T&D losses of 18.5% may just be an estimate, and is possibly grossly incorrect. In fact a recent study has indicated that the T&D losses are close to 30%.

Fig. 5 gives an estimate of T&D losses at different voltage levels and it may be seen that the largest loss takes place at 11kV and 430 levels. Fig. 6 classifies the various factors that contribute to T&D losses.

2.1 Rural distribution

In the absence of planning and analysis ad hoc growth takes place. For example, in the national drive for rural electrification and energization of pump sets, the policy that was adopted was "to connect a village to be electrified to the nearest village that has been electrified". This happened to be, at that instant, the cheapest way of undertaking electrification. The distribution transformers were also chosen somewhat arbitrarily out of a standard selection of 25, 63 and 100 kVA transformers. Different States vied with each other to reach the target of 100% rural electrification. There was no planning, but a desperate bid to reach a number by arbitrary connection as described. As a result, 11 kV feeders grew in length, meandering all over the place. Fig. 7 shows how the 11 kV feeders have grown randomly in a Taluk (sub-district) in Karnataka State. The ΣI^2R loss is high [≈15%] and the terminal voltages at certain feeders were as low as 7.5kV [≈280 volts instead of 430 volts and low enough to damage the induction motors of the pump sets.]

If, on the other hand, the distribution was planned, the feeders would have been drawn radially (Fig. 8) as far as possible, like the veins in certain types of leaves. The ΣI^2R loss would have been less than half. If conductors of correct sizes are used, ΣI^2R loss would be further reduced and the worst terminal voltage would be better than 10kV [≈380 volt when stepped down] even at feeder terminal.

Now that nearly 100% villages in Karnataka State have been electrified and use more than 45% of the total electrical energy [according to the figures of KEB], the losses in the

randomly laid feeders are significantly large and terminal voltages are very low. The situation is, unfortunately, still worse in a number of other States.

When faced with local political pressure, the SEBs undertake Systems Improvement Programmes. These programmes normally involve drawing Express Feeders [a feeder from the nearest substation to a particular load point without tapping] and the setting up of new substations. The 11kV network is accordingly sectionalized. Needless to say, both these solutions, particularly setting up of new substations, are very expensive and the SEBs can ill-afford to carry out Systems Improvement of this type (which incidentally does not involve much analysis or computation) throughout the state. Distribution losses continue to be high – in fact they continue to increase with increasing power since the losses vary approximately as P^2 [where P is power].

The radial distribution of the feeders, like the veins in a leaf, may be an ideal configuration but it cannot be implemented easily because of various constraints. On the other hand the present distribution network is just a random growth and leads to large loss and poor voltages. The solution obviously lies in between.

A CAPSI programme precisely helps to achieve this.The software was developed in the Department of Electrical Engineering of the Indian Institute of Science. It uses interactive graphic technique for an implementable system improvement. The main objective is to 'straighten out' the feeders, to the extent possible, by load redistribution within geographical constraints and those imposed by the right of way. Changing cross sections of feeders [close to the substation] or providing parallel feeders where necessary, are taken up as the next step. Switched shunt capacitors are used where essential and providing new substations come as the last choice. A number of options are tried, the cost evaluated in each case and the pay back period calculated. An engineer familiar with the area provides information on the local topology and the constraints that exist. As the system improves, the full load voltage limit of 10kV [regulation of about 10%] is available further and further down a feeder and serves as a suitable guideline for systems improvement. [See Appendix I.] Once cost-effective systems improvement is achieved the solution is retained. The same exercise is repeated with projected load growth and if the system modification still sustains and is within acceptable limits, the solution is frozen and the modified network is printed out [Fig. 9]. The basic steps in CAPSI are summarized in Appendix I. The software has been substantively updated now making the programme more user friendly.

Appendix II provides some of the basic results of a systems improvement study carried out at Chikkodi Taluk [Karnataka State] using CAPSI. The computed cost was Rs. 80 lakhs [Rs. 8 million].

The saving in avoided installed capacity was 3.0 MW which would, when the study was carried out, amount to Rs. 7.5 crores [Rs. 75 million]. This would now come close to about Rs. 14 crores.

The KEB, however, chose to carry out the changes using their standard method of installing new substations and express feeders and the cost came to Rs. 12 crores instead of about Rs. 1 crore using results from CAPSI.

It may be noted in this context that other software packages for systems improvement have been developed since and are available in the market. What is of course unique about CAPSI, to the best of the author's knowledge, is that

I. it is highly cost-effective, which is an essential requirement for improving the vast distribution network in a country like India;
II. it utilizes the field experience of the local engineer dealing with the network in an interactive graphic mode and presents an implementable programme;
III. it makes use of simple criteria guiding one to an implementable near optimal solution.

A number of SEBs in India are still indifferent to using computers for systems analysis and systems improvement and continue with the km–KVA method, although a number of the more forward-looking SEBs have been using computers for distribution systems improvement.

Undertaking studies for systems improvement, however, demands accurate information of systems data which need to be compiled and computerized. This is discussed in Section 3.0.

Distribution losses at 430 volt [LT] network are large and need to be reduced. This is a more formidable task since the maps of LT network are not readily available with most electricity boards.

It is often suggested, unfortunately without proper studies being carried out, that the LT network be replaced by 11 kV and small dry type transformers installed at the door steps of the consumers, thereby reducing LT distribution losses. It is necessary to carry out complete studies and the feasibility of such an exercise and its cost-effectiveness vis a vis other options. Funds and availability of skilled man-power on an extensive basis may prove to be the major constraints.

A simpler solution is to shift the 11000/430 distribution transformers from their present locations, usually on the roadside, to the load centre in the village, thereby carrying the total load to the village at 11 kV rather than at 430 volt. This would significantly reduce ΣI^2R losses at the LT level. The

same strategy would be highly effective in the urban distribution system also. This effort would improve terminal voltages to a great extent.

3.0 Urban distribution and systems improvement, supply restoration and peak power management

The CAPSI is highly suitable for achieving systems improvement in the urban sector also. It is absolutely essential to have updated maps of the urban distribution network particularly of the underground cables. Some of the utilities do maintain maps down to 11 kV. The LT distribution of power which is done either by cables or by over-head lines needs to be properly mapped and with the help of CAPSI affordable modification should be arrived at. The ratings of transformers are extremely critical and depending on the loading pattern, suitable ratings need to be selected. The main constraint in urban distribution systems improvement is that the existing cable trenches often need to be used. However, changing cable sizes, altering feed points and changing transformer ratings as guided by the computer can, to a significant extent, reduce losses.

3.1 Supply interruptions

Accidental supply interruptions are most commonly caused by cable faults or overhead lines touching each other or due to insulation failure and often due to transformer failure. As stated earlier, supply interruptions also occur due to load shedding when generated power fails to meet the peak demand and the frequency drops. In Bangalore city for example, morning peak caused mainly by water-heating is truncated by shedding loads in certain areas [Fig. 10].

Two softwares have been developed in the Electrical Engineering Department, IISc to cope with the problems of supply interruptions.

3.1.1 Supply restoration following cable faults

Cable faults are fairly common these days in the metropolitan cities in India, particularly during rainy seasons. Restoring power supply, by switching over the load served by the faulted cable to other cables by manual switching, has been causing major problems of overloading. An algorithm has been developed, described briefly in Appendix III and in detail in references 9 and 10, to work out a computer aided strategy for supply restoration. Since switching is manual, the switching operations should be kept at the minimum. A software has been developed for computer guided restoration of power supply for Bombay Suburban Electricity Supply [BSES] and tested on a very large cable system.

3.1.2. Peak Power Management

Arbitrary load shedding by the Electricity Board has been

causing serious problems for the consumers. Unfortunately there has not been any attempt made by the SEBs to carry out any programme of Demand Side Management (DSM) to contain the peaks within affordable limits. Being a state monopoly, an SEB can afford to be arbitrary and get away with it.

A new proposal for decentralized peak power control has been made in which the operator tries to limit power consumption at local 11-kV substation level with suitable incentive and disincentive schemes. A prerequisite for such efforts is a dependable, short-term load forecasting scheme which has been developed by using a modified Kalman filter. Industrial loads recorded as in Fig.16 can be coupled with the expected load of a region to evolve a programme to contain peak power. Appendix IV briefly describes the method which has been elaborated in reference 11.

Distribution Automation is presently being introduced in the city of Thiruvananthapuram and a few other places in India. The objective is to introduce SCADA (Supervisory Control and Data Acquisition) at distribution feeder level to reduce T&D losses and by supervisory control to maintain the system at "Normal" operation state rather than the usual "Alert" or "Emergency" state in which the power system perpetually finds itself.

Distribution Automation using Computers and Communication System ought to be the desirable target but it involves massive investment and may have to be confined to the major cities of the country. Until then, the objective may have to be carried out through intermediate affordable stages.

4.0 Data Systems

Distinction is made between two types of data. One may be called Operations Data and the other Systems Data.

4.1 Operations Data

Operations data provide the day to day and hour to hour energy/power scenario in the entire electrical system of a State and the systems data provide information on the network configuration of different voltages and the load distribution at the receiving end. Data system in the power sector is highly advanced in most developed countries and is being continually updated with improving communication and computer systems.

A glimpse of the existing system in India and possibilities of updating it are briefly discussed.

It may not be out of place to mention here that the Indian power sector is divided into five electrical zones as shown in Fig.12. The Regional Boards come under the Ministry of

Power. SEBs are independent but they interact with the Regional Electricity Boards. For example, Tamil Nadu, Andhra Pradesh, Karnataka and Kerala SEBs constitute the Southern Regional Electricity Board.

SCADA system has long been introduced in various Load Dispatch Centres, where the line flows are continuously on display. In some utilities network and power flow at sub-station level voltages are also available. In most cases, data acquisition is the main objective and "security control" [by remote controlling] is seldom carried out.

Coming to data system at the distribution level one finds considerable inadequacy in most of the Electricity Boards. As has been mentioned earlier, the substations are fitted with electro-mechanical meters to read energy and ammeters are used to compute power outflow. Very little, however, is done with the data after they are entered into the books. For example, none of the substations would bother to carry out energy accounting or plot load curves and keep track of the load variation during 24 hours. Load curves can however be highly useful to understand system demand and arrive at policy decisions. An example of a study carried out at Channapatna 66/11 kV substation [Karnataka State] is presented below as an example.

The power supply to most of the rural sector in Karnataka State is strictly restricted for best parts of the year. As stated earlier the objective is to limit the total peak load and the energy consumption. A typical supply schedule would be:

3-phase supply for 6 to 8 hours
1-phase supply for 8 to 10 hours
No supply for the remaining period.

3-phase supply is provided for running motors for the agricultural pump sets, which constitute more than 90% of the rural load. Single-phase supply provides power for lighting only. The restriction is often lifted after a good monsoon since agricultural load naturally drops and the Electricity Board can meet the peak load and energy requirements. The electro-mechanical meters in Channapatna were replaced by static electronic meters, which record all the major electrical variables every half an hour for 35 days. This was done for all the 10 feeders in this substation. The recordings were made throughout the year so that pre-monsoon and post-monsoon consumptions could be duly recorded. For two months [July and August] the supply restrictions were lifted and 3-phase power was provided for 24 hours.

Meter reading instruments [MRI, which are small hand-held meters] were used to receive the data stored in the meters to be downloaded into PCs. Load curves obtained from the

computer for the months of June [with restricted power supply] and August [without restrictions] are shown in Figs. 13 and 14 respectively for a particular feeder. The results are as could be expected. The peak load in June exceeded 3 MW whereas the peak during August was almost half [1.5 MW]. Load factor for June was highly distorted whereas load factor during August was about 0.75 which is desirable. Apart from the inconvenience to the users caused by restricted power supply, motors of pump sets are damaged for being operated at poor voltages and distribution transformers are grossly overloaded. The following observations are also significant.

Average percentage energy loss in distribution:
During the month of June [restricted] : 12.0%
During the month of August [unrestricted] : 6.9%
This is inevitable since distorted load consumption [as in June] leads to larger T&D losses.

This explains the large number of transformer burn out due to over loading.

The example quoted above gives results one would have expected but no quantitative statements of this kind of obvious but essential information are available with the Boards because the data collected with the help of conventional meters cannot be used to this end. It is , therefore, essential that all sub-stations are not only provided with static meters but that the meters are properly read and the data down loaded into computers for subsequent use for making policy decisions.

The Channapatna study presented to KEB helped to bring home the point that restricted supply to the agricultural sector, intended for overall peak power control, does not only lead to large line loss but is one of the major factors contributing to transformer burn out.

4.1.1. Energy accounting in the rural sector

It is imperative that the present method of collecting data and logging them needs to be discontinued and replaced by the installation of electronic meters with regular down loading of the collected and stored information into computers.

As has been stated earlier, agricultural load which constitutes a substantial section of the total load is usually unmetered. This makes proper energy accounting an almost impossible task. It has been repeatedly suggested that the KEB hides large T&D losses by inflating agricultural consumption which is not metered. Even if each agricultural load was metered, reading each of them would be a difficult task. [In Karnataka State alone there are 1.2 million pump sets.] Employing linesmen to read these meters lays bare the possibility of faulty billing, adding substantially to the commercial loss.

It would be a reasonable means of measuring the load/energy of a village or villages fed from the LT side of a transformer if one could install an electronic meter on the transformer itself to measure power and energy supplied from the LT side. The readings would include the line loss on the LT distribution no doubt but these losses can be reduced substantially if the 11000/430 volt transformers are placed close to the load centre or the centre of the villages. In Karnataka State again there are more than 0.1 million distribution transformers (including urban distribution). It would be well within the means of the Electricity Boards or the Corporations to download the data from such meters periodically and carry out exhaustive energy accounting and compute system losses.

4.1.2. Automatic meter reading [AMR]

Automatic meter reading is now standard practice in many utilities and services in developed countries. In recommending the strategy to be followed by the State Electricity Boards in India to procure data from substations and customer level, one has to consider the cost involved in the process.

It is felt that experience of other countries that have gone through this process can be of immense value.

In the initial stage it is recommended that MRIs may be used effectively for data acquisition.

An affordable and cost effective proposal would consist of the following steps:

1. Static meters would be installed in all substations and major consumer [at 11 kV and above] premises.

2. Different zones are to be provided with PCs and data from substations and major users in the zone are to be downloaded into these computers with the help of MRIs.

3. The data are processed and compressed with appropriate software and may be accessed through telephone lines from a central computer system at the Board Head Office.

Fg. 15 provides a block diagram of such a proposal. Communication of the data to a central location [the Head Office of the Board or Corporation] can be carried out by any of the methods represented in Fig. 16. To begin with the use of the existing telephone network may be the best option.

The proposed system may be eventually replaced by AMR. Modems may be used to transmit data directly to a zone where the data are processed and transferred to a central computer. This facility can be eventually extended to customer level.

4.1.3. Urban and Industrial load

Overall system automation will help DSM. For example load

curves from major HT industries as shown in may be moderated by a suitable incentive/disincentive tariff structure to persuade major users to avoid peak hours. Time of Day [TOD] metering is an old concept but is just being ushered into the Indian power sector and proper policies and instrumentation must be evolved.

4.2 Systems data

The major problem that one encounters in carrying out systems studies is the absence of up-to-date maps of networks, particularly at lower voltage levels. Most 66/11kV substations prepare the 11kV network of the area served from the sub-station. The maps are often not drawn to scale. The number of distribution transformers and their ratings are not always correctly represented.

Whereas it may be unwieldy to attempt to prepare maps for the LT network, there is no reason why updated maps of 11kV network cannot be prepared and stored into computers by scanning them. If the task is distributed to the substations to update the maps fed from there, the zonal computer can store the systems data of all the substations that come under it.

These data in the zonal computer can be updated as and when they are altered and accessed from the Central Computer for systems study.

5.0. Conclusion

Insufficient power generation in India leads to the perpetual failure to meet both peak power and energy demand and the Electricity Boards resort to indiscriminate load shedding as the only means of 'Demand Side Management' and maintain the power system perennially in the 'alert' or 'emergency' state with occasional grid collapse. The power sector is presently being unbundled and private involvement is being encouraged to provide funds and take over the management of what has turned out to be an unwieldy system.

As stated in the abstract, this paper has focused on two of the major inadequacies of the power distribution system in India with particular reference to Karnataka State, namely:

[a] system inefficiency leading to interruptions, large losses and poor voltages,

[b] inadequate data procurement and data base management.

These basic inadequacies unfortunately exist in most developing countries and have to be met with utmost urgency.

An interactive software that offers a highly cost-effective method of strengthening distribution systems and of systems improvement has been developed and briefly outlined in this paper. Implementable methods for restoration of power

suppl: following cable faults and load forecast for DSM have also been briefly described.

An equally urgent requirement of data acquisition and data management in the distribution system required for energy accounting, policy decisions, systems improvement and possible DSM, on which studies are now in progress, has been outlined. Different Boards in India have been involved in implementing SCADA to a greater or lesser extent. The focus has been the urban sector. But as rural consumption keeps growing, greater attention needs to be paid to rationalize the rural distribution system and access data from villages.

As stated earlier, the distribution network in India has grown and was not planned. Restricted resources have led to ad hoc modifications of the system as and when changes became imperative. Inefficient methods of data procurement have invariably led to faulty conclusions and unwarranted controversies.

Distribution is perhaps the most disorganized section of the power sector in India.

A comprehensive effort to strengthen the distribution system is long overdue.

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12. *Power Line:* Vol. 3 No. 8, May 1999

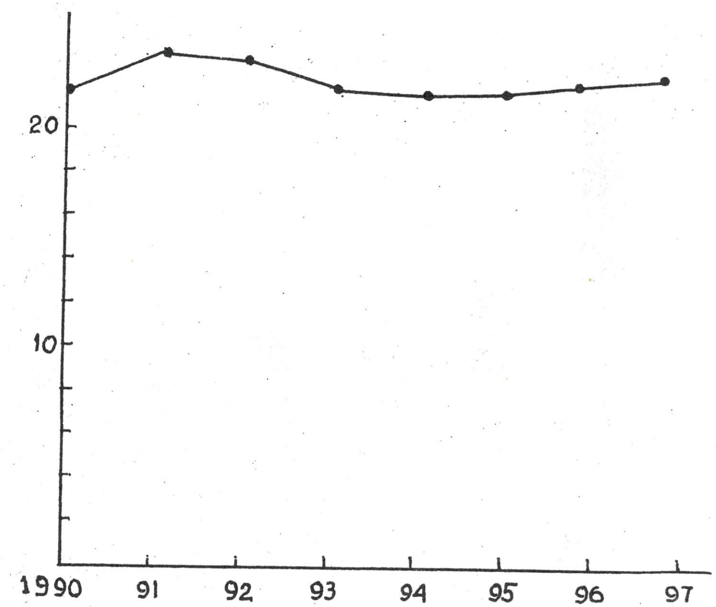


Fig.1 Percentage T&D Loss of Electrical Energy

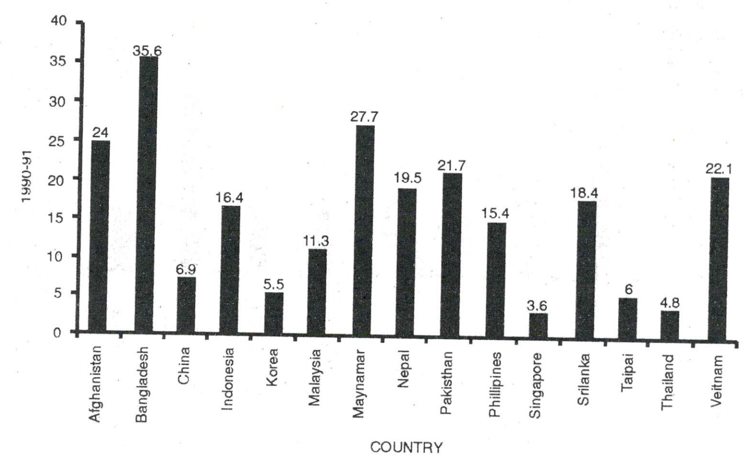


Fig.2 T&D Losses – Asia Pacific Region

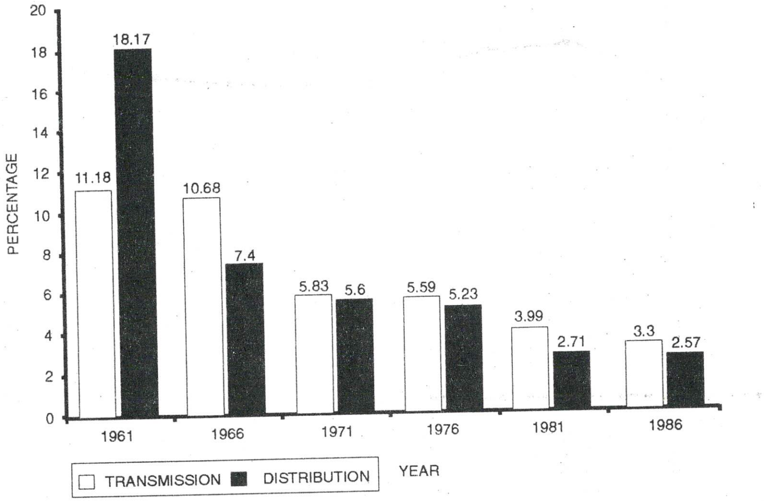


Fig.3 T&D Losses – South Korea (Ref.3)

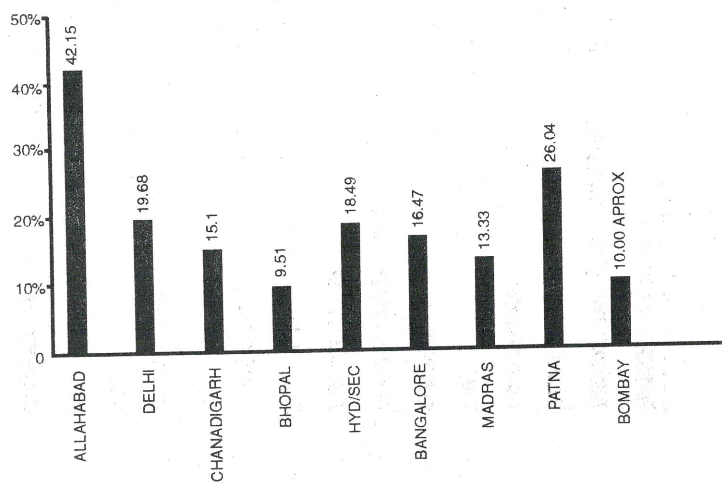
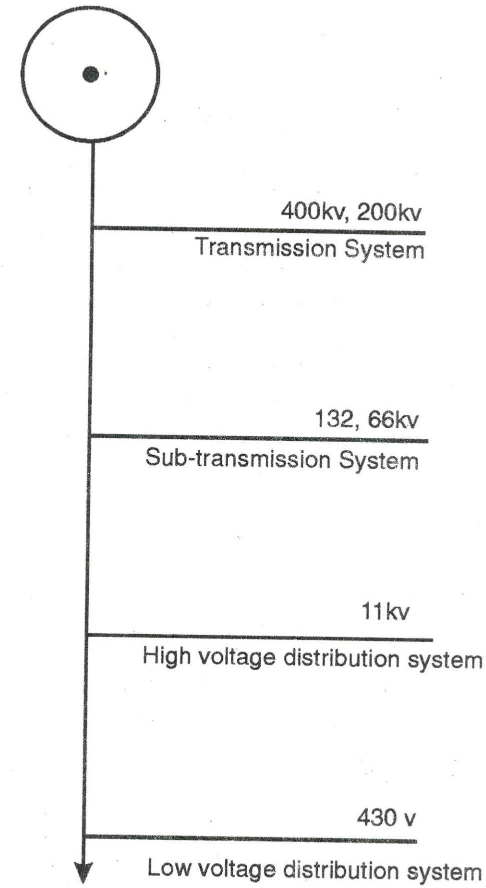


Fig.4 Percentage T&D Losses in Major Indian Cities



S. No.	System Element	Target Level	Max. tolerable Limit	Existing Average Level in India
1.	Transmission System	2.00	4.00	4.50
2.	Sub-transmission System	2.25	4.50	4.00
3.	High voltage distribution system	3.00	5.00	7.00
4.	Low voltage distribution system	1.00	2.00	7.50
	TOTAL	8.25	15.5	23.0

Percentage Technical Losses in various elements of a power system

FIG. 5 (Ref. 3)

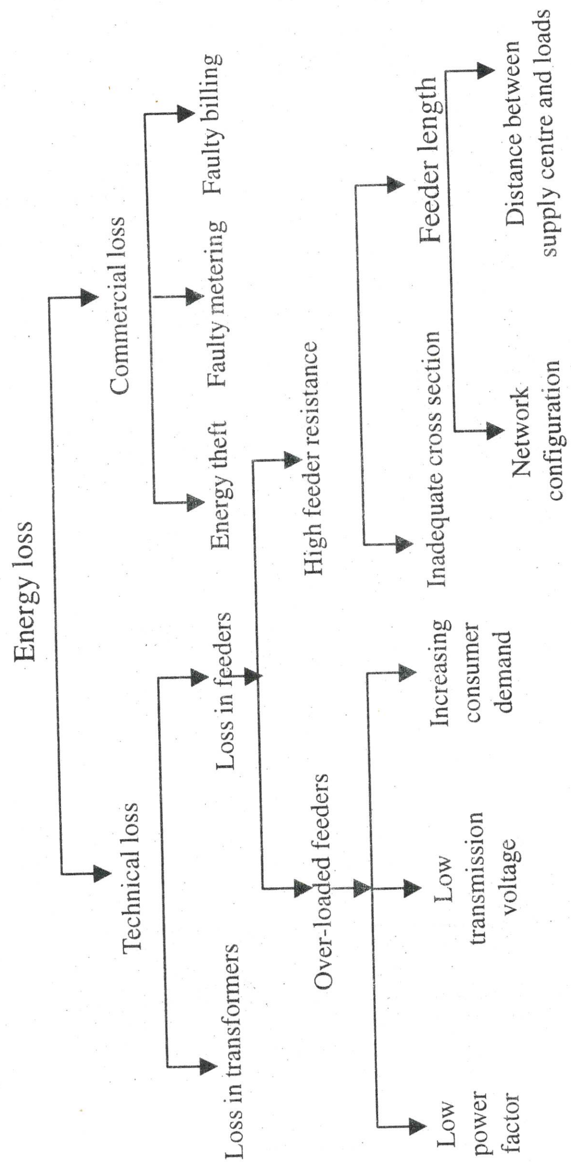

Energy loss
Commercial loss
Technical loss
Faulty billing
Faulty metering
Energy theft
Loss in feeders
Loss in transformers
High feeder resistance
Over-loaded feeders
Feeder length
Inadequate cross section
Increasing consumer demand
Low transmission voltage
Low power factor
Distance between supply centre and loads
Network configuration

Fig.6

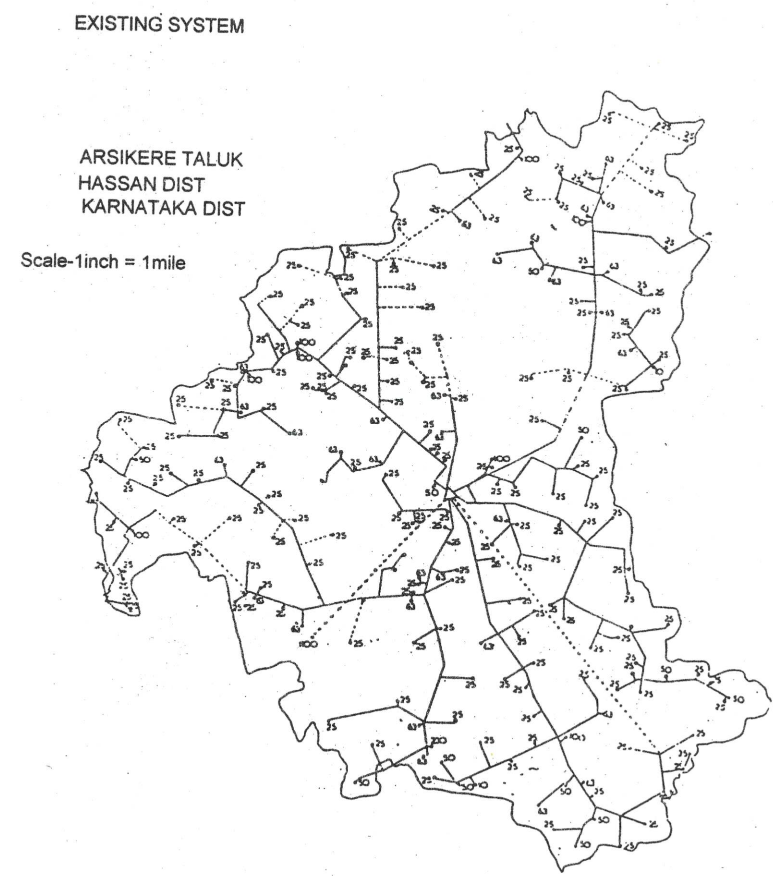

EXISTING SYSTEM
ARSIKERE TALUK
HASSAN DIST
KARNATAKA DIST
Scale-1inch = 1mile

Fig.7

MODEL SYSTEM

ARSIKERE TALUK
HASSAN DIST
KARNATAKA STATE

Scale 1 inch = 1mile

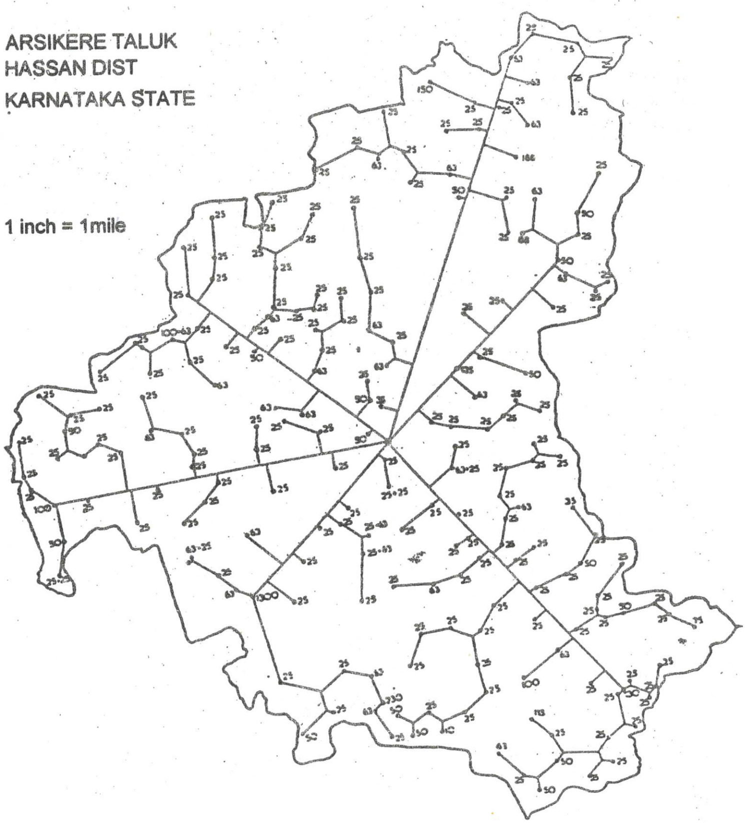


Fig.8

MODIFIED SYSTEM

ARSIKERE TALUK.
HASSAN DIST
KARNATAKA STATE

Scale 1 inch=1mile

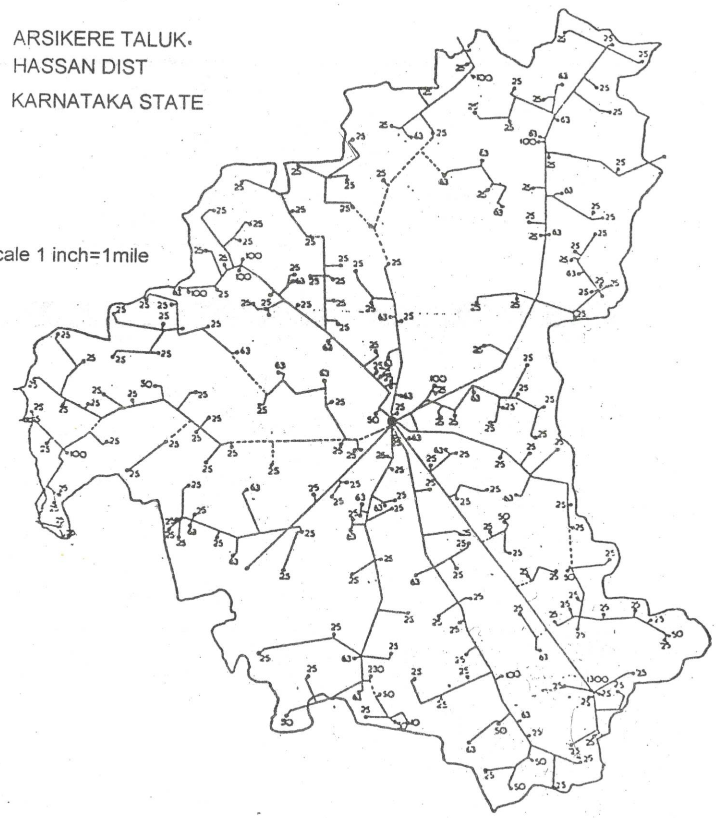


Fig.9

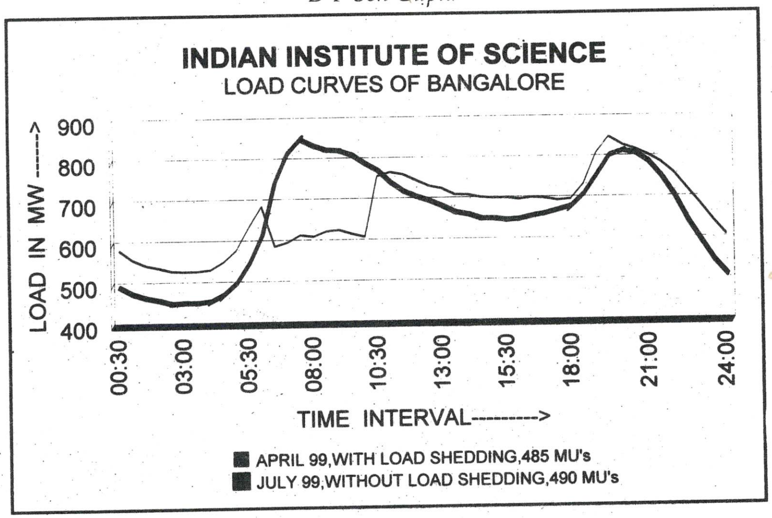


Fig.10

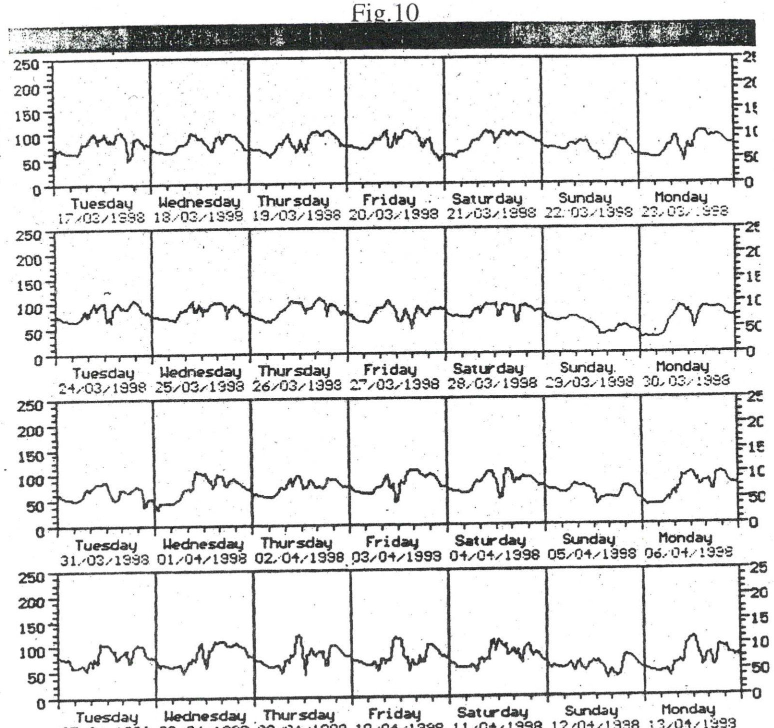


Fig.11

F

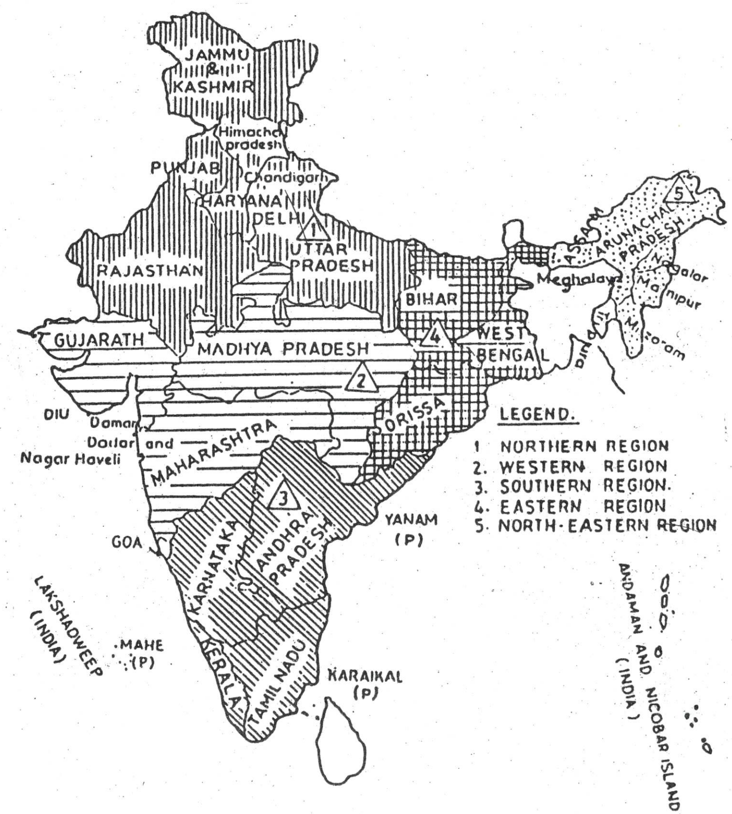


Fig.12 The regional divisions (for REB) states and Union Territories of India

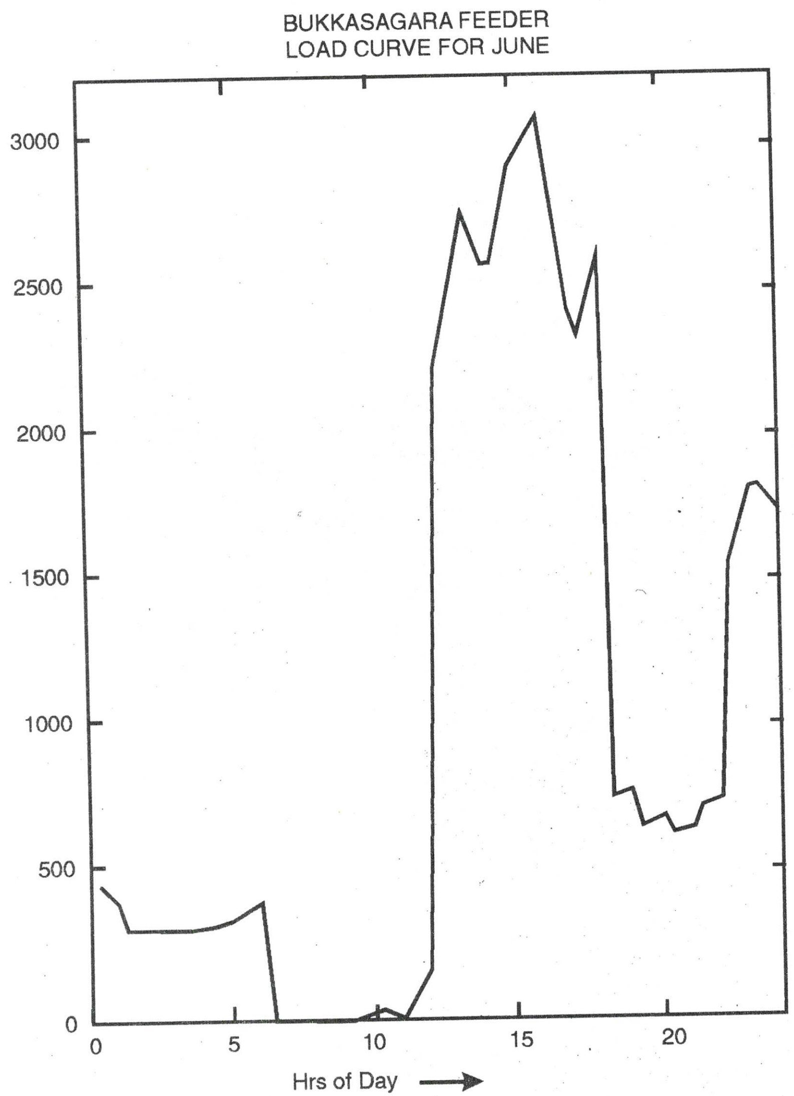


Fig.13 Load Curve: June

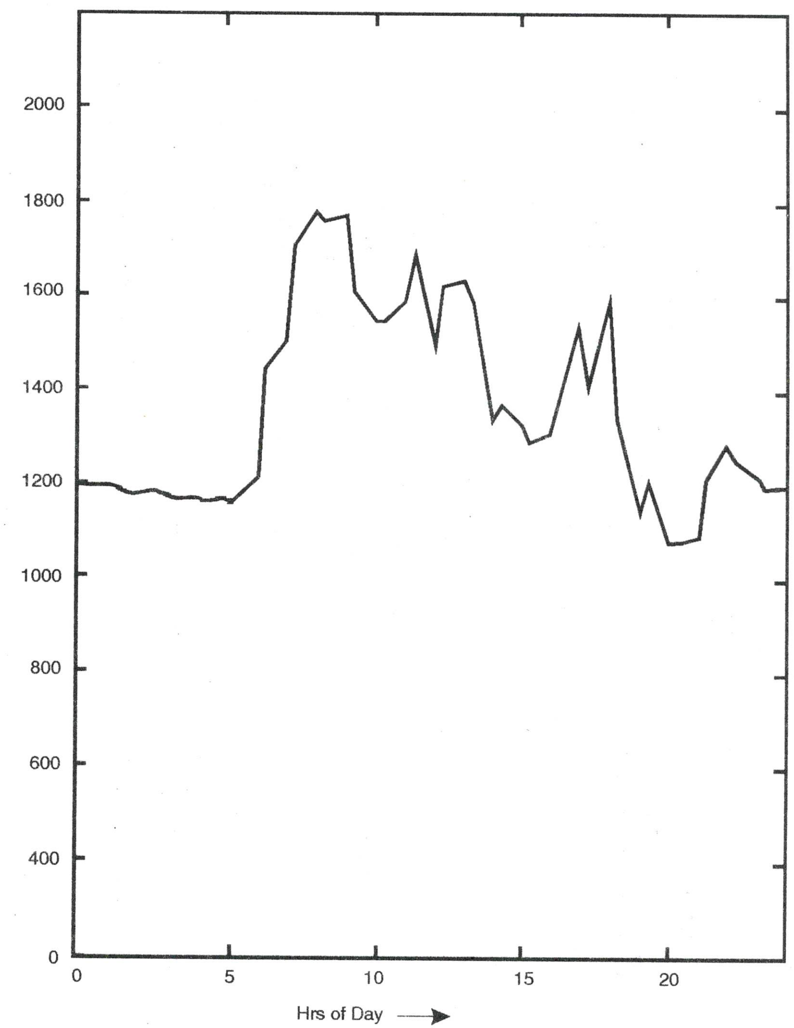


Fig.14 Load Curve: August

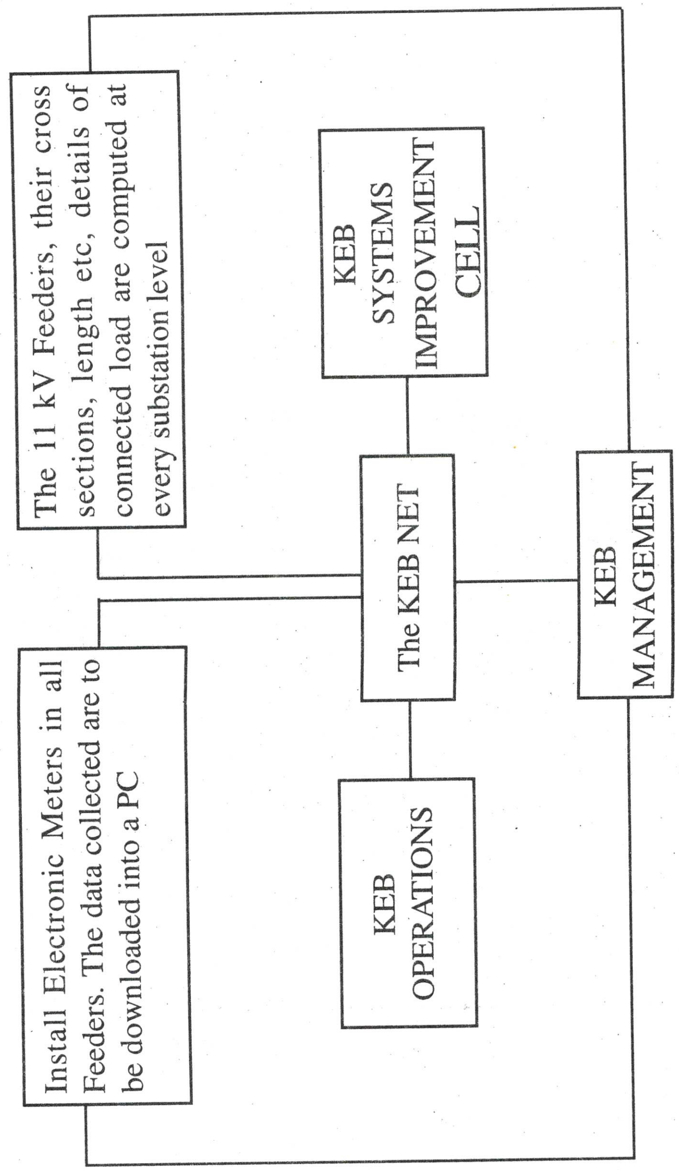


Fig.15

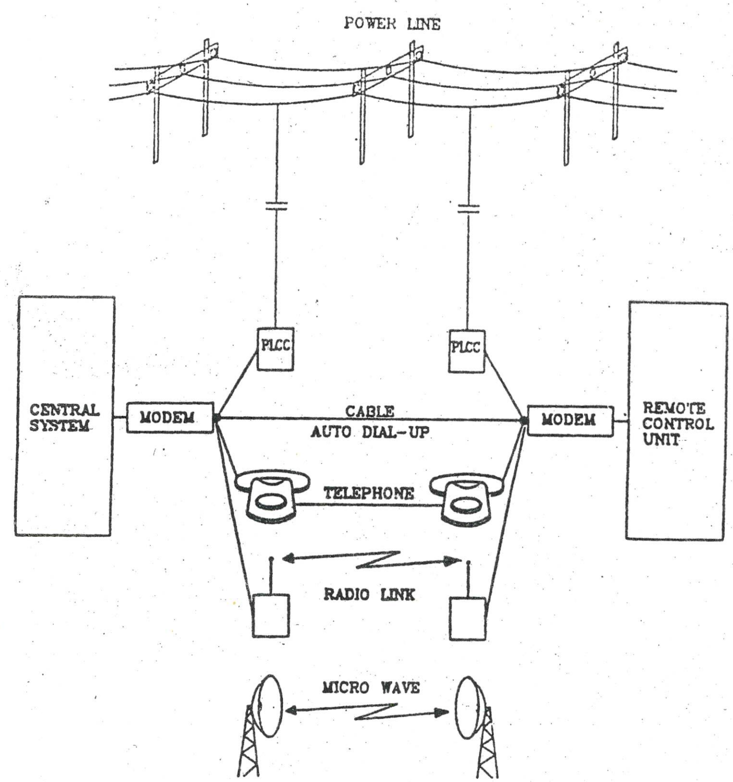


Fig.16 Communication Media

APPENDIX - I

Basic steps in CAPSI:

The Computer aided method is summarized as follows:

1. The co-ordinates of all nodes with their numbers, loads, power factors are input through a digitizer.
2. The network is drawn and displayed on the VDU and its performance in terms of losses and voltages at every node, their mean and standard deviation is computed and displayed on command.
3. Instructions for network alterations are entered.
4. The built-in software computes the performance again and the cost of the alteration.
5. If the alteration is cost effective and worthwhile it is retained or it is erased through appropriate instructions.
6. After a few trails, the final decision is arrived at.
7. The altered grid map is printed out with clear instructions as to which conductor length have to be removed and which lengths are to be linked and where shunt capacitors should be installed if they are to be used, at all.
8. A project report in a format required by the Electricity Boards giving all the node voltages, section losses total 'losses, load dispatched, load delivered before and after modifications with present and future loading [say after 7 years], the payback period etc. is printed out.
9. The data on the existing and the modified system may be transferred to a disk to be stored in a library and to be recalled as and when necessary.

One of the most difficult aspects of the optimization method is to decide when an optimal solution is reached. Optimality is particularly difficult to define for problems on hand.

A simple graphics technique has been developed to help the operator to decide when to terminate the programme. The network is ordinarily represented in one colour and on the press of a key a feeder changes its colour [becoming red] to indicate where the limit of 10kV is reached. Beyond that point the voltage is less than 10kV. In a heavily loaded feeder the 10kV boundary is relatively close to the sub-station where the voltage is assumed to be 11 kV. In the rest of the feeder, the voltage drops further and further down attaining even 7 to 8 kV. The objective is to obtain about 10kV at the terminal of the network. The colour of the feeder, like the miniscus of a thermometer, indicates where the 10kV boundary is reached. Modifications are carried out until, ideally, the entire network turns red even when the projected load 7-10 years later is used in the computation.

It may not be very economical to try to achieve 10kV or above even at the farthest end of a tree when the projected load is used. The programme may be terminated when most of the feeder lengths fall within the 10kV boundary.

The greatest advantage of this programme is that it is interactive and the knowledge of the local engineer, his experience and judgement lead to a feasible and implementable solution.

APPENDIX II

A summary of the results of systems improvement in Chikkodi Taluk, Karnataka State:

An exhaustive study in systems improvement was carried out by the KEB engineers in collaboration with IISc for Chikkodi Taluk in Belgaum District using CAPSI. The following section is an extract from the report presented to KEB.

SUMMARY OR RESULTS

System Improvement for Chikkodi Taluk, HT distribution

Area	1,270 sq. kms.
Population	4.2 lakhs
Connected load	90 MVA
Loss:	
Power	5.3 MW
Energy	6.15 M.U.
Worst voltage	8.1 kV
After improvements:	
Loss:	
Power	2.76 MW
Energy	3.2 M.U.
Saving:	
Power	2.54 MW
Generated power	3.05 MW
Energy	2.95 M.U.
Worst voltage	10.2 kV
Investment	Rs. 80 lakhs
Payback period from energy saving	3.5 years
Power saving due to avoided installation	Rs. 7.5 crores.

KARNATAKA ELECTRICITY BOARD-CHIKKODI TALUK

Station-wise peak load losses and voltages before and after improvement

Name of sub-station 33/11 kV	BEFORE IMPROVEMENT				AFTER IMPROVEMENT			
	Existing		After 5 years		Existing		After 5 years	
	Peak load losses-kW	Minimum voltage- kV	Peak load losses- kV	Minimum voltage- kV	Peak load losses-kW	Minimum voltage- kV	Peak load losses - kW	Minimum voltage - kV
Chikkodi	2039	8.12	3321	7.5	530	10.27	863	10.01
Kabbur	134	10.44	218	10.3	191	10.32	311	10.1
Nippani	680	8.55	1107	7.7	33	10.22	542	10.0
Sadalga	977	8.83	1591	8.23	611	10.15	995	10.0
Ankli	1081	8.59	1761	7.92	296	10.4	482	10.28
Bhoj	371	9.81	604	9.48	367	10.24	598	10.00
Kadaklat [Proposed]	-	-	-	-	224	10.25	365	10.00
Kotwadi [Proposed]	-	-	-	-	213	10.28	347	10.1
TOTAL	5282	-	8602*	-	2765	-	4503*	-

* On the assumption that the systems will not be strengthened and future load will be catered from the distribution system only.

APPENDIX III

Optimal Restoration of Power Supply in Large Distribution Systems in Developing Countries

Abstract

A computer aided optimal method has been developed for the restoration of electric supply to areas isolated from the network following a fault in a distribution system. A search technique is used where the search is guided by appropriate heuristics. The optimum solution entails finding the strategy which involves the operation of minimum number of switchgear for rerouting the supply within the constraint of specified loading. This is an essential requirement in countries like India where the circuit breakers are almost always manually operated and a number of transformers and feeders operate close to their rated capacity. It pays therefore to adopt different strategies at peak load and off peak conditions since the number of breaker operations is so critical. The heuristic search that is developed is applied to a large distribution system and provides very good results.

It is imperative that power supply be restored rapidly following a fault. A methodology for restoring electric power in a very large distribution system in a developing country is outlined in this appendix.

The restoration of electric supply to isolated areas of large-scale urban distribution systems is a difficult task. When a fault occurs on a feeder, the faulted section has to be first identified and isolated. The isolated sections will have to be fed from alternative feeders until the faulty cable is repaired, a task that could take some time. The restoration of supply to isolated sections involves the opening and closing of switchgear so as to feed the isolated sections from alternative routes. It is necessary that in the process of restoring power, there is no overloading of buses, transformers, and line sections.

The present practice of restoring supply in developing countries is for the operating personnel to make the decision on the spot, relying on past experience. It is difficult for the operating personnel to keep in mind the entire system, especially if it is large, and changing and growing all the time. The memory and computational speed of the computer can be very usefully exploited to offer feasible solutions. The final decision can rest with the operator. The program will aid the personnel in obtaining the optimal solution quickly.

A number of different approaches have been suggested for solving the problem of restoring electric supply after the onset of a fault that interrupts it. The methods proposed are integer programming which is difficult to implement for

large distribution systems, and expert systems, which do not as yet have the scope to deal with complexities in a developing country.

A heuristic search based methodology for optimally restoring electric power supply has been found to be particularly suitable for the case of a developing country. This methodology is the basis of computer software that has been developed and applied to a large sub-grid in Bombay (India) city.

A tree search methodology is adopted with novel heuristics for solving the problem and it is found that breadth-first, rather than depth-first more suitable for our purposes. The search tree is pruned thus saving considerably in computation time. Realistic studies in the context of a developing country prove the effectiveness of the method and the network to which the methodology has been applied is easily the largest in the literature.

In a developing country, switchgear operation mostly manual, is not controlled by a computer. In India, for instance, the switchgear operators are dispatched by bicycle or scooter to the location of the switches that need to be turned on or off. Thus, while load balancing etc. are important, most of the cost is related to the number of switches that need to be operated. Thus in this model, the objective is to minimize the number of switchgear operations.

Next, since service restoration is manual, the time taken to restore operations is not as small as would be in situations where computer control is used. Hence, it is imperative that service be restored as quickly as possible. Trying to find a solution to restore power supply so that peak load for the next 24 hour period is met will take a significant amount of time. Also, it will lead to a large number of manual switching operations. The strategy of restoring supply soon, in order to meet the load expected in the next few hours, and then, after the system stabilizes, resorting to peak-load satisfaction may be a better strategy. Thus, it is necessary to experiment with a number of strategies for restoring power that may or may not satisfy peak-load requirements.

If the time required for obtaining the solution is very critical, then the method can be used in advance of an actual fault. A few alternative strategies computed by this method can be easily stored in the computer for a few anticipated locations, and as soon as the exact fault location is communicated to the operator, he would be ready with a switching strategy.

Sometimes it may not be possible to feed all areas after a fault occurs. In such a case it will be necessary to resort to load shedding. In such a contingency, it should be ensured that minimum load is shed and certain loads are spared. A priority ordering of the nodes has not been considered in this paper. If the nodes are given priority ordering (hospitals and essential services having high priority for instance, then load shedding can be carried out according to the priority of the nodes.

Another approach is for the algorithm to 'learn' the suitable criteria for optimality and the appropriate control strategies by the use of some examples. In addition, the practical experience of the operating personnel can be built into the program in order to guide the search. There are many ways of improving the heuristic search procedure. Details of this method are described in references 9 and 10 of this paper.

APPENDIX IV

Short-term load forecasting for demand side management

Abstract:

A method for short-term load forecasting which would help demand side management is briefly described in this appendix. This is particularly suitable for developing countries where the total load is not large, especially at substation levels, and the data available are grossly inadequate. It is based on the Kalman filtering algorithm with the incorporation of a 'fading memory'. A two stage forecast is carried out, where the mean is first predicted and a correction is then incorporated in real time using an error feedback from the previous hours. This method has been used to predict the local load at 11kV and also the bulk load at 220kV. The results and the prediction errors are presented.

Short-term load forecasting is the prediction of power demand with lead times ranging from an hour to a week. Short-term load forecasting is necessary so that the quantity of generation may be estimated and, on this basis, load management planned to meet the expected demand. In developing countries the power sector is often unable to meet peak demands. It seems essential that the scheduling of generation is to be planned carefully since one has to work within stringent limits. Hence, suitable strategies are necessary for generation control and load management. For this purpose, short-term load forecasting has to be carried out as accurately as possible.

In developing countries, load management usually takes the form of 'load shedding'. 'Power Cuts' or 'voltage reduction' at substation levels are often resorted to. In the absence of centralised controls, decentralised load management needs to be carried out and reallocation of local peak loads can only be made if the local short-term load may be predicted. The prediction of local load at the 11kV level is significantly more difficult than the prediction of bulk load which exhibits a stronger statistical pattern due to an averaging effect. Most papers on load forecasting usually deal with bulk load and can therefore, report fairly accurate predictions.

Figs. 1a and 2a give a sample of the data used by us for the purpose of forecasting. Fig. 1a shows the load curve at 220kV over a period of several weeks. Fig. 2a gives the load curve for 11kV. It can be seen that the load shape more or less repeats every week, except for some fluctuations. It is also evident that the repetitive pattern is much stronger at the 220kV level than at the 11kV level. The peak load at 220kV is less than 600MW and the peak load at 11kV is less than 30MW. Most papers on load forecasting usually deal with bulk load of the order of gigawatts, and it can be seen that the quantum of load for which prediction was carried out by us is comparatively very small. At this level, the accuracy of forecasts will not be as good as that for bulk load. Short-term load forecasting at the quantum of load we have dealt with is, however, essential for load management, especially if it needs to be decentralised as in countries with poor communication links.

One of the major inputs in standard predictions is weather data. Although national weather forecasts are carried out nowadays in developing countries, it is seldom that reliable local weather data and their correlation with load demand are readily available at substation levels to be incorporated into load forecasting.

A simple method of error feedback has therefore, been devised to make corrections in the prediction, especially for the peak hours, by observing the deviations of the off-peak predictions from the measured values of the actual load at early hours of the day.

Kalman filter algorithm was found particularly suitable for predicting the average local hourly loads, and the dynamic corrections were carried out subsequently. The study has been based on two years' hourly load data collected from 11kV and 220kV substations in Bangalore. Suitable corrections have been incorporated to take into account abrupt changes resulting from sudden load shedding or occasional wrong entries.

A fading-memory Kalman filter has been developed to assign variable weightage to past data. This has not only resulted in reduction of dependence on data far back into the past, but also improved the accuracy of prediction to a certain extent. Space for data storage and the time taken for computation are both significantly low and makes this method highly suitable for use in small computers.

The load dispatch centre can undertake the generation planning when the anticipated load is known one week ahead. This forecast can then be compared with the sum of the forecasts made at the 11kV level. The expected generation, import and export of power, are then checked for adequacy. In the event of an expected shortage, remedial measures may be taken at the local levels to reduce the demand at critical hours. By using the one-week-ahead predictions, gross planning is carried out and predictions made one hour ahead would enable final corrections to be made. This will provide a lead time during which additional generation or import of power may be attempted, failing which voluntary load shedding is tried at local levels. In this way arbitrary power cuts may be avoided. Fig. 3a gives a simplified flowchart of the short-term load forecasting method. Details are available in reference 11.

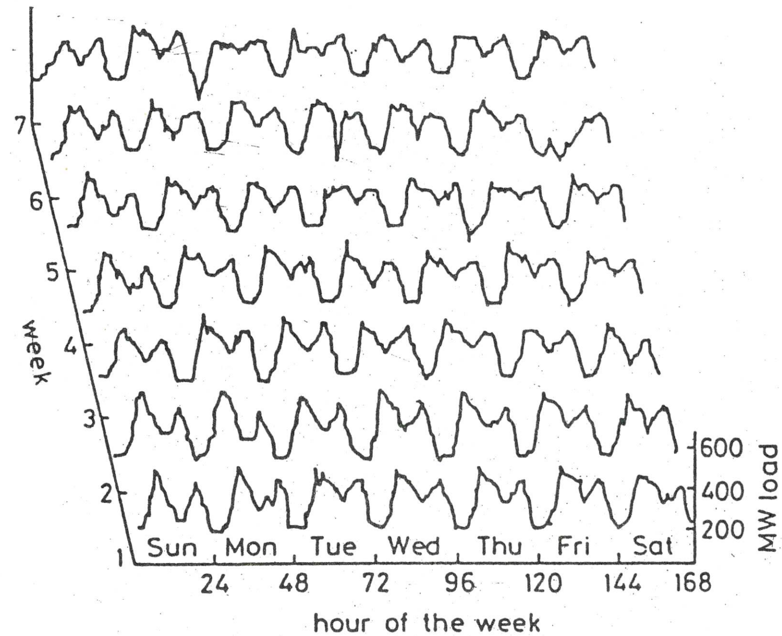


Fig. 1a Load variation over period of several weeks 220kV level

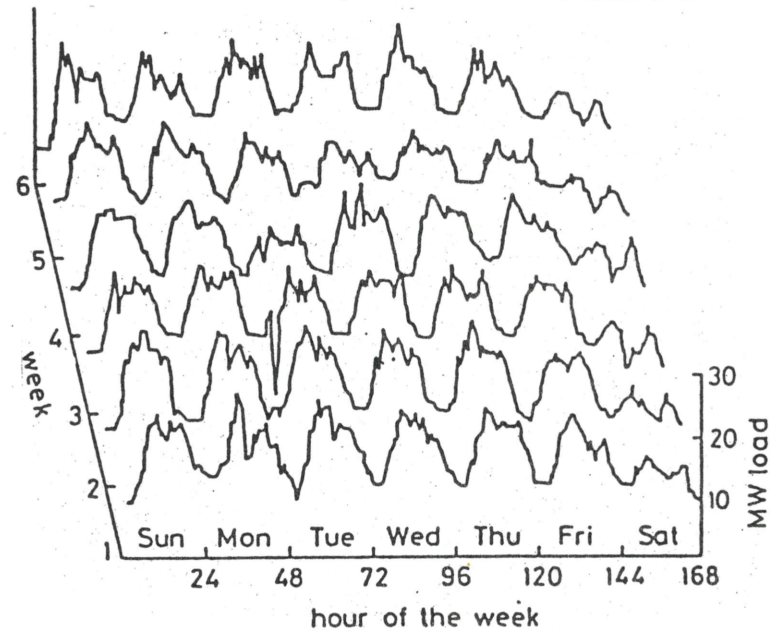


Fig. 2a Load variation over period of several weeks 11kV level

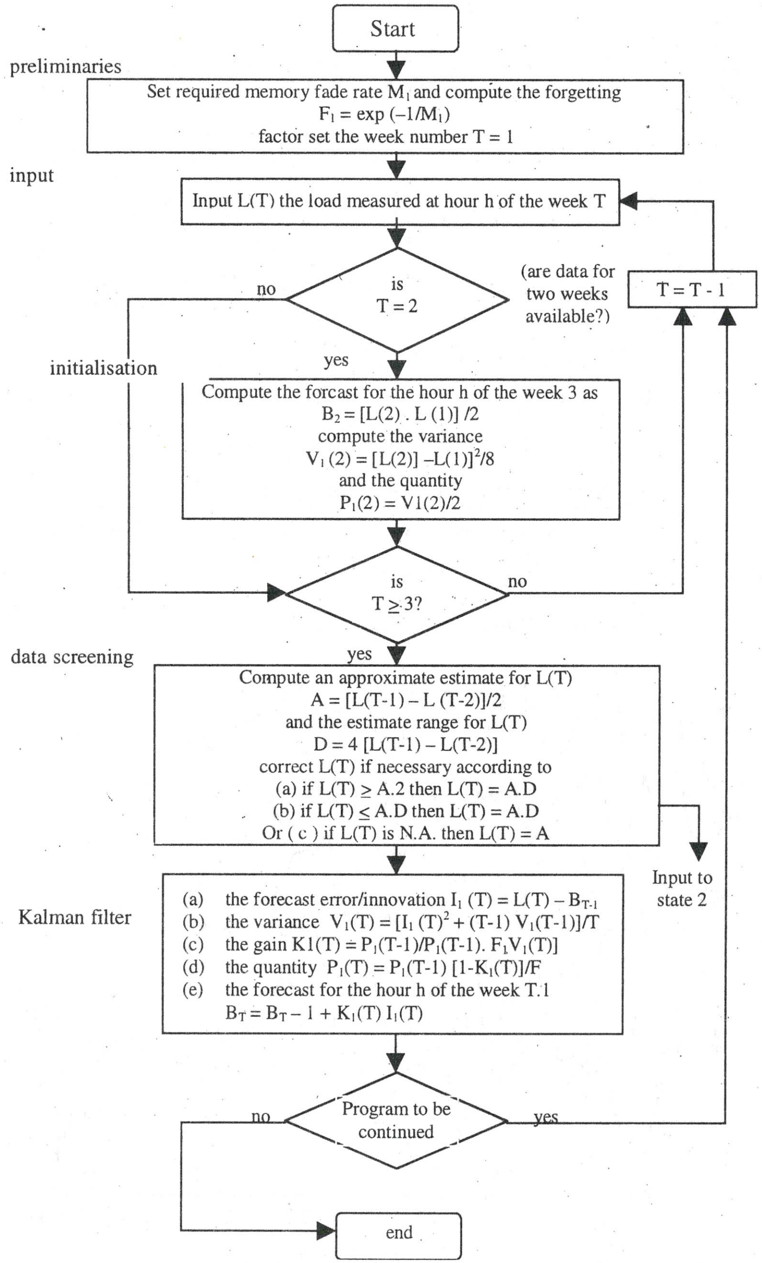


Fig. 3a Simplified flowchart of proposed short-term load forecasting method.

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