4 LONG-TERM SYSTEM EXPANSION PLANNING

Keeping in view the required volume investment volumes involved and the time taken to implement power projects from identification to commissioning, planning the expansion of interconnected systems needs to be undertaken for relatively long time horizons, normally between 15 and 25 years.

The purpose of these studies is to establish the most economic strategy for the development of the system, which strongly concentrates on the determination of the optimum timing, sizing and sequencing of generation projects.

Objective function aims at establishing the least-cost solution, namely the minimization of all discounted investment, operation and maintenance costs over the planning horizon under consideration. Normally the net present value of resulting cash flows is chosen as the basic parameter (criteria of excellence) to compare alternative expansion strategies.

The constraints are given by the requirement to satisfy forecasted power and energy demand, output of existing plants and proposed projects, reliability, etc. Therefore, each feasible expansion sequences should consider:

- Forecasted power and energy forecasts
- Addition of new plants keeping in view output, cost and earliest commissioning dates
- Refurbishing and/or retirement of existing plants
- Reliability requirements

The scope of the work and its level of detail depend on many factors. Some of them are addressed below.

4.1 REGIONAL (RURAL) INTERCONNECTED SYSTEMS

The population in many rural areas is normally sparse, distributed over large areas. Their income level is low and consequently their energy consumption is also low. Mainly due to poor accessibility the information available is frequently limited. The distribution of the loads in time and space play an important role in the approach adopted for these areas.

When dealing with the expansion planning, mainly due to insufficient data and type of load, which is predominantly domestic, simplifications and relaxations are frequently made in case of rural areas. Independently of these conditions, the objective function aims at finding a least-cost solution to satisfy the forecasted demand.

Owing to lack of industrial loads, electric systems in rural areas have relatively low load factors with relatively high peaks. Therefore, the peak load is critical, occurring in winter.

On the other hand, in isolated and rural areas, the projects have to be planned with relatively high plant factors to ensure the satisfaction of the forecasted demand. The minimum discharges and consequently the expected output are expected to occur in winter.

Other important aspect to consider is the geographic distribution of the load centers. Therefore, the analysis may include:

- Strictly isolated and independent supply system for each load center
- Isolated system serving groups (clusters) of nearly located load centers
- Regional interconnected system serving clusters of load centers
- Connection to the national grid
- Combination of above

4.1.1 METHODOLOGY

Module DIPEO i2/4 titled "Manual on Selection of Priority Development by means of Alternative Regional Power Development Models (RPDMs) for Isolated systems" describes the methodology employed to determine the least cost hydro generation option for rural electrification of a given region. It involves the following steps.

- Availability of input data like existing power plants, estimated demand forecast of load centers, total cost of ranked identified/planned power projects, distances between load centers, and unit cost of transmission lines, etc.

- Development of alternative power supply system by combining the nearby load centers, which are connected to, identified potential sites to meet the forecasted demand over the planning period. Each power supply system connected with alternative potential sites is called a regional power development model (RPDM).

- Analysis of RPDMs as isolated or combination of two or more to serve the demand over the planning period with least cost.

- Selection of the least cost power supply system and comparison of this to the best alternative method of serving the load over the whole planning horizon.

4.1.2 DESCRIPTION OF MODELS

The RPDM is a Power Supply System, which is defined as a load center or a group of load centers to be served from proximal hydro power stations through a medium voltage transmission system. These are developed for each system in the planning region in order to find the solution with the least comparative net present cost. The combination of load centers depends upon a number of factors which are listed below.

- Nearness of load centers to each other
- Location of main centers
- Location of identified hydropower potentials
- Existence of access roads between load centers
- Risk of natural geodynamic events
- Geographical barriers or hindrances

The main characteristic of each system is that it will primarily function as an isolated power system. However, since the objective is to supply energy to the region as a whole, the Region is to be treated as one system that may be one isolated internally interconnected system or combination of more isolated systems to be interconnected with each other at certain stages of development.

The RPDMs are designed to cover the growing maximum power demand of the system over the whole planning period from the identified potential sites. Within the planning period the identified schemes are added just before the total rising demand can reach the generating capacity of the system throughout the year. The dates of commissioning of projects have to be in accordance with their necessary time of planning and construction.

The characteristics of the transmission system: the length, and size of conductors which link potential sites and load centers are defined within each model in accordance with the level of losses and voltage drop consideration.

Low voltage distribution and customer connection costs within the load centers for this comparative purpose is not included, since it is independent from the RPDM selected.

The individual alternative RPDMs are compared with each other on the basis of net present cost of all investments and operation costs including generation and transmission to the load centers.

The calculation for the comparative net present cost also includes the capital investment made to add capacity to serve peak system losses.

The management of the whole data, cost calculation of transmission system and calculation of net present cost of each model is made by means of a spreadsheet which shows the process of analysis and the assumptions of calculation, which are listed below.

- Discount rate 5-15%
- Planning period 20 years
- Useful life of HPPs 60 years
- Useful life of generating equipment and transmission system 30 years
- Operation and maintenance of civil works 1% yearly
- Operation and maintenance of units of generation 5% yearly
- Operation and maintenance of transmission system 5% yearly
- Maximum voltage drop 5%

4.1.3 INPUT DATA FOR RPDMS

4.1.3.1 DEMAND FORECAST

Demand forecast of each load center should be estimated as described in previous chapters. Keeping in view the reliability of the data and the need to assume some parameters, optimistic, intermediate and conservative scenarios should be considered. The intermediate demand forecast may be selected for the base case and sensitivity analyses should be done with the other two scenarios.

4.1.3.2 HYDRO POWER POTENTIAL

A catalog of identified sites should be prepared. Besides technical data, such as plant capacity and expected annual output, the catalog should include the estimated costs for each site.

The earliest commissioning time of each site should also be included in the catalog.

4.1.3.3 EXISTING POWER SUPPLY SYSTEM

An inventory of all available generating plants in the region should be carried out. The inventory must include both hydro and thermal plants (private and public) with indication of their capacity.

4.1.3.4 IDENTIFIED AND PLANNED POWER POTENTIAL

Includes recently identified as well as previously studied and proposed projects. The parameters of all the projects (i.e. power and energy output) included in the catalog should be determined using the same criteria and cost base.

Efforts should be made to ensure that the basic data used for all projects have the same level of reliability. Similarly, the level of detail and date of cost estimates should be homogeneous for all the projects.

4.1.3.5 OTHERS

Other inputs are, the transmission system costs, conductors features and electrical basis of calculation, operation and maintenance cost, load characteristics and economic basis of calculation.

4.1.4 PREPARATION OF RPDMS

The Regional Power Development Models (RPDM) are developed as power supply systems. The demand forecast for the load centers in planning region has to be analyzed in order to develop alternative systems to serve the power demand. In the models, the maximum power demand of the system within the planning period is always covered with the total installed power of selected power potential. Within the planning period, the hydro power stations are added just before the total rising demand exceeds the generating capacity of the system.

4.1.5 COST OF TRANSMISSION SYSTEMS

Cost of the transmission system is determined by computation of economic costs of transmission line and installation costs as per DIPEO module i5/3 "Cost of Medium Voltage Systems". Selection of voltage level is essential and usually in these remote and far flung areas with dispersed load centers, 33 kV transmission and primary distribution system is recommended.

The technical characteristics of the transmission line and the cost of transmission system is developed by means of a simple circuit analysis program.

The technical characteristics of the transmission line i.e. size of the conductors, the admitted voltage drop and the capacity lost in the transmission are in accordance with the maximum power demand of load centers and the lengths of sectors.

The total length of the transmission system was divided by sectors, each sector links either two load center or a load center and potential site. The total cost of the transmission system is based on the unit cost of transmission lines.

4.1.6 UNIT COST OF TRANSMISSION LINES

The economic costs for the transmission systems need to be developed by obtaining the Cost Insurance and Freight i.e. C.I.F for various components of the electrical system. Based on these prices and estimating the cost of the civil works, the costs of construction can be determined.

The economic cost per km of transmission line may be calculated for different conductors i.e. Dog, Rabbit, Gopher, and Panther. For the analysis of unit costs, the cost of material, the cost of the conductors and the cost of labor have been separately determined.

4.1.7 COMPARATIVE ANALYSIS

4.1.7.1 BASIS OF COMPARISON

The basis of comparison of the alternative RPDMs is the comparative net present cost of the models. The present worth of benefits is proportional to the energy demand to be covered, thus same for all models and does not need to be considered in this comparison.

The most economical solution to cover electricity demand for all planning region over the full planning period is the solution involving least net present cost.

The calculation of the comparative net present cost is a relative economic proceeding, which studies the investment for the RPDM along a defined planning period. The calculation of the investment is carried out with the estimated costs of selected power schemes, cost of transmission system cost of operation and maintenance for the system and cost of losses.

Low voltage distribution and customer connection costs within the load centers for this comparative purpose are not included since it is independent from RPDM selected. The estimated cost of power and energy losses is also included in the calculation of the comparative net present cost.

Following are the cost effective components:

- Investment into hydropower plants
- Investment into transmission systems
- Operation and maintenance of power supply systems i.e. civil works, electro mechanical equipment and transmission systems.

The costs and benefits ignored in the comparison are listed below:

- Distribution transformer capital and recurring costs
- Low voltage system capital and recurring costs
- Services and meters capital and recurring costs
- Commercial costs and other overheads
- Customer cost recoveries (benefit)
- Proceeds from sales of energy (benefit)
- Indirect benefits
- Customer surplus

4.1.7.2 COMPARATIVE NET PRESENT COST

Comparative net present costs are calculated for each RPDM, covering the total maximum power demand as per intermediate scenario. Sensitivity analyses may then be carried out using the optimistic and pessimistic demand forecasts.

The criteria for the selection of power potential projects are

- The power scheme with least cost/kW are considered first.

- The selected scheme should be located either within the area of the considered system or nearby the area of the system.

- The capacity of the scheme has to match the total maximum demand of the system at least for a period of three years.

The analysis is repeated for each system in the region.

4.1.7.3 RANKING OF ALTERNATIVE POWER DEVELOPMENT (RPDMS RANKING)

The alternative RPDMs calculated for each system or combined systems are ranked in decreasing order of net present cost. It must be ensured that all the alternatives are compared on the same basis and that none of them is favoured due to special circumstances which may distort the results. With is especially important with regard to the deficits, reserve requirements, retirement of old units, etc.

4.1.7.4 HIGH RANKING POWER DEVELOPMENT MODELS

The alternative RPDM with the least comparative net present cost for any individual system. Sometimes, for some individual systems, the hydro power plants in the RPDM with least cost are located out of the system area. This situation indicates that that a combined system may be more suited to the hydropower plants in the RPDM with least cost.

4.1.8 COMBINATION OF HIGH RANKING MODELS

Since it is aimed to start electrification of the region as a whole from the very beginning, and for the sake of equivalence while comparing various options, the best possible combinations of the system models ranked to meet the demand for the whole are considered.

Basically this means to compare the various possible combinations of various systems (taking isolated or in combination) possible combination are:

Option A: To serve the demand of all load centers in the region combining all systems.

Option B: To serve the demand of clusters of load centers (isolated systems)

Option D: To serve the demand of clusters of load centres (isolated systems), all systems isolated.

4.1.9 SELECTION OF HYDRO POWER SCHEMES FOR IMPLEMENTATION

The sequence of development of projects has to be made considering the demand and the required investment keeping in view the earliest commissioning date in accordance with the required time for investigation, design and construction.

4.1.10 IMPLEMENTATION SCHEDULE FOR RECOMMENDED PROJECTS

Should provide the basis to establish the work programs for each individual project, from office studies and field investigations up to the final implementation.

4.2 NATIONAL INTERCONNECTED SYSTEMS

This is a classical problem for which extensive work has been done. International financing agencies, namely the World Bank, have adopted certain tools and procedures to evaluate projects and development strategies. The computer program package WASP (Wien Automatic System Planning) developed by the International Atomic Energy Agency has been installed in many countries to assist in the planning process.

In many countries; state-owned power utilities have been using WASP and other similar computer packages to carry out capacity expansion planning studies. Taking into account the recent trend towards privatization, some adjustments in the approach are being proposed.

The aspects to consider are described in the following paragraphs.

4.2.1 BASIC STEPS IN PLANNING

This chapter contains an overview of the basic step followed for planning of development projects. Special consideration is given to limitations and constraints normally encountered in developing countries.

DEFINITION OF OBJECTIVES

In general, almost irrespective of their nature, development projects are aimed at improving the living conditions of the population. This is the case of projects in sectors such as public health, education, energy, etc.

The importance given to every sector at national level depends on governmental policies. If properly formulated, the policies should allow a balanced development, according to the needs.

Developing countries are confronted with the challenge of providing satisfactory living conditions to a fast growing population. The demand for development projects imposed on every sector increases parallel to the population. However, in most of the cases the natural resources are either limited or the financial resources scarce.

The result of above situation, if not properly solved, is a gap between supply and demand. This difference, which is basically a deficit, is reflected in terms of a limited quantity and/or poor quality of services provided. In many cases the demand is depressed and can not grow due to limited supply, which means that even making use of the total available supply the prevailing needs are not properly satisfied.

Under these conditions, the planner faces the problem of satisfying a demand for certain infrastructure and/or services with limited resources. Some fundamental questions may arise, such as:

Does planning make any sense at all in this case?
What to do under these circumstances?
What should be the objectives of planning?

The answer is a clear YES and a rational planning should have as overall objective the optimum utilization of available natural and financial resources, even if the requirements are not completely satisfied. Planning works are expected to provide sufficient information to ensure that decisions are properly and timely taken.

Additional questions may be formulated aiming at a more precise definition of objectives. These can only be replied in a specific manner according to the nature of each sector and particular case. In this regard, following concepts should be clearly understood:

- Will the proposed development be evaluated in terms of economic efficiency criteria?
- Is the project of such nature that economic efficiency cannot be established or utilized to properly evaluate its suitability?

To the first category of projects belong typically developments related to productive activities such as factories, agriculture, energy, etc. The output of these projects can be quantified in terms of monetary units and decision on their suitability can be made on basis of the required investments and the expected revenues.

The second type of projects has more a social component, which in many cases cannot be easily quantified. Typical of this category of developments are hospitals, schools, water supply schemes, etc. The quantification of output in terms of monetary units is not possible and the planner needs to rely in some other means and criteria to determine the benefits of a certain project.

In any case, once the objectives have been established, the next action to be undertaken is the definition of the so-called "Criteria of Excellence", which will help us in the selection of better alternatives from less attractive ones. These criteria may be considered as a sort of objective function.

The criteria of excellence, depending on the nature of the planning work under consideration, may comprise both quantitative and qualitative elements, such as:

- Maximization of regional and national welfare
- Minimum discounted cost over the whole planning horizon
- Minimum adverse impact on the environment

DATA COLLECTION AND DIAGNOSIS

A further step in a systematic planning is the collection of relevant information. The main purpose of this work is to carry out a diagnosis regarding present conditions.

It is difficult to establish a general rule with regard to the time and efforts required for data collection. These activities strongly depend in every case on the degree of development of the sector under consideration, manpower available and the time constraints for completion of the work.

However, once a planning work is started, the activity of data collection becomes a continuous effort. Evidently, more knowledge will be gained and better planning may be possible if more information is available. However, the objectives of the planning work should be kept in mind to decide to which extent data will be collected to ensure results with a satisfactory degree of reliability.

Why is a diagnosis so important? Knowing where we are it is needed to decide where and how to proceed. Unless we know about our present situation, no rational planning can be claimed. The knowledge of our present conditions provides the starting point for the planning work.

The diagnosis will always give the information required to decide where and how to proceed. Planning does not always mean the development of new infrastructure. As results of the diagnosis we may obtain information regarding following aspects:

- Quality and quantity of service provided.
- Needs for repair and maintenance of existing facilities
- Need of adjustment in operation to increase the output of available facilities.
- Capability of personnel and training needs
- Change in policies to modify consumption and/or utilization patterns.

The diagnosis provides the means to achieve an understanding of the past developments and their expected impact in the future. In this regard, we may be able to establish if supply was sufficient to ensure a proper demand growth. If the supply was constrained the demand growth was suppressed, leading to deficits and a service of poor quality.

The diagnosis may also provide additional information, which can be used to obtain a comprehensive understanding of the situation. This may include among others a proper understanding of the interaction of the case under consideration with other sectors of the society and the economy.

FORECAST FUTURE REQUIREMENTS

This comprises the analysis of possible developments of future requirements. Evidently, a proper forecast of future needs should take into consideration the past developments.

There are many ways and procedures to forecast future requirements. These may range from very simple estimates on basis of assumed growth rates to more sophisticated models, which may take into consideration interactions of all sectors of the economy (Input-Output models).

In engineering practice, where infrastructure developments are involved, the forecasts of future requirements are subdivided as follows:

- Short-term forecasts, which may extend from 1 to 3 years.
- Medium-term forecasts, which may cover a period from 3 to 10 years.
- Long-term forecasts have no upper limit, but due to practical reasons may extend up to a maximum of 30 years.

The time horizons may obviously vary according to the nature of the sector (public health, education, etc.) and projects under consideration. However, proper account should be made of the various steps and time required for implementation of almost every development project, which include:

- Identification
- Planning
- Design
- Financing
- Tendering and award of contracts
- Construction

The methods to be used in every case to estimate future requirements will strongly depend on the availability of basic data as well as time and personnel at disposal. The quantity and quality of data available will provide a realistic framework concerning the methods to be used. However, a proper application of the selected methods will depend also on the qualification and experience of personnel involved.

The reliability of the forecasts varies obviously with the time horizon. It is expected that short-term forecasts will normally have a higher reliability than long-term forecasts. In other words, we may be able to make a better estimate of near future events as compared to developments that may occur after a long period of time.

A rational planning implies that decisions should be made according to the reliability of the forecasts. If a proper diagnosis was carried out, it can be expected that the short and even medium-term forecast will have a relatively high reliability level. For long-term forecasts, it is a normal practice to rely on sensitivity analysis which may correspond to different scenarios. This approach serves to evaluate the impact of uncertain events.

The forecasted requirements are used in planning to give an indication of targets or lower bounds, which must be observed. In general these bounds are not absolute, which means that they may be violated if deficits exist or are tolerated. Alternatively, various scenarios may be assumed, from pessimistic to optimistic, aiming at establishing the possible impact of different development strategies.

RESOURCE EVALUATION

The next step in planning constitutes the evaluation of available resources which may be utilized to satisfy the expected future requirements.

Under ideal conditions, the evaluation of resources should be exhaustive. However, this is seldom possible due to various reasons, such as:

- Scarcity of basic data on available resources
- Insufficient technological development
- Shortage of manpower
- Shortage of funds

Although the lack of a complete knowledge on available resources due to shortages of various natures constitutes a typical problems in developing countries, the scarcity of basic data on some resources and the technological development affect both developing and industrialized countries. As a matter of fact, less developed countries are getting the benefits of technological developments in industrialized nations.

The decisions to be made comprise different stages of development, from identification to implementation, which will have associated costs. The quantification of the resources should include a realistic estimate of the following:

- Associated costs for every stage of project implementation, from identification to implementation
- Time required for every stage of project implementation, from identification to implementation

However, selected development projects are expected to be feasible, which implies that all following conditions are fulfilled:

- The project is technically sound
- The project is economically competitive against other alternatives
- Financial viability ensures project implementation and later operation
- There are no political objections against the project
- Social feasibility is achieved
- The project is environmentally acceptable

Following the formulation in terms of an optimization problem, the availability of resources provides constraints in terms of upper bounds while requirements constitute lower bounds. In both cases, these bounds are soft and cannot be applied strictly from the mathematical point of view as any violation of the constraints would make the problem unfeasible.

STUDY ALTERNATIVES TO SATISFY FUTURE REQUIREMENTS WITH AVAILABLE RESOURCES

Keeping in view the objectives, different alternatives to cover the forecasted requirements with available resources are evaluated. Merits and demerits of each alternative, qualitative and quantitative, are accounted for.

Planning is basically a tool for decision-making. Therefore, the aim of a planner should be to identify a reduced number of attractive alternatives. Although in theory a relatively large number of alternatives may be possible, in practice is the number of alternatives relatively small, which is the normal case in developing countries. An extremely large number of alternatives does not necessarily mean that a proper planning work has taken place.

To reduce the number of alternatives, so-called "Screening" procedures are adopted. The selected alternatives can be studied and evaluated in more detail, which allows a careful analysis of those alternatives, which are more attractive.

SELECT AND RECOMMEND PLAN FOR IMPLEMENTATION

The selected implementation plan should include a series of recommendations which will include:

- Activities, which will help, solve problems identified during the diagnosis.
- Actions to be undertaken to cover the forecasted short-term requirements.
- Actions needed to satisfy the forecasted medium and long-term requirements

4.2.2 BASIC STEPS IN POWER PLANNING

The basic steps needed for the development of power projects are discussed. The chapter begins with the definition of objectives and concludes with the selection and recommendation of a plan. Considering that all basic steps in power systems planning will be presented and discussed in detail in subsequent chapters, this chapter is intended to provide an overview to understand the interaction among the various steps.

The concepts presented in this chapter assume that a systematic approach towards capacity expansion planning is desirable. It does not rule out the possibility of implementing emergency programs due to abnormal events, such a natural disasters (earthquakes, floods, etc.).

DEFINITION OF OBJECTIVES AND PLANNING HORIZON

It is evident that the aim of every power utility, independently of its size, is to provide electricity to the consumers. How the service is provided and the policies on which it is based constitute a fundamental part of the objectives to be accounted for while planning the expansion of power systems.

There are however some important differences to be considered according to size of the interconnected system which influence the approach:

- The planning for large interconnected systems tends to be based more on economic efficiency, although not all consumers may be affected in the same manner and to the same extent.
- The planning of small isolated systems in rural areas has a significant social component. Therefore, economic efficiency may be of secondary importance.

Keeping in mind these basic differences, the objectives in planning of electric systems should be discussed in the following paragraphs according to the importance given in every case to economic efficiency.

A further consideration in the definition of objectives with regard to power supply in is the quality of service, which is measured in terms of continuity and reliability of the service. This also implies that electric parameters like frequency and voltage at the point of consumption are maintained at nominal levels. This leads us to consider the need to have different types of reserve available in the system, which implies that additional capacity is needed to ensure a satisfactory supply when disturbances occur due to failure of certain elements.

The lack of reserve in a system implies that the service to some or all consumers, depending on the extent of the disturbances, has to be interrupted when main elements, such as generating unit or transmission lines, trip. It is evident that different criteria have to be applied to isolated as compared to interconnected systems.

The quality that may be considered as acceptable for an isolated system in a rural area may not be adequate for a large interconnected system. Operating a system with higher standards implies also higher costs for the power utilities regarding generation transmission and distribution of the electric energy. Keeping economic efficiency in view, consumers should bear these costs, which is what normally happens in developed countries.

Alternatively, when developing countries cannot afford standards of industrialized nations because the consumers cannot bear the cost, either the quality of service is lowered or the power sub sector is directly or indirectly subsidized.

The simple statement that planning is made to cover the demand is not sufficient. Planners in developing countries, when defining the objectives for planning the expansion of large interconnected systems, need to keep in mind the following:

- Will the proposed program cover only the minimum requirements? This implies that the proposed program will provide satisfactory results if all elements in the system are in operation. Non-availability of some elements due to tripping or other reasons will result in interruption of supply to the consumers.
- Will provisions also be made for reserve to ensure continuous service to all consumers?

In both cases the national economy is directly affected. Deciding on a program with minimum investments may lead to an unreliable system with deficits and frequent interruptions. The impact on the economy due to the unserved energy can be quite significant considering that the economic cost of unserved electric energy is much higher than the cost of generated energy.

On the other hand, increasing the reliability of the system may require an intensive investment program. As funds are normally scarce in developing countries, decision makers at governmental levels are reluctant to accept such system expansion strategies. Requirements and priorities among different sectors have to be taken into consideration when the allocation of funds is decided. The general case is that priority will be given to investments which satisfy the basic needs of the population, such as food, housing and public health.

What should the planner do under these circumstances? The answer is very simply, but requires a good understanding of the system and a significant amount of work. The planner should be capable of carrying out realistic analysis of most likely scenarios of system expansion, with and without reserve, evaluating both the cost of unserved energy and the associated fixed and variable costs.

Evidently, a "Criteria of Excellence" in any case will be the minimization of the discounted costs incurred for construction, operation and maintenance of the system. This means that the planning efforts will aim at finding a least cost solution which satisfies the standards established.

The planning horizon should be selected according to:

- Size of the system, in terms of installed capacity and geographic coverage of the interconnected network
- Present balance between supply and demand
- Projects in hand and their degree of development
- Financial resources available

The results of the planning efforts will be a series of recommendations on actions to take aiming at covering the demand for power and energy throughout the complete planning horizon. The recommendations will not necessarily deal only with the implementation of new projects. Other actions may be needed to improve the existing system, for example:

- Improvement of operating policies
- Repair of some elements
- Replacement of some elements
- Modification of tariff structures
- Investment policies for the development of the power resources

Therefore, some actions will be needed in relatively short time, while others will have a longer period for their implementation. It is a common practice to divide the planning horizon in three basic periods, as follows:

- Short-term
- Medium-term
- Long-term

The uncertainties in the planning increase with the length of the planning horizon.

For medium and large systems, planning horizons vary between 20 and 30 years. Longer planning horizons become extremely uncertain and may not help properly in the process of decision-making.

DATA COLLECTION AND DIAGNOSIS ABOUT EXISTING SYSTEM

When undertaking a planning work, we may ask about type of data to be collected and to what extent. The answer is obvious; ideally we would like to collect all data available. However, the effort has a limit in terms of manpower, time and financial resources. Besides, data is continuously generated and its collection is an activity without end.

When deciding about the data to be collected, the planners should consider the following:

How much data is sufficient?
What type of data is needed?
How much data needs to be collected?

One of the basic results of data collection efforts should be a realistic diagnosis of the system in terms of:

- Present balance between supply and demand
- History of operation and availability of system elements

- Reliability of the existing units
- Cost of generation, especially thermal power plants
- Maintenance costs
- Remaining useful life

The balance between supply and demand should not be considered from the viewpoint of the quantitative difference between the generating capacity and the system requirements. The quality of the service is also a parameter to be considered as part of the diagnosis. For the consumer, besides continuous service this includes basically the system frequency and the voltage levels.

Other aspects to be considered in the analysis are the system losses, which can be technical and non-technical. Losses are unavoidable, however very high losses make the system inefficient as they increase the cost of supply. If deficit already exist, the losses increase the gap between supply and demand.

The history of operation of existing power stations provides realistic information on their availability and their effective capability throughout the year. The power stations are planned and designed according to certain information available. For planning purposes, this information can be used until the commissioning of the plants. When a commercial operation starts, the data used should reflect the real capabilities of the units. The use of design values at this stage may be misleading. This applies to hydroelectric and thermal power stations.

The reliability of a power station depends on many factors, such as operation and maintenance. However, an inadequate planning and design or a low quality construction may also lead to poor reliability and reduced generating capacity, for example:

- Head losses in water conduits, such as tunnels and canals, are higher than expected.
- Reduction in water availability due to diversions or reduced supply.
- Sediment deposited reduced regulating capacity of reservoir or obstruct intake
- Fuel contains contaminants which damage the equipment
- Regulations regarding environmental concern and emission of pollutants

An improper operation and maintenance reduces the availability and reliability of the system. Only the statistics of operation can provide a realistic picture. For this reason, planners should not only rely on standard values from literature or manufacturers.

There may also be external reasons, not necessarily related to the power station, which may affect the availability, such as:

- Insufficient infrastructure to transport the fuels in case of thermal power stations
- Shortage of funds to purchase fuels
- Transmission lines damaged through terrorism

The cost of generation of a thermal power station is directly related to the cost of fuel and the specific fuel consumption of the units, which strongly depends on aging and use.

When evaluating the conditions of a power station, planners need to know about the remaining useful life of the unit. The useful life for planning purposes should be understood as the economic life, which requires an estimate of remaining years during which the power station can be operated economically as compared to other alternatives available. If the plant cannot be operated economically because the cost of generated energy is too high or significant investments are needed to keep the units running, the planner should decide between following possibilities:

- Retirement

- Replacement
- Refurbishing/Remodeling

Retirement and replacement are the decision normally taken with regard to thermal power stations. Refurbishing and remodeling may apply to both hydro and thermal power stations, as well as transmission lines.

POWER MARKET STUDIES/DEMAND FORECASTING
Power market studies and demand forecasting are required to determine future power and energy requirements. These studies are undertaken for interconnected systems as well as for isolated rural areas where the service is not available.

The power market study allows to determine:

- Structure of the demand, with identification of consumers
- Consumption patterns of consumers
- Growth patterns of consumption, if service was available in the past

The demand forecast is normally based on power market surveys. There are many methods available to carry out these studies. The degree of sophistication of the method used strongly depends on the data availability and reliability. The type of data used needs to be properly accounted for.

The simplest way of forecasting the demand is on basis of statistics of gross generation, assuming growth rates. The approach is basically used for existing systems with various years of operation. The statistic already includes system losses and the consumption of auxiliaries. The method looses attractiveness and reliability in following cases:

- The demand growth is restricted because the supply is limited.
- The demand exceeds the supply capabilities and significant deficits occur.

On the other hand, when evaluating statistics of existing system care should be taken of special events, which may have affected the power availability. In this respect, blackouts and interruptions should be properly treated when the records are processed. These events should be considered in other part of the analysis and not for demand forecasting.

Obviously, this approach cannot be used when dealing with rural electrification projects, when electricity is being introduced. If the community did not have electricity in the past, there will not be any statistics of generation available.

Alternatively, the demand may be forecasted on basis of power market surveys. The loads are estimated from the viewpoint of the consumer. The total system demand will then be calculated by adding the expected system losses and the consumption of auxiliaries.

SHORT-TERM
Short-term demand forecasting needs to have the best possible level of reliability. The information is mostly related to existing facilities and is normally needed to take decision regarding:

a) Budgetary requirements for system operation, especially if thermal generation plays an important role and fuels are needed for the operation of thermal power stations
b) Investments for repair or replacement of system elements
c) Operation policies, such as:
    - System reliability and reserve requirements (Spinning reserve, load shedding schemes, etc)

- Load shedding strategies when deficit exists
- Reservoir operation, if applicable.

d) Policies regarding electricity pricing and tariff structures.

MEDIUM AND LONG-TERM

These are necessary to define investment policies, especially with regard to the need of adding new capacity to the system. The reliability of these forecasts decreases with the length of the planning horizon and the decision should be taken accordingly. It is therefore a common practice to assume various scenarios, i.e. medium, optimistic and pessimistic, to account for uncertainties in the forecasts. These alternative growth patterns of demand are then used to carry out sensitivity analyses concerning the system expansion programs.

There are many methods and procedures for medium and long-term demand forecasting. The method used is highly influenced by the availability of basic data and the experience of the personnel. Due to the interaction of the power sub sector with the rest of the economy, mostly these methods are based on correlations with macroeconomic parameters.

RESOURCE EVALUATION

Resource evaluation to increase the capacity of the system implies the quantification of available power potentials, which may include following possibilities:

- Extension of available facilities, such as:
    - Increase installed capacity by adding units
    - Increase regulating capacity in case of hydroelectric plants
- Identification of attractive sites.
- Detailed study of selected sites.
- Remodeling of existing facilities.

This general classification applies to both renewable and non-renewable energy sources.
Each type of source will then be accounted for according to its availability.

The extension of available facilities may be possible in many ways. However, there is normally more flexibility with thermal power stations as compared to hydroelectric power stations. In the extension of thermal power stations a proper fuel supply should be ensured. Availability of cooling water may also be important, but there are many technical solutions for this.

On the other hand, once constructed a hydroelectric power station operates under a given head and discharge availability. Increasing the head may not be always easy, as the elements working under pressure need to be adjusted to higher pressures. Therefore, the most common extensions are made by increasing the discharge through diversions or augmented regulating capacity. Alternatively, the capacity may be increased to generate secondary energy during the flood season, provided that the solution is economically feasible and competitive against other energy sources.

The identification of available potentials, leading to an inventory of attractive sites, is always desirable to be sure that proper decisions are being made. The identified sites should include an estimate of the power and energy potential and cost of development, including any complementary additional infrastructure that may be required, such as roads and transmission lines.

Additionally, the social and environmental impact of the proposed projects should be properly accounted for. These may include:

- Resettlement of population in areas flooded by reservoirs
- Water logging due to raising of surface water levels

- Emission of air pollutants due to quality of fuels
- Difficulties in the disposal of nuclear wastes
- Contamination of water bodies due to heat and chemical wastes

The number of potential sites can be very extensive and some criteria are needed to select the most attractive ones. The selection procedure, often mentioned in the literature as “screening” includes both technical and economical considerations. In this respect, the projects should be classified according to the nature and the type of load to cover as:

- Peaking
- Base load
- Medium load

In other words, a plant conceived for peaking purposes, such as a gas turbine or a hydroelectric plant with daily pondage, cannot be directly compared with a power station adequate to cover the base load, which typically corresponds to a steam unit or hydroelectric plant with a large seasonal reservoir.

In both extreme cases mentioned above, the energy generated should be properly valued. Using an average value may lead to the planning and design of hydroelectric projects with reduced capacity to ensure an almost continuous operation. Under these circumstances, the construction of gas turbines for peaking purposes cannot be justified.

It is well known that energy during peaking hours is more expensive than during off-peak hours. A simple explanation for this is the fact that the capacity required to cover the demand during peaking hours has less utilization times. However, investments have to be made to have this capacity available. Due to thermodynamic and mechanical constraints, steam power stations are not conceived for peaking purposes, although they are more economical. Only in extreme cases, old units are started and shut down for peaking purposes, but their operation is not economical. Gas turbines, although more expensive, are suitable for peaking purposes and can be started and shut down in few minutes. This does not mean that these units are not used also for base load generation, as is often the case during emergencies or when the system operates with deficit, and the high price of energy generated is compensated by a higher cost of unserved energy. Gas turbines are also used in combined cycle plants, operating continuously in order to use the residual heat for steam production.

Other considerations, which apply basically to hydroelectric stations, relate to the seasonal and multiannual availability of discharges for power generation. The occurrence of low and high flow season as well as wet and dry years directly affects the generating capacity of the units. To account for this, planners frequently use the concepts of:

- Firm power and energy, when making reference to the plant output available with a high degree of reliability. This value is defined on basis of discharges available during the low flow season and dry years.

- Secondary power and energy, when consideration is made of output levels above the firm generation, and is defined according to availability of discharges during the high flow season.

What these concepts lead to is that selection of projects should be basically made in terms of energy produced according to its availability as follows:

- Seasonally: firm and secondary
- Daily: peak and off-peak

Selected sites should be studied in more detail to determine their feasibility. The work begins with the technical considerations and proceeds with other stages as required. The process is normally dynamic in nature and the technical conception of the projects may be adjusted to ensure that all feasibility conditions are satisfied.

A similar approach may be followed in the study of refurbishing and/or remodeling of existing facilities. Merits and demerits of alternative solutions have to be investigated and evaluated on the same basis. The remodeling may comprise the replacement of parts or the complete facility, leading to an improvement in the overall operation and costs as compared to present conditions.

STUDY EXPANSION ALTERNATIVES TO COVER DEMAND
The forecasted demand is to be covered with the existing plants and the available projects. Some of the existing power stations may reach their useful life during the planning horizon and may be retired, requiring the addition of new capacity to compensate the loss. The basic objective is to achieve this target with minimum overall cost, which include capital investments, operation and maintenance.

The satisfaction of the demand comprises quantitative and qualitative aspects. The quantitative considerations refer to the fulfillment of power and energy requirements, while the qualitative aspects imply the supply of service to the consumers with a satisfactory level of reliability, keeping parameters such as frequency and voltage within acceptable margins.

The most common way of analysis is through the consideration of aggregated supply and demand. On one side, the total system demand is lumped together without considering its geographic distribution. In a similar manner, the supply capabilities are aggregated neglecting their physical location. Balances of power and energy as well as other analysis regarding system reliability, which deals with quality of supply, may be possible.

A more realistic approach implies the consideration of geographical distribution of supply and demand, which leads to a so-called disaggregated analysis. Besides the power and energy balances, the interaction with the grid may also be analyzed. Bottlenecks in the transmission system and their effect on the quality of the service to the consumers may be identified and corrected.

Independent of the approach adopted, aggregated vs. desaggegated, there are other important considerations to make with regard to the availability of generation in general and hydroelectric generation in particular. If the planning is made in terms of available average energy, during dry years the system may not be able to cover the demand or will have to rely on more expensive generation. A safer planning may be possible if the generation assumed for hydroelectric power stations considers only the firm power and energy output. This approach has the disadvantage that an intensive investment program is required to construct the power stations. The secondary energy would have no value and becomes therefore surplus.

Other important consideration which affects mostly developing countries relates to the treatment of deficit and the policies towards it. If a country has limited financial resources, compromises are required to distribute the funds according to the needs of the population. Evidently, basic needs such as food health and housing have a higher priority than electrification. Under these circumstances, the planning has to consider the effects of deficit and shedding of loads due to insufficient capacity.

SELECT AND RECOMMEND PLAN
The expansion strategy is selected on basis of the criteria of excellence adopted. The proposed plan may include recommendations on policies, correction of technical problems identified as well as with respect to the addition of new capacity in the system through extension of existing facilities and/or implementation of new projects.

It is always convenient to include sensitivity analyses in the results. This information provides a better understanding of the recommendations given and their implications. The analysis of scenarios may include the comparison of costs associated with optimistic and pessimistic demand forecasts, the delay in implementation of important projects, etc.

However, considering that planning is basically an aid for decision making, the number of cases included as part of the sensitivity analyses may be limited to avoid confusions. The type of decision required in every case has to be clearly stated according to its nature, which may be:

- Policy issues concerning energy pricing
- Budgetary requirements for system operation
- Study and preparation of projects
- Capital investments for repair or replacement
- Capital investments for implementation of new projects

Priorities, deadlines as well as monitoring and control measures are also needed to ensure a smooth execution. Although formulating a plan is a tremendous task for the planners, its implementation becomes the real and most difficult challenge. If a plan is not prepared according to the nature and situation of the country in general and the power utility in particular, it will most likely fail.

4.2.3 DEFINITION OF OBJECTIVES AND PLANNING HORIZON

The definition of objectives is highly related to governmental and institutional policies. These need to be considered when defining both the objectives and planning horizon for the plan to be developed. The chapter will therefore recommend ways to consider the short and long-term requirements as well as the possible measures to be adopted according to prevailing policies, demand, availability of resources, manpower and capital.

4.2.3.1 OBJECTIVES

Every country is aiming at a sustained improvement of living conditions of the population. Independently of the level of development, the required actions will normally tend to stress on priority needs. In this context, electric power should constitute an element contributing to the overall development of the economy.

When dealing with planning of electric systems, some fundamental questions arise. These refer to:

Who will benefit from the service?
To what extent?
Is economic efficiency important?
Is there a need to make any social considerations?

Evidently, the answers to these questions may be different for an isolated system serving a rural community as compared to a large interconnected system. In the same way, every country will have a different viewpoint according to the degree of development in general and electrification in particular.

However, a decisive aspect in the definition of objectives is the political targets and/or commitments of the governments. Socially oriented governments may tend to adopt policies which, through lower pricing, make electricity accessible to a large portion of the population. On the other hand, conservative governments may adopt policies based more on economic efficiency, leading to the conclusion that only those who can afford the cost are entitled to benefit from the service.

In general there are many complications in developing countries which make evaluation of these decisions rather difficult. Market distortions due to taxes, import duties and subsidies make the pricing of energy extremely difficult. A strict analysis on basis of economic efficiency may not be correct as there are significant differences in income among the population which require subsidized energy prices and even rationing to meet the energy needs of low income consumers.

From the viewpoint of the supply, there is always an evident need to develop indigenous renewable and non-renewable energy sources, although preference is given normally to renewable sources.

QUANTITATIVE ASPECTS

The quantitative aspects refer basically to the balances between supply and demand of power and energy, which most likely having a multiannual trend (increasing or decreasing), may also vary seasonally, weekly and daily. It is the aim of the planners to satisfy the demand under all possibly thinkable conditions, which may include:

- Reduced generating capacity of hydroelectric units due to adverse hydrologic conditions.
- Bottlenecks in supply of fuels
- Price increases in fuel supplies
- Delays in implementation of new projects
- Forced outages due to maintenance and repair requirements
- Random outages due to failure of system components
- Retirement of old units

GENERATING CAPACITY OF HYDROELECTRIC UNITS

The stochastic nature of streamflows should be properly accounted for, as these may affect both the availability of head and discharge for power generation. The extent to which the power and energy output is affected by the hydrologic regime depends on the characteristics of the power station.

Power and energy production in stations located at the foot of the dam are very sensitive to pond level fluctuations. This condition is aggravated if the reservoirs are operated for multiple purposes, as in this case the rule curves may not favour hydropower generation. On the other hand, high head power stations may be less sensitive in terms of power output, but total energy produced may be affected by reduced inflows.

Variable pond levels and discharges may also affect in case of low head power stations located along rivers. High flows imply a higher tailwater level which reduces the available head and hence the power output. Therefore, it may happen that a low head power station produces more energy during medium and dry years as compared to wet years.

BOTTLENECKS IN FUEL SUPPLIES

Bottlenecks in fuel supplies may be of different nature, and may include problems such as:

- Insufficient infrastructure to store and transport the fuels
- International controls and regulations on the use of certain fuels, such as uranium
- Internal regulations on the use of certain fuels
- Lack of funds

An insufficient infrastructure may occur in case of railways, pipelines, waterways, roads, etc. Improvement of this infrastructure may be beyond the technical and economic possibilities of the project, leading to shortages which reduce the generating capacity.

There is an international lobby aiming at having a strict control on the transfer of nuclear technology to developing countries. If local supply is limited, developing countries have to depend on technology and supplies from more advanced nations. Through treaties, such as the one on non-proliferation of nuclear technology, the supply may be restricted to such an extent that the generating capacity is affected.

Internal regulations, which could be based on financial or environmental reasons, may give preference to use only certain types of fuels for power generation. This has been the case in recent years in industrialized nations with respect to the use of nuclear power.

Often the main reason for lack of generating capacity in developing countries is the lack of funds to pay the bill for imported fuels. These problems occur most of the time in countries which are net importers of fuels.

How well do the basic objectives account for the possibility of bottlenecks in fuel supplies? Are we making assumptions which can be achievable?

PRICE INCREASES IN FUEL SUPPLIES

Price increases in the international oil market, as already observed in 1973, may lead to constraint the operation the thermal power stations. The financial burden imposed by such conditions may not be possible to be covered by the tariff, even when fuel surcharges are applied.

Although it is difficult to foresee the future trends of fuel prices, while defining the objectives planners should consider the possible effects of a plan which includes thermal generation. The impact of price changes will depend on the share of thermal generation and the amount of imported fuels as compared to indigenous generation, if any.

DELAYS IN IMPLEMENTATION OF NEW PROJECTS

This applies to both generation and transmission systems. A delay in the commissioning of a project creates a void, which has to be covered by some means if available. Alternatively, the service has to be rationed according to availability.

Delays may occur due to technical and non-technical problems which may arise during the planning, design and implementation phases of projects. The possibility of delays in commissioning of new projects will have to be accounted for when formulating the objectives with regard to the type power stations and the resources needed to operate them.

FORCED OUTAGES DUE TO MAINTENANCE AND REPAIR REQUIREMENTS

Forced outages of units due to maintenance requirements may lead to unavailabilities which may vary from a few hours to some days. For example, steam power units once shut down require some time to cool down. The new start of such units takes also some time until working temperatures and pressure of steam have reached nominal values.

Hydroelectric power stations, if properly designed and constructed, will have less forced outages than thermal power stations. When formulating the objectives, the planners may have to consider the effect of non-availability of the units in accordance with the required maintenance.

RANDOM OUTAGES DUE TO FAILURE OF SYSTEM COMPONENTS

Random outages of system elements may be due to natural phenomena, such as storms, lighting, etc., as well as human errors of different nature. These outages may increase due to:

- Insufficient/improper maintenance
- Aging
- Use

Already at the initial stages of a planning work, the planners will have some knowledge about the conditions in which the available facilities are being operated and their effect on the overall reliability of the service. Therefore, some of the basic considerations when defining objectives will have to refer to the actions to be taken with regard to existing system.

RETIREMENT OF OLD UNITS

Do we expect to take any action with regard to the existing units? Although the terms "economic life" and "useful life" are frequently used with regard to system components, in developing countries these expressions often have little meaning. The system components are in some cases operated beyond the ranges recommended by manufacturers, leading to deterioration of the equipment after a few years of utilization.

If the objectives include an improvement of the efficiency, some actions will probably be needed with regard to the existing facilities. System efficiency cannot be improved only through the addition of new elements.

QUALITATIVE ASPECTS

When dealing with the quality of service the planners, following are the basic parameters to evaluate it:

- Interruptions
- Voltage and frequency levels

From the technical point of view, the reduction in the number of interruptions in the service can only be ensured in every system through a proper evaluation of causes and effects. Obviously, a better quality is always associated with higher efficiency of equipment and personnel.

Capital investments only cannot solve the problem of poor quality. Improper administrative skills and lack of technical know-how are factors which negatively affect power utilities in developing countries. A deficient administration may not be able to cope with problems such as high non-technical system losses, management of stocks of spare parts, etc. leading to frequent failure and even damage of system components.

From an economical viewpoint, electricity is viewed as being an intermediate product which is used to produce final goods which are demanded by the consumers. Therefore, the outage cost is measured in terms of the effects on the production of final goods and services in various sectors of the economy (1).

CONTINUITY OF SERVICE

Continuity of service is possible through a proper planning which ensures the availability of system elements under adverse conditions. This condition, somehow implies that adequate reserve is available to guarantee the service to the consumers, keeping the system running, both economically and safe.

In other words, an adequate knowledge and understanding of the system capabilities is needed to avoid operating system components beyond their limits. Many technical measures may be possible before damaging system components due to overloading, excessive wear, etc.

RELIABILITY

A fundamental requirement placed on electric power systems is to maintain high service quality and to preserve the integrity of interconnected system operation. Service quality is measured in terms of continuity of supply with frequency and voltage within a narrow range around their nominal values.

Reliability has established itself as a factor in commercial competition between alternative energy supplies. Different indices and methods have been introduced for evaluation of power system reliability performance. There are several requirements which must be met to achieve reliable power system performance. These requirements can be developed from the following five objectives:

- To preserve the system security by planning and operating the system such that more likely contigencies can be withstood without adverse stress and loading.
- To preserve system integrity by planning and operating the system so that less probable, more severe contingencies can be withstood without separation and shut down.
- To limit the extent of power system failure by provision for controlled separation, load shedding and generation tripping.
- To promote rapid restoration by provision for secure communication and control capability and independent auxiliary power supplies, and by providing restoration plans and training in restoration procedures.
- To provide for strategic capabilities by reducing dependence upon single fuel type or single fuel source, or dependence upon single design plant. To provide for diverse import capability of energy, to plan emergency energy allocation, and to provide emergency operating practices for severe shortfall conditions.

In general terms, it is not economically justified to set absolute elimination of major failures of power systems as a technical objective.

It is technically and economically feasible to design and operate power systems to achieve the reliability objective of infrequent or low risk of failure and the confinement of extent of power system shutdown. These objectives can be achieved with the technical resources in the electric industry.

4.2.3.2 PLANNING HORIZON

The selected planning horizon is strongly dependent on the objectives of the planning work. If our concern is with the operation of the existing facilities, the planning horizon will extend a few years in the future (from 1 to 5 years) or up to the time when new additions may be required.

If on the other hand, our aims are to formulate a program which will consider selection, study, design and implementation of new projects, the planning horizon will have to extend sufficiently in time to include the all these phases of planning and implementation of the projects with the associated cash flows.

SHORT-TERM

From a practical point of view, short-term planning horizons are needed when analyzing the operation of the existing system. From the technical viewpoint, short-term planning permits the evaluation of the real capabilities and constraints in the system.

On the other hand, short-term planning allows the determination of Short Run Marginal Costs (SRMC), which gives an indication of the suitability of existing tariff structures.

MEDIUM AND LONG-TERM

Independently of the size of the system, the planning horizon should be extended into the future to allow a proper analysis of possible development strategies. The implementation of projects extends over a time period which may vary from a few years to decades, according to their size, nature and complexity. Normally, the power utilities should be capable of implementing their expansion programs through the collection of necessary funds by means of the tariffs. Medium and long-term planning provide the framework to determine the expected Long Run Marginal

Costs (LRMC), which are the basis for the design of the tariff structure. There are no standard solutions for this and every power system has to be analyzed in detail.

4.2.3.3 STRATEGIES

Although some adjustments are normally needed due to changing conditions at national and international level, a system expansion plan should provide a solid basis for decision making with regard to:

- Study and implementation of generation projects
- Expansion of the national grid
- Financial planning
- Tariffs

DEMAND MANAGEMENT

Demand or load management is technique used to achieve a controlled growth of power and energy demand. Consumption may be promoted though incentives or discouraged through penalties of some sort. This may be achieved through technical and economic measures, which depend on the type of effect desired.

In rural areas, the policy may be to promote the use of electricity to reduce the consumption of firewood for cooking and heating to protect the environment or to reduce the consumption of kerosene, which is often imported and distributed subsidized.

The opposite may happen with interconnected systems, where consumption needs to be rationalized, aiming at an improvement of the load factor of the system and the use of electricity for productive activities.

- Tariff structure
- Voltage and frequency

LOAD SHEDDING

The term "load shedding" needs to be properly defined. In Pakistan, the term is used to describe the actions taken to ration the power available due to the lack of generating capacity. Power cuts are preprogrammed and the shedding of loads takes effect under steady state conditions.

However, the term is also used in other systems, under dynamic conditions, to define the sequence of power cuts needed to maintain the system frequency between desired levels after the tripping of generating units. The power cuts take place automatically through the activation of under frequency relays, which are set according to the "load shedding scheme". The load shedding scheme is specifically defined for every system, according to the characteristics of the power stations and loads, spinning reserve available, governors response, etc.

In countries like Pakistan, where power deficits already exist, the term load shedding is mainly applied to the programmed power cuts needed during some months of the year due to lack of generating capacity. Under these circumstances, the system is operated to maximum capacity without spinning reserve. The only way to reduce the drop in system frequency after tripping of a generating unit is to further increase the power cuts to the consumers.

The operation of a system with sufficient reserve margins has an associated cost, which can be measured in terms of capital investment for implementation of the projects and operation of the system. The volume of these investments is strongly affected by the growth of power and energy demand.

On the other hand, the lack of generating capacity leading to power deficits and unstable system operation has also an impact on the economy. A limited system capacity causes a restricted growth of power and energy demand. However, the lack of power may also have negative impact on the economy, reflected in terms of poor or no development of productive activities, higher costs of energy through the intensive utilization of less efficient generating units, overuse of equipment, poor or insufficient maintenance, etc.

Evidently, any decision to be made has an associated cost. The responsibility of the planners in developing countries is to find the strategies which will provide reasonable solutions according to the circumstances.

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4.2.4 DATA COLLECTION AND DIAGNOSIS

The type and amount of data to be collected strongly depends on the objectives and time horizon. However, certain amount of data will be needed independently of any type of assumption or constraint.

In this respect the collection and evaluation of historical demand and system data constitutes a basic step. This allows to carry out a diagnosis of the systems, which constitutes the basis for any future planning.

4.2.4.1 DEMAND

Demand data collected should allow a good understanding of past requirements, which will be the basis to evaluate future development trends. The information should include power and energy requirements and their distribution in time.

DAILY, WEEKLY AND SEASONAL VARIATION

Demand for electricity follows certain patterns according to the time of the day, day of the week and season of the year. How strong these occur depends on factors such as:

- Type of consumers
- Geographical location
- System characteristics and degree of development

Daily load variations are related to human activity, productive and non-productive, and different patterns may be observed according to the type of consumers, which define the characteristics of the load.

For the study of daily variations, the power requirements during peaking hours are important to know the capacity required to cover the demand. Normally the peak loads occur at the evening time, when electricity is required for lighting, cooking etc. However, in highly industrialized regions the industrial processes may define the peak demand.

When there is a significant component of domestic and urban load, the time of occurrence of peak loads is normally affected by the season and occurs in general around 1/2 hour to 1 hour after sunset.

Weekly load variations are mainly affected by productive activity and the distribution of weekdays. Lowest power demand is observed during weekends, when productive activities are minimum. On weekly basis, the maximum loads are observed towards the middle of the week.

Seasonal variations occur mainly due to climatic changes and the energy needs to keep inhabited areas at reasonable temperatures. Electric power is required in winter for heating and in summer for cooling purposes. Other important factor is the availability of daylight, which is shorter in winter and longer in summer days.

HISTORICAL GROWTH PATTERNS

Intuitively it is expected that historical growth patters provide the best picture about the development of the system load. However, the information should be critically analyzed to determine the factors which have influenced it patterns.

If supply has been unrestricted, demand may have grown in accordance with population, industrialization processes and the economy in general. However, this can also mean decreasing demand patterns when the economic system suffers a recession, as has been the case in many developing countries during the last decade.

On the other hand, the demand may have been restricted by insufficient generation, bottlenecks in the transmission system, low reliability leading to frequent blackouts, financial problems which may restrict the generation of thermal power stations, etc.

An adequate understanding of factors affecting the power demand is needed to assess the their relative importance. This constitutes the basis for a reliable forecast of future developments.

4.2.4.2 SYSTEM CHARACTERISTICS

This information comprises basically the technical characteristics of the physical system components. An up to date account of the system is always required, as it constitutes the starting point to decide on actions to be taken to improve overall system performance, addition of new elements, etc.

GENERATION

The data on the generating system should be collected and analyzed according to the characteristics of the available power stations. Proper distinction should be made also between type of units in order to allow the evaluation of their performance both independently and on comparative basis.

TRANSMISSION

The information on the transmission system should be classified according to the technical characteristics of reaches and should include the corresponding substations. The up to date availability of this information is quite important, as it is needed for the day-to-day operation.

On the other hand, reliable transmission network analyses, such as load flow, stability and short circuit, can only be made if the correct information is available.

DISTRIBUTION

Normally this information is not required in the study if expansion alternatives. However, its availability may be helpful in the study of demand growth.

4.2.4.3 POWER AND ENERGY SUPPLY

This information is related to the production and transport of electricity.

GENERATION

The production of the power stations is normally recorded in a systematic manner, with a discretisation of 1 hour or less. The information is compiled generally at the power stations and the control centers.

Various working groups within the power utilities, according to their needs, determine statistics on generation, such as weekly, monthly, annual, etc. values. Salient features, such as annual energy production, peak loads, etc. are frequently published in yearbooks.

From the viewpoint of planning, statistics on generation constitute fundamental information, as it is associated with the largest investments and operational costs within the interconnected systems.

GROSS GENERATION

The gross generation corresponds to the total production of the plant without subtraction of the requirements for auxiliary equipment. The information is normally collected on unit basis and is determined as the sum of the output of each individual unit.

AUXILIARIES CONSUMPTION

To operate, every power plant needs auxiliary equipment whose characteristics vary according to the plant type, layout, etc. Auxiliary equipment is needed for the supply of cooling water, water treatment plants, cranes, lighting, etc.

Without considering the special case of pumped storage plants, normally thermal power plants have higher requirements than hydroelectric plants for the operation auxiliary equipment. In case of steam units, relatively large volumes of water are pumped for cooling purposes. Additionally, the supply of fuels from the source to the combustion chamber may also consume significant amounts of energy.

NET GENERATION

The net generation is calculated as the difference between gross generation and the consumption of auxiliary equipment. The net production constitutes the available output of the power plant to supply the system demands.

TRANSMISSION

The availability of power and energy is determined on one side by the net production of the units and on the other by the losses in the transmission system. This is a simple balance between the inputs and outputs into and from the transmission system.

However, in practical cases observed in developing countries there are often many difficulties with the availability and reliability of data concerning the power and energy flowing through the transmission system. These problems are frequently associated with the shortage and even lack of equipment, poorly calibrated equipment, shortage of qualified personnel, etc.

Modern control systems allow the remote monitoring and operation of the transmission network. Data is collected and directly stored on magnetic media, but the problem in developing countries is that a total coverage of the system is not possible.

DISTRIBUTION

The complexity in the collection and processing of power and energy flow in the distribution system is enormous. Therefore this data may be obtained through commercialization units of the power utility.

4.2.4.4 AVAILABILITY

The availability of system components has a direct impact on the quality of service provided. High availability rates are normally associated with a services meeting the desired standards.

MAINTENANCE REQUIREMENTS
The operation of the elements of an interconnected system, according to their nature, requires maintenance. This should be provided according to the design and specifications given by the manufacturers. Therefore, it may be needed that the elements undergoing maintenance may be taken out of operation for a certain period of time.

In case of scheduled maintenance, the outages of system elements may be often programmed in such a way that the continuity of service is not interrupted. However, this may not always be possible and some scheduled disconnections may be needed.

FAULTS
Unscheduled outages due to faults in system elements may be considered at the design stage to ensure that the element is not damaged and can therefore be brought into operation after the fault is corrected. In this regard, adequate protection should be foreseen to avoid destructive faults.

OTHER CAUSES
Outage of system components may not always be due to technical problems. Besides extraordinary natural phenomena, such as earthquakes, storms, etc., human activity may also decrease the availability of certain elements. One of these cases is terror attack against the available infrastructure, especially transmission lines in isolated areas.

4.2.4.5 SYSTEM LOSSES
The system losses, technical and non-technical, are a parameter which indicates the efficiency with which a system is operated. Obviously, lower losses are associated with higher efficiencies and vice versa.

Technical losses can be determined through the monitoring of system elements. It is always expected that although some elements may reduce their efficiency due to aging and/or wear, overall system efficiency should remain high.

On the other hand, non-technical losses are usually determined at consumer level. What it means is that a balance is made between the energy delivered and the energy billed to the consumers.

TECHNICAL LOSSES
Technical losses are intrinsic to the system and unavoidable. However, they are expected to remain within the range foreseen at the design stage. The analysis of losses constitutes therefore a very important step, as their reduction contributes to the improvement of overall system efficiency.

GENERATION
Losses in the generating system can only be determined on basis of the net output of the units, provided that the inputs are known. In general, losses in generating units are determined according to the deviation of the actual power output from the originally foreseen and may vary according to the type of plant under consideration.

In case of thermal power plants, higher fuel consumptions for same output are an indication of a reduction in overall efficiency. The causes may need to be investigated in detail in every specific case.

For hydroelectric plants, losses are determined on basis of higher water requirements for same power output. The losses, which may be due to increased hydraulic losses in water conduits or wear of the turbine elements, may be quantified also on basis of the deviations from design levels.

TRANSMISSION
Provided that reliable information is available, transmission losses are determined for every reach as a balance between power input and output on both ends of each line. Therefore, total system losses are determined as an addition of losses in every reach.

DISTRIBUTION
Distribution losses, both technical and non-technical are normally the largest in an interconnected system. Their control is always difficult due to the length of the lines and coverage of the networks.

However, distribution losses should be considered in the planning process, as they require an additional output from the generating plants to ensure that the power reaches the consumers.

OTHER LOSSES
Other losses are basically so-called non-technical losses which occur in the administration process of the power utility. These are caused by many reasons, which mainly include:

- Improper metering systems
- Unpaid bills by consumers
- Theft

The statistics on non-technical losses are inferred on basis of data regarding energy supplied and billed to the consumers. Information on the subject is usually available and can be obtained through commercialization departments of power utilities.

4.2.4.6 COSTS
Investment and operation costs are incurred at various levels and stages to ensure the proper functioning of power utilities. This information is a primal input for planning activities, as an objective of this work constitutes the minimization of costs.

The statistics on costs is not always easily available, especially in developing countries. Reasons for these difficulties are many, but the basic cause may be traced back to deficient administration and management.

The planner should be aware of the difficulties in order to be in the position to critically evaluate the information available. In any case, any comparison made should be on the same basis, which implies uniformity in assumptions with regard to the dates of the costs, exchange rates for foreign currencies, etc. The task may no be easy if the information has been collected and processed with different criteria, investment projects have been constructed over longer periods of time due to unexpected delays, financing has been available from various sources and under different conditions, etc.

Other problems arise during high inflationary periods, especially if the economy is affected by governmental intervention. It turns out to be very difficult to determine the real cost of the inputs (goods) needed, as these may be affected in a different manner by the adopted measures. Besides, exchange rates of foreign currency may be artificially fixed to control inflation, leading to distortion in prices of imported goods.

In any case, efforts have to be made to ensure that reliable and comparative information is available, which implies that special provisions in terms of time and manpower have to be made to ensure that the data used fulfills the requirements.

GENERATION
Generation costs have three basic components:

- Investment
- Production
- Operation and maintenance

Investment costs are those incurred for the construction and commissioning of the power stations.

Production costs apply basically to thermal power stations, as these costs are associated with the inputs needed, basically fuels, for power generation.

Operation and maintenance (O&M) costs are associated with manpower and materials needed to ensure that the power stations produce electric energy during their useful life with acceptable efficiency and reliability.

TRANSMISSION
Transmission costs basically comprise:

- Investment costs
- Operation and maintenance

Both types of costs should include both lines and substations forming part of the transmission network.

DISTRIBUTION
Distribution costs basically comprise:

- Investment costs
- Operation and maintenance

TARIFFS
The analysis of existing tariffs should be included as part of the planning efforts. The information provides insights into various aspects of the power utility, such as:

- Effect of pricing on the demand growth (Elasticity of demand) in various sectors of the economy.
- Capability of the power utility to cover the foreseen investments through revenues from the sale of electric energy.
- Suitability of pricing scheme in the context of the national economy.

Tariffs have always a political component, which in many cases leads to distortions caused by subsidies, special financial arrangements, etc. Therefore, the planner should be aware that adopted rates do not always reflect the market value of electric energy.

STRUCTURE
The tariff structure is adopted according to the nature of consumers served. These mainly comprise:

- Domestic
- Commercial
- Industrial, including agro industry
- Agricultural
- Public sector

Subdivisions may be adopted for each one of above according to geographical location, political aims, etc.

SPECIAL CASES

Special cases may occur in the exchange of bulk power and energy with other power utilities. Prices may be adjusted according to amount, season, time of the day, power and voltage level, type of energy (hydro or thermal), place of delivery, etc.

4.2.5 POWER MARKET STUDIES/DEMAND FORECASTING

The power market studies are foreseen to provide information from the side of the consumer, indicating past, present and expected future consumption patterns.

When dealing with existing systems, this information is always available in the electric power utilities and normally is officially published. Complementary data regarding the national economy, such as Gross National Product, may be collected from governmental offices.

In case of rural electrification, scattered information may be available from the areas of interest. The data probably available relates to population growth and some other basic statistics. Therefore, special efforts are frequently needed to collect appropriate data which can then be used for demand forecasting purposes.

The chapter will concentrate on the analysis of the available data, needs for additional data and procedures to carry out short and long-term demand forecasts.

4.2.5.1 POWER MARKET

Power market surveys should be able to provide sufficient information on the power and energy requirements of the consumers. The idea behind power market studies is the determination of the potential for power consumption.

STRUCTURE

Under demand structure are meant the different types of consumers, which basically may comprise:

- Domestic
- Commercial
- Industrial
- Agriculture
- Public
- Special uses

Domestic consumers are located in inhabited areas, including urban and rural communities. Energy is required mostly for lighting, cooking, ironing of cloths, heating and cooling, etc. In more developed societies as well as in high income groups in developing countries, power may also be used to move small motors in the households, such as small water pumps, wash machines, etc.

Industrial consumers may be located both in urban and rural areas. The energy is used for productive activities. The type of industrial requirements depends on the degree of development. In developing countries, agro-industry is always an initial requirement. Other applications are then implemented in accordance with the development.

Strictly agricultural applications basically comprise water uses for irrigation and drainage.

The consumption of the public sector in urban and rural communities has a significant component through street lighting. Other uses comprise the lighting and other uses in public facilities such as schools, hospitals, governmental offices, etc.

Special uses, which may be treated as special loads according to their relative importance with respect to the overall system demand, comprise applications such as mining, etc.

SEASONAL VARIATION

Consumption of energy in general is affected by natural and human factors. The degree on which each of this factors influences the consumption patterns is determined by uses given to energy, the living standard of the consumers, the availability of energy sources in terms of quantity and cost, etc.

With respect to natural effects, power demand varies with time, and main patterns are as follows:

- Seasonal variations, which are in most of the cases influenced by the climate.
- Weekly variations, which are due to the occurrence of working days and weekends
- Daily variations, affected by the availability of daylight, influence the activities of the consumers

The seasonal variations may influence the consumption patterns in following ways:

- Shorter and cooler days in winter may induce to use electricity for lighting during longer periods. Electricity may also be used for heating purposes.
- Longer and hotter days in summer may imply a less use of power for lighting but an increased consumption for cooling purposes.

The weekly variations are basically related to productive activities. Normal patters are as follows:

- Power consumption increases from the fist working day, reaching a maximum in the middle of the week.

- Power requirements are relatively low during weekends.

Demand also decreases during holidays. However, these do not occur regularly and need to be treated separately.

The daily variation of loads is related to the availability of daylight, which affect the human living and working habits. The natural trend is to begin the day with the sunrise and to rest a few hours after sunset. Some variations may exist according to the location with respect to the latitude (distance from terrestrial Equator), climatic conditions, etc.

Besides the natural phenomena, consumption patterns may also be affected by energy pricing.

GROWTH PATTERNS

Naturally, demand growths due to higher individual consumption, increasing number of consumers, industrial development, implementation of special projects, etc. However, due to the deterioration of the national economy due to internal and external factors, the growth may be slowed down or even decreased.

A typical case in developing countries is the restricted growth due to lack of capacity of generation and/or transmission systems. If the supply is not available, the demand will stagnate until new capacity is added. Statistics of demand clearly show the irregular pattern, with some periods of slow growth followed by periods of extraordinary development.

The other extreme is the case of rural electrification in areas in which the service is introduced for the first time. In this case, statistics are not available and the demand may be estimated on basis of comparison with other communities.

4.2.5.2 SHORT-TERM FORECASTING

Short-term forecasting is required basically for system operation planning and is expected to reflect long-term, seasonal, weekly and seasonal variations of the load. The data is normally available in terms of hourly records (time series) of active power.

Long-term variations in this context refer to growth trends, which in statistical terms may be considered as instationary effects (1). The time series become stationary after the trend id removed.

Seasonal effects may be related to climatic changes throughout the year and may be caused by power needs for heating and cooling, lighting, etc.

Weekly variations are simple to identify as they are associated to the distribution of working days and weekends throughout the week. Some special consideration should be paid to holidays.

In the same manner, the variation of the load during the day is usually well known and is represented in terms of the daily load curves, in which the load is plotted against time for every hour of the day (Fig. 4-1). The adopted values are determined on basis of the recorded generation at the power stations and therefore include already the system losses.

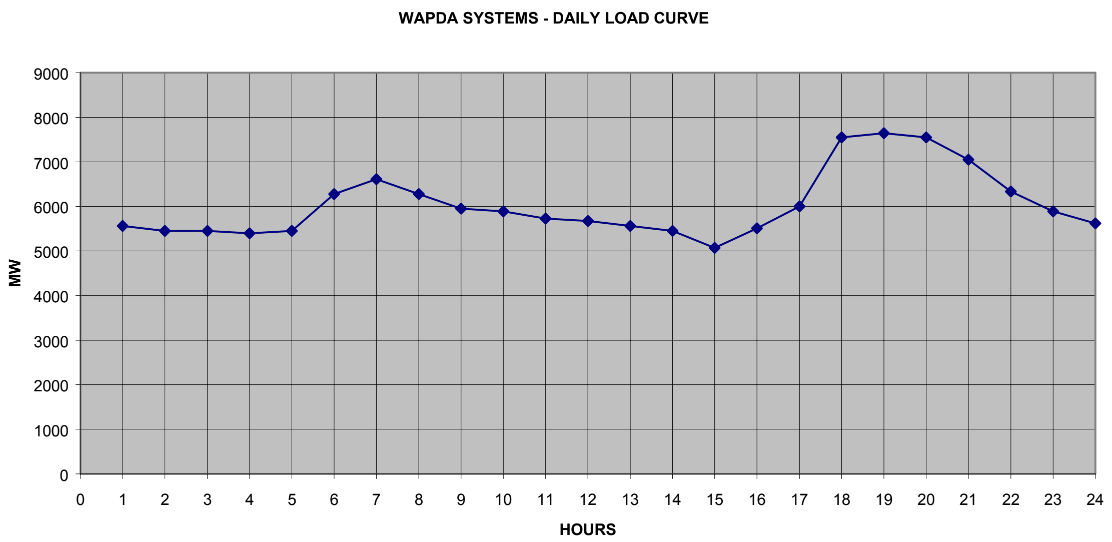

Fig. 4.1 Daily Load Curve

In this respect, the daily load curve for systems having deficit of supply is not representative of the real demand. The power demand is restricted by the availability of the generating units and does not correspond to a natural consumption pattern. Therefore, an analysis of time series, with consideration of seasonal, weekly and even daily variations of the load, may not give adequate information.

Other problems requiring special considerations in developing countries are interruptions of service (partial or total blackouts) due to poor system stability and/or unforeseen external acts, such as natural disasters, war and terrorism. This last sociopolitical phenomenon has been a serious obstacle for a reliable power supply in various countries of the world.

The available data should be carefully analyzed to identify the basic reasons for abnormal behavior of the load. The statistics and/or derived parameters and models for demand may need some adjustments to avoid unreasonable forecasts. In simple terms, blackouts are not forecasted and should therefore be removed from the statistics.

METHODS
There is a large number methods used for short-term load forecasting, which vary according to system characteristics, balance between supply and demand, data availability and experience of personnel.

The spectrum begins with simple empirical methods, which include:

- Extrapolation of loads recorded the previous day.
- Extrapolation of loads recorded the previous day and the same weekday the previous week.

Statistical methods are based on the analysis of time series and may consider two basic types:

- Regression models, which may be based on the correlation of various independent variables.
- Autoregressive models, which are based on the recorded load data.

Regression models are used when external phenomena, such as climate, have a significant effect on the demand. Parameters such as temperature, cloud cover, etc., may be correlated with the recorded loads to forecast future demand. However, reliable weather forecasts are needed to apply these models.

Autoregressive models are applied when the available statistics are sufficiently adequate to forecast the loads. Among the various methods available, in practical applications of load forecasting following are best known:

- Decomposition, which considers the decomposition of the time series in its various components, which include:
    - Trend
    - Cyclicity
    - Weather dependence
    - Randomness

- ARMA (Auto Regressive Moving Averages) are also very popular due to the availability of ready-made computer models.

LOAD CHARACTERISTICS
Characteristics in this case imply both magnitude and distribution in time and space of the load.

LOAD FORECAST
Load forecasts in WAPDA are based on empirical methods, on basis of recently recorded information. On one hand, an important obstacle to use more sophisticated techniques has been the difficult accessibility of the data. Until recent months, it has been rather cumbersome to obtain time series of hourly loads for the whole system. Most of these problems will be solved with the commissioning in 1990 of the National and Regional Control Centers.

On the other hand, due to the increasing power deficit and corresponding load shedding, the demand forecasts are basically estimates. This applies especially to the peak loads, which cannot be covered due to above reasons.

The added generation of all power stations in the system provides only an indication of the capabilities of the system. Therefore, a demand forecast in this case is required to establish load-shedding strategies, and this has been the use given to the estimates made in recent months.

4.2.5.3 MEDIUM AND LONG-TERM FORECASTING

Medium and long-term forecasts are prepared according to the type of analysis and data requirements of models to be applied. Therefore, the normal case is to make these forecasts on monthly and yearly basis.

METHODS

Methods for medium and long-term forecasting may vary from simplified projections of past growth patterns to sophisticated models, which take account of the interactions between all sectors of the economy. However, due to availability of data some differences exist between the methods used for rural areas as compared to large interconnected systems.

The analysis for rural areas follows a rather special approach due to the lack of historical data on electricity demand. In this case, population growth becomes a pivoting value which combined with targets regarding electrification coverage is used estimate the demand. Fig. 4.2 shows the flow chart of a method used for demand forecast in rural areas in North-Pakistan according to the method used by SHYDO-GTZ.

Interconnected systems rely more on available data. However, the problems of restricted growth due to limited supply as well as unserved power and energy have to be properly accounted for.

The best known methods can be classified as follows:

- Trend extrapolation
- Regression models on basis of econometric parameters
- Input-Output models

Trend extrapolation is based on the analysis of generation data, from which the expected growth patterns are derived and/or assumed. The procedure is well known and widely applied due to its simplicity. As an example, Figure 4-3 shows a forecast of power and energy demand for WAPDA system, on basis of assumed annual growth rates, for the period 1986-2010.

Regression models on basis of econometric parameters are used basically for small and large systems.

The application of the method for larger systems is made normally according to the following three steps:

- Considering past electricity demand as the dependent variable, macroeconomic parameters, such as GNP, are assumed as independent variables.
- Regression analyses are carried out to determine the goodness of various models.
- After selection of a model, electricity demand is forecasted on basis of predicted macroeconomic parameters.

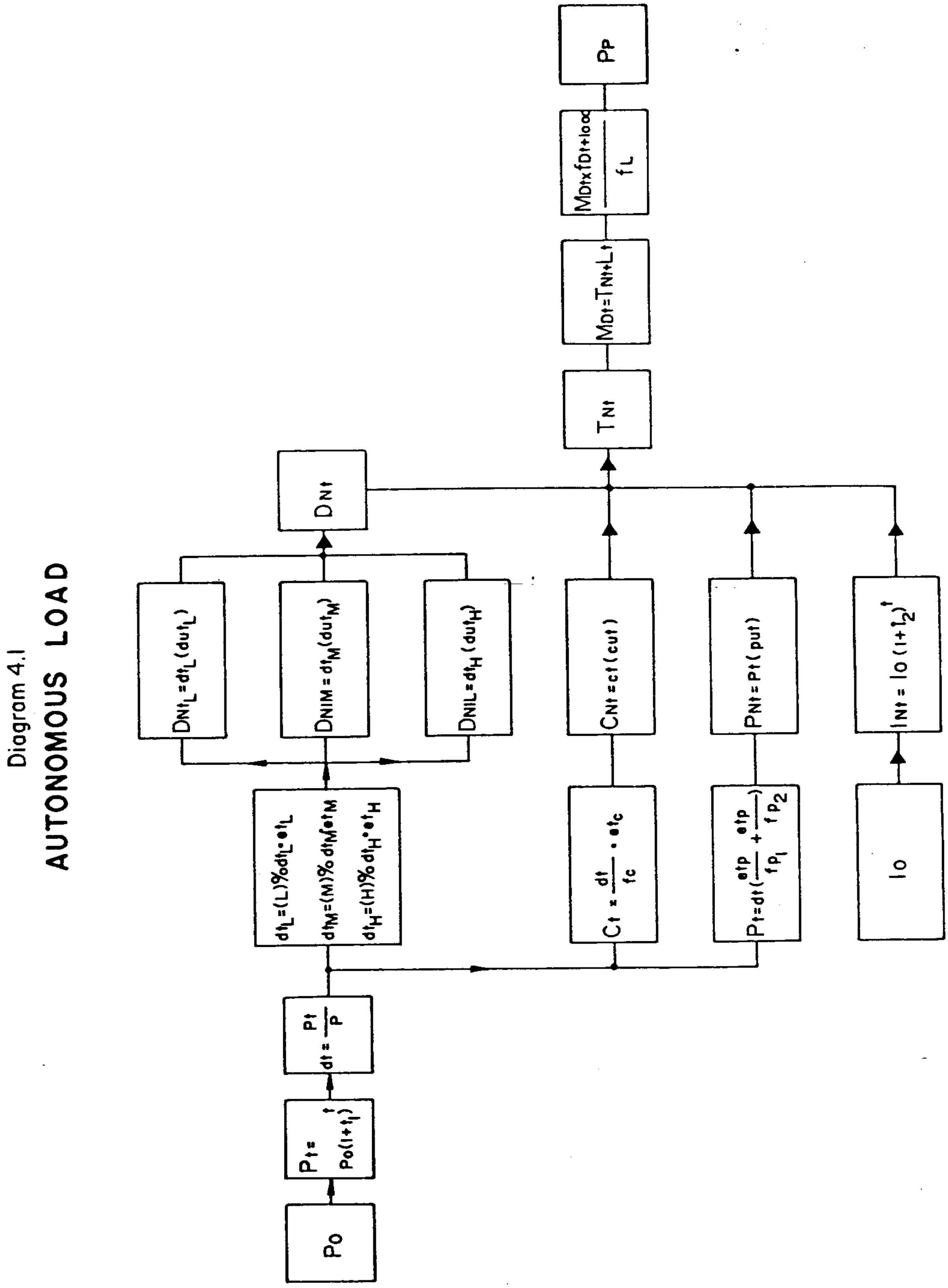

Fig. 4.2 Flowchart of method used for demand forecast in rural areas

Input-Output models have been applied in industrialized nations in the past and in Pakistan in recent years (3). These are the most complex models applied and require a large amount of data. Besides their complexity, these models require data of a certain degree of reliability which is difficult to obtain in developing countries.

POWER AND ENERGY DEMAND FORECAST
In WAPDA, a preliminary analysis of power and energy demand forecasts is shown in Figure 4-3. In general, it is expected that losses will reduce and overall system efficiency will improve in the future.

The growth rates in future are reduced stepwise for both power and energy. However, the load factor is kept constant.

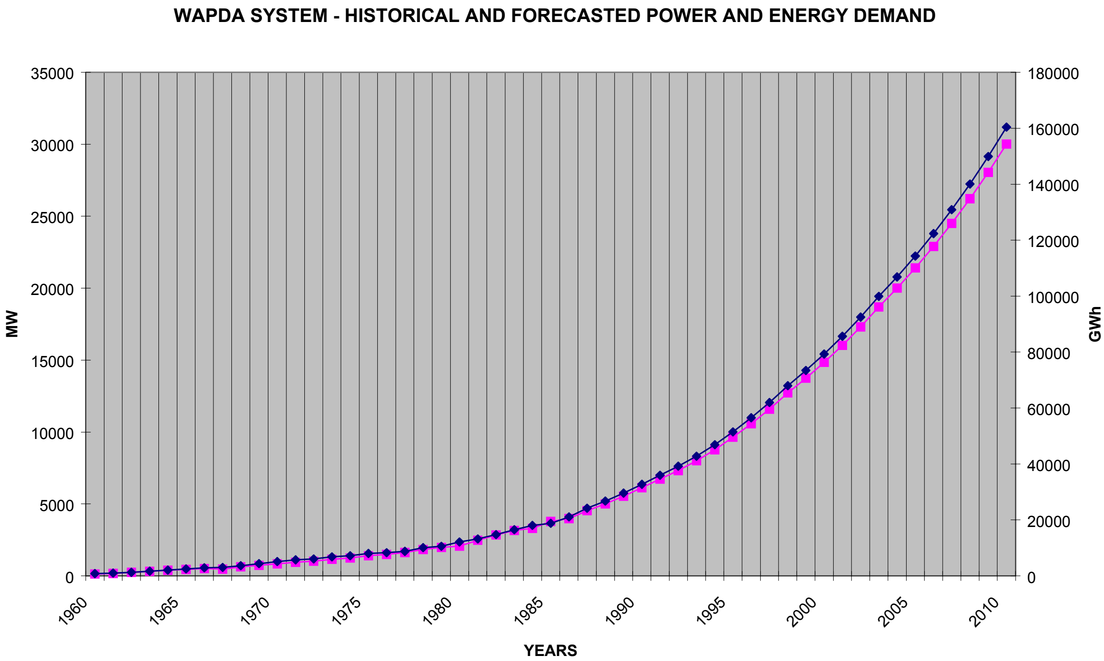

Fig. 4.3 WAPDA System – Historical and Forecasted power and energy demand

REFERENCES

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4.2.6 RESOURCE EVALUATION
The evaluation of resources comprises the improvement of existing facilities as well as the implementation of new projects. In any case, investments are required to increase the generating

capacity of the system. Therefore, an adequate evaluation can only be possible if realistic cost estimates for different plant types are available.

4.2.6.1 EXISTING SYSTEM

The first step in the evaluation of available resources should begin with the existing facilities. In this respect, the planner should evaluate the following:

- Is the system optimally used?
- Is operation of the units still economical?
- Is operation sufficiently reliable?

Decisions need to be met with regard to the expenditures needed to keep the system running. These may comprise among others;

- Programmed maintenance costs
- Operation costs, especially for thermal plants
- Repair costs

RETIREMENT OF OLDER UNITS

Old units may be retired if their operation is not economical as compared to other alternatives. Uneconomical operation may occur due to:

- High operation costs of thermal power stations due to wear of certain components
- Special repair requirements to keep the units running
- Special measures needed to protect the environment which may require the addition of new components

REFURBISHING/REHABILITATION

Refurbishing or rehabilitation of power stations can take place in many ways, which depend on:

- Type of power station (hydro or thermal)
- Aging
- Operational requirements

Hydroelectric power stations are mostly affected by the wear of hydromechanical equipment due to sediments, and cavitation. Both basically attack those parts in contact with flowing water. Erosion due to abrasive sediments and cavitation mostly affect turbine runners, wicket gates of Francis turbines, nozzles of Pelton turbines, etc. Rehabilitation in these cases may be part of the periodic maintenance, provided that these problems were properly considered at the design stage and may even include the replacement of damaged parts.

However, these problems may become a serious obstacle for the satisfactory operation of the power station if the damage occurs frequently. These conditions may occur due to loss of trapping capacity of reservoir, improper operation of sediment traps, etc., which may lead to a higher flow of sediments into the water conduits.

Other rehabilitations may be related to repair and/or reconstruction of major civil works, such as dams, tunnels and powerhouses. The magnitude of these investments normally exceeds those required for the hydromechanical equipment.

Thermal power stations, having significantly more mechanical components than hydroelectric plants, are also affected more by wear and fatigue. As a matter of fact, for planning purposes, the useful life of thermal power stations is always assumed less as compared to hydro plants. Additionally, there is a constant technological development in the field which tends to make obsolete available facilities. The decision on the rehabilitation of a thermal power station should be carefully evaluated, taking into account that the cost of generated energy is mostly affected by the fuel consumption, which is directly related to the efficiency of the units.

Aging is a fact of life, which affect both machines and human beings. Obsolescence may be reflected in lower efficiencies of various equipment components, mostly the so-called prime movers, which include turbines and generators. Rehabilitation of these parts, for hydro and thermoelectric plants, may imply the complete replacement of the components. The associated costs should be carefully evaluated to ensure an improvement of the overall operation of the plant.

Rehabilitation of power stations due to operational requirements may be due to some addition to the system, which may help improve the efficiency of existing facilities. This may be the case of constructing a regulating reservoir upstream of an existing hydroelectric plant or the conversion to combined cycle of existing gas turbines.

4.2.6.2 NEW PROJECTS

The typical case in every planning study is to have a list or catalog of potential projects with different level of investigation and study. Some of them may be at a very preliminary level, such as identification, while others at an advanced stage. The reliability of the technical and economical parameters depends obviously on the available information and knowledge about the projects.

When comparing projects, proper account should be taken of the reliability of the information on which they are based. It is always desirable to have a comprehensive and up to date list of attractive projects. These catalogs can be obtained through a systematic identification, evaluation and "screening" of identified sites. The term screening refers to the selection of those attractive sites and schemes, which are recommended for more detailed study and/or implementation.

According to the planning stages of a project, following phases are typically defined:

- Identification/Inventory
- Pre-feasibility
- Feasibility
- Detailed design and tender documents

Each stage in the preparation of a project leads to a more detailed knowledge of the in terms of basic data, layout, characteristics and dimensions of elements, construction sequence and methods, costs and economic feasibility. However, in general terms, following major items are considered.

BASIC DATA

- Available infrastructure
- Climate
- Topography
- Hydrology
- Geology
- Subsoil conditions
- Environment

The processing and synthesis of the basic data leads to the determination of parameters, which may be defined as:

DESIGN PARAMETERS

- Capacity of available infrastructure during construction and operation of the project.

- Effect of extreme climatic conditions in winter and summer, which may affect during implementation and operation of the project.
- Availability of water for hydro power generation
- Design floods
- Seismic risk
- Availability of construction materials
- Permeability of subsoil
- Bearing capacity of the subsoil
- Available reserves, in case of indigenous fossil fuels
- Constraints imposed by the need to preserve the environment, such as air and water quality.

The design parameters are the basis for the definition of layout of the project and dimensioning of elements. Therefore, the results of the engineering works should lead to the determination of the technical feasibility of the project, reflected in a design.

PROJECT DESIGN

- Project layout
- Dimensioning of elements
- Estimation of quantities and costs
- Construction planning, including methods and time sequence

A final aspect in the preparation of a project refers to the determination of the economic and financial feasibility.

ECONOMIC AND FINANCIAL EVALUATION

- Economic evaluation
- Financial evaluation

The technical feasibility of a project is sometimes referred to as the "hardware" aspects of the project. This is due to the fact that the selection of layout and dimensioning of the project have to be made according to available conditions at site, which especially affect the civil work of he project.

The "software" aspects of the feasibility correspond then to the economic and financial evaluation, which is based in many cases on assumptions which are exogenous to the project. These include for example the minimum acceptable internal rate of return, cost of fossil fuels, such as oil, coal and natural gas, in the international market, availability of funds and interest rates, etc.

The degree of detail required obviously increases, from identification until implementation is achieved, according to the different stages of project planning. In the same manner, the time, manpower and human resources invested at every stage need to increase accordingly.

Although not always properly recognized, the identification of potential sites is the most critical stage and requires the maximum knowledge and experience. This applies especially to hydroelectric projects and requires a combined effort of office and fieldwork. The evaluation of identified sites, which most likely will require the analysis of alternatives, should lead to the selection of schemes for more detailed study.

After identification, the selected projects may be taken up for pre-feasibility and/or feasibility studies. There is no clear definition of the scope and detail of each one of these studies and sometimes the pre-feasibility level is omitted to save time. However, international financing agencies, such as the World Bank, Asian Development Bank (ADB), etc., when involved in the financing of these activities usually require to carry out both types of studies.

However, in case of small schemes, the pre-feasibility studies can be skipped and only a study at feasibility may be undertaken. For obvious reasons, taking into account the volume of investments required to implement a small power scheme, the cost of engineering should be minimized.

The results of a feasibility study should provide a clear picture about the technical and economic feasibility of the project. It is expected that all thinkable sites and layouts have been investigated. Characteristics, dimensions and number of project elements have been selected keeping in view the need to find the technically and economically most attractive solution.

The final stage of a project preparation is constituted by the detailed design and preparation of tender documents. The resulting documents, which include specifications, Bill of Quantities (BOQ) and drawings, are the basis for the bidding/tendering process, provided that the project implementation is made on basis of International Competitive Bidding (ICB).

4.2.6.3 HYDROELECTRIC PROJECTS

There are many ways to classify hydroelectric power plants. These may include among others:

- Head available: low, medium or high head
- Pondage : run-of-the river, daily, weekly or seasonal
- Type of service: isolated or interconnected
- Operation and control: manual, semiautomatic or automatic
- Coupled machine: synchronous or asynchronous generator or other type of machine without generation of electricity (small units)

For the purposes of this course, the hydro plants will be classified on basis of the available head as follows:

- Low head, with heads up to 25 meters
- Medium head, between 25 up to 100 meters
- High head, above 100 meters

An exact classification is not possible and the given values may be used as a reference only. Manufacturers tend to make such classifications according to the typical type of turbine which may be used. In this respect, following may be considered:

- Kaplan turbines are used for low head sites
- Francis turbines are typically used for medium size heads
- Pelton turbines are typically used for high head sites.

Charts are available to select the suitable type of hydraulic turbine for the available head and discharge at site. It is evident that for the same output, the size of the equipment increases with decreasing head as higher discharges need to be accommodated through the turbines.

The main aspect concerning hydroelectric projects is that they are site dependent, which means that the schemes should be placed where the potential - head and discharge- are available.

The study of hydroelectric projects begins therefore with the identification of the potential sites. There may be some differences in the approach adopted for high head projects as compared to low head schemes. The basic reason is the nature of each type of project with regard to the availability of resources.

A basic rule of thumb is that low head projects are placed in river or canal reaches with large discharges and small gradient, which are normally available in the plains. Both machines and civil structures have to be designed to accommodate relatively large water discharges. The subsoil is normally formed by alluvial deposits, constituted by clay, silt, sand and gravel.

In Pakistan, these conditions are found within the irrigation system of the Indus River, and the identified sites are mainly related to existing hydraulic structures. The available head is usually associated to existing fall structures, such as barrages and canal falls, constructed to regulate flows, diversions into distributaries and erosion control. The area is mostly inhabited and some infrastructure, including roads and transmission lines is available.

High head projects are identified in areas where the topographic relief is more abrupt and river reaches have steeper gradients. These conditions are found in mountainous areas. Considering that the river catchments are of small and medium size, the discharges are usually not very large. The dimensions of the water conduits and equipment tend to be smaller. However, the length of canals, tunnels and penstocks may be large, depending on the layout.

A special consideration regarding medium and high head schemes should be given to the need of constructing dams for diversion and/or regulation of discharges. The characteristics and dimensions of these structures vary according to the conditions at site and the characteristics of the project.

The height of the dam contributes to the total available head and its dimensioning is highly related to the economic feasibility of the project.

In Pakistan, potential for medium and high head schemes is available in the northern areas of the country, which include sites on main Indus and its tributaries. Large schemes have been identified and recommended for further study. At present, efforts are being made to evaluate the available potential of medium size schemes in the tributaries.

The output of a hydroelectric plant can be calculated using the formula:

$$P = 9.81 * \eta_{(T)} * \eta_{(G)} * Q_{(T)} * H_{(n)} \quad \textbf{(6-1)}$$

where,

P = Power in kW
$\eta_{(T)}$ = efficiency of turbine
$\eta_{(G)}$ = efficiency of generator
$Q_{(T)}$ = turbine flow, in m^3/sec
$H_{(n)}$ = net head, in meters

For preliminary analysis, the average efficiencies of turbine and generator may be assumed as:

$\eta_{(T)}$ = 0.835
$\eta_{(G)}$ = 0.95

Formula (6-1) can be expressed as:

$$P = 9.81 * 0.85 * 0.95 * Q_{(T)} * H_{(n)}$$

$$= 8.2 * Q_{(T)} * H_{(n)} \quad \textbf{(6-2)}$$

More detailed estimates of turbine efficiency may be determined on basis of the efficiency hill charts. However, the proper information should be used for the type of turbine under consideration. These charts are developed on basis of physical model tests in the laboratory and are then adjusted according to the characteristics of the prototype.

The net head available is determined after deducting the head losses from the gross head. The head losses are specific for every plant and should be determined accordingly. Some typical values may be used for roughness coefficients in water conduits, as well as for local losses at intakes, valves, etc.

LOW HEAD

These projects are constructed at sites where discharges are relatively high. This technology has been widely developed in Europe, allowing to harness the hydroelectric potential of rivers such as Danube, Rhine, Rhone and others.

Originally, the sites were equipped with so-called Kaplan turbines with vertical axis. A typical layout for this turbine type is given in the literature. The water flows into the turbine spiral, which helps to direct the flows towards the turbine runner.

The aim to increase the efficiency of the generating units associated with the need to reduce costs of civil works concluded with the development of machines with horizontal axis. The idea is to minimize the changes in flow direction to reduce head losses within the turbine. The typical machine is the so-called bulb-turbine. The turbine and generator are directly coupled and rotate at the same speed.

There are also variants of the classical bulb turbine which have been developed to overcome some of the problems which may occur under certain circumstances. The pit-type turbine offers more space inside the bulb. Turbine and generator are coupled through a speed increaser, allowing the utilization of high speed generators.

The available area for the water flow around the bulb and pit-type turbines is basically the same for units of the same size. The reduction in the diameter of the bulb in case of the pit-turbine is compensated by an access shaft of larger size.

The STRAFLO (STRaight FLOw) is a turbine of special design in which the generator rotor is mounted at the outer side of the turbine blades. Presently only one manufacturer in the world has patented this turbine type. The space requirements for these turbines are smaller as compared to bulb and pit-type turbines. However, some problems may occur with the sealings in rivers with high sediment content.

According to the flow regulation, the low head turbines can also be classified as follows:

- Double regulated, both wicket gates and rotor blades can be adjusted to achieve maximum efficiency.
- Single regulated, either the wicket gates or the turbine blades can be adjusted.
- Without regulation, both wicket gates and rotor blades are fixed.

Ideally, all turbines should be selected as double regulated as these allow a proper adjustment of the units according to available head and discharge. However, the cost of these units is higher as compared to the other types of turbines.

Low head turbines can achieve some degree of standardization for given head ranges. In other words, a turbine of certain size can be selected for a head range and the number of units is varied according to the discharge available at every site. This may is being considered in Pakistan for the development of heads available at various fall structures within the irrigation system.

With regard to the net head available for power generation, these stations are very sensitive to head losses and require therefore a uniform water flow towards the powerhouse. Head losses are mainly concentrated at the entrance, basically the trashracks.
Other important aspect to be considered when calculating the output of a low head power station is the effect of discharges in the tail water levels of the plant. The use of a dry year as most adverse scenario to determine the power output may not give a clear picture about the limiting operational conditions and output of the station. Higher discharges through the turbines cause an increase in the tail water levels, reducing the available head.

The effect of the hydrologic regime on a low head power station should be evaluated taking into consideration the combined effect of head and discharge. Therefore, for low head stations on rivers, the power and energy output should be estimated for dry, wet and medium years.

In the same way, the daily operation of the station may have an effect on the total energy output during the year. Provided that some regulating capacity is available, the station may be operated to supply some peaking capacity. The increased power during the peaking periods may result in a reduced annual energy output due to the loss of head caused by higher tail water levels. Generating the maximum capacity under these conditions requires the release of larger water volumes through the turbines.

The civil cost of a low head power station is site dependent and should be calculated for every scheme according to the selected layout.

MEDIUM AND HIGH HEAD
The layout of medium and high head projects are strongly site dependent and can seldom be standardized.

High head power stations are less sensitive to head variations, but their power and energy output may be affected by the discharges.

Medium head plants, if operated with a seasonal reservoir, are very sensitive to head and discharge available. Typical cases in Pakistan in this respect are the power stations at Tarbela and Mangla.

For planning purposes, the availability of power and energy from a hydro power station is defined according to the reliability as follows:

- Firm power and energy, guaranteed 100% of the time. This output is available under the most adverse hydrologic conditions, which may occur during a dry year.
- Secondary or non-firm power and energy, available during average and wet years.

The impact of the hydrologic regime on the output of a power station depends on the variability of flows and the available regulating capacity. Therefore, these analyses are made on basis of time series of flows to determine the effect of sequences of wet and dry periods on the reservoir.

The firm output of a power station with a seasonal reservoir is determined on basis of the so-called "critical period analysis", which implies the identification of the worst sequences of flows during a certain period of time which empty the reservoir. The firm output is determined from this analysis in terms of water releases which can be guaranteed all the time, even during the period in which the reservoir reaches its minimum level. Obviously, the reservoir is expected to recover after reaching its lowest level.

Reaction turbines, such as Francis, are normally used for medium head sites, although in recent years these units have been used for higher heads.

Impulse turbines, such as Pelton, are installed at sites with large heads.

SMALL HYDRO
Small hydroelectric developments, similarly to the larger schemes, should also be subdivided according to the available head.

There is a large variety of turbines which can be used for small head, small hydro schemes. The selection of the turbine type depends on the site conditions and head available.

There is no universal definition to classify power stations as small. Following table gives some idea of the criteria adopted in other parts of the world:

Country/Organization	MICRO	MINI	SMALL
Austria			0 – 5000 kW
USA	0 - 1500 kW		1500 – 15000 kW
UNIDO	0 - 100 kW	101 – 2000 kW	2001 – 10000 kW
Sweden	100 – 1500 kW		
China			6000 kW/Unit
OLADE	0 – 50 kW	51 – 500 kW	501 – 5000 kW
Pakistan			5000 kW

In Pakistan, sites with installed capacities up to 5 MW are classified as small and are therefore considered for the electrification of local areas.

4.2.6.4 THERMOELECTRIC PROJECTS
FUELS
From the viewpoint of energy conversion, when dealing with thermal generation there are two general categories of fuels:

Fossil fuels
Nuclear fuels

FOSSIL FUELS
There are three general classes of fossil fuels:

- Coal
- Petroleum
- Natural gas

Other fuels, such as shale oil, tar-sand oil and fossil fuel derivatives are somewhat different but are always considered as fossil fuels.

All fossil fuels were produced from fossilization of carbohydrate compounds. These compounds, with the chemical formula Cx(H2O), were produced by living plants in the photosynthesis process as they converted direct solar energy into chemical energy. Most of fossils were produced during the Carboniferous Age of the Paleozoic Era, some 325 million years ago. After the plants died, the carbohydrates were converted by pressure and heat, in the absence of oxygen, into hydrocarbon compounds with a general chemical formula CxHy.

COAL
Coal is the most abundant fossil fuel and is thought to be originated by fossilized vegetation. It is estimated that approximately 6 meters of compacted vegetation were necessary to produce a 30 cm. seam of coal. The vegetation is converted into coal through pressure and temperature. As the

aging process progresses, the coal becomes harder, increasing the carbon contents and decreasing the moisture content. The stages may be summarized as follows:

- Compacted vegetation
- Peat, which is a very low grade fuel
- Brown coal
- Lignite
- Sub bituminous coal
- Bituminous coal
- Anthracitic coal

There are a number of coal properties that should be considered when selecting a coal for a given application. Among these properties, the most important are

- Sulfur content
- Burning characteristics
- Weatherability
- Ash-softening temperature
- Grindability
- Energy content

While sulfur is one of the combustible elements in the coal and generates energy, the primary combustion product, sulfur dioxide (SO2) is a major atmospheric pollutant. It is difficult and expensive to remove the sulfur before the coal is burned or to remove the sulfur dioxide from the combustion products. It is important for the coal to have low sulfur content, not more than 1%.

The coal must be selected according to the combustion system to be adopted. A free burning coal tends to break apart as it burns, exposing the unburned coal to the combustion air. A caking coal produces a fused coal mass as it burns so that much of the fixed carbon does not burn. A high value of free swelling index for a given coal normally indicates that the coal is a free burning coal.

The weatherability is a measure of the ability of the coal to withstand exposure to the environmental elements. If the coal crumbles severely during storage, the small particles may be washed away during rainstorms, producing monetary losses and environmental pollution.

The grindability index is inversely proportional to the power required to grind the coal to a certain fineness. The anthracitic coals, because of their hardness and the lignitic coals because of their plasticity have low grindability indexes.

The ash softening temperature is the temperature when the ash becomes very plastic, below the melting point of the ash. High ash temperatures are desirable when the ash is handled as a solid.

The energy content or heating value of a coal is the amount of chemical energy in a given volume of fuel. This may be expressed in British Thermal Units per pound-mass (Btu/lbm) or kilojoules per kilogram (kJ/kg).

PETROLEUM

Petroleum has been widely used in industrialized and developing countries as an energy source, even when indigenous oil was not available. However, the oil crisis originated after the embargo in 1973 and recent developments in the Persian Gulf have led to a review of energy. The economic dependence and consequent impact in the economy originated by price escalation is a major source of concern in oil importing countries.

The largest oil reserves in the world, as of 1990, are as follows (values in billion Tons):

Saudi Arabia	-	43.4
Kuwait	-	13.5
Irak	-	13.4
U.A.E.	-	12.9
Iran	-	12.7
Venezuela	-	8.2
USSR	-	7.9
Mexico	-	7.7
USA	-	3.5
China	-	3.2
Libya	-	3.0
Nigeria	-	2.2
Norway	-	1.6
Algeria	-	1.2
Indonesia	-	1.1
India	-	1.0

Petroleum is thought to be originated by partially decomposed marine life. Petroleum or crude oil is normally found in large domes of porous rock. Depending on the type of residue left after the lighter fractions have been distilled from the crude, three categories have been defined:

- Paraffin based crudes
- Asphalt based crudes
- Mixed based crudes

The composition of crude oils is fairly constant, with following distribution

Carbon :	84 to 87%
Hydrogen :	11 to 16%
Oxygen plus Nitrogen :	0 to 7%
Sulfur :	0 to 4%

There are six commercial grades of oil as follows:

Nr. 1 : lightest and least viscous oil used for vaporizing burners
Nr. 2 : general purpose domestic heating oil
Nr. 3 : no longer commercially available
Nr. 4 : heating oil which can still be pumped without heating at moderate temperatures
Nr. 5 : heavy and viscous oil
Nr. 6 : also known as "Bunker C" is the heaviest and most viscous

Both Nr.5 and Nr. 6 fuel oils require heating before pumping.

The most important properties of petroleum and petroleum derivatives are:

- Heating value
- Specific gravity
- Flash point
- Pour point

The heating value of petroleum is given as a function of the specific gravity. Therefore, the heating value on a unit mass basis increases as the specific gravity decreases or as the API grade (American Petroleum Institute) and Be grade (Baume) increase.

The specific density is expressed as the ratio between the density of the fluid and the density of water. The specific gravity of petroleum is normally expressed in API of Be units. The relationship between the specific gravity s and these the units is:

$$S = \frac{140}{130 + Be}$$

$$S = \frac{141.5}{131.5 + API}$$

In both cases water has a gradation of 10 and the specific gravity is inversely proportional to Be and API values.

The flash point of a liquid fuel is the minimum fluid temperature at which the vapors coming from the fluid surface will just ignite.

The pour point of a petroleum product is the lowest temperature at which the oil or oil product will flow under standard conditions. It is determined by finding the maximum temperature at which the surface of an oil sample in a standard test tube does not move for 5 seconds when the tube is rotated to the horizontal position. The pour point is equal to this temperature plus 5 degrees Fahrenheit.

Oil has various advantages over coal when burned. Oil is cleaner and easier to handle, store and transport. It is also easier to burn and has little ash.. However, there are some problems encountered in the combustion of fuel oil. Although there is little ash produced, it is difficult to remove. Some crudes have a significant sulfur fraction and although it can be removed before the oil before it is burned, it is an expensive process. Another problem element found in some crudes is vanadium. Vanadium oxidizes during combustion to vanadium pentaoxide ($VaO5$) and this compound causes rapid corrosion of ferrous materials found in most boilers.

GASEOUS FUELS

Almost all gaseous fuels are either fuels or byproducts of fossil fuels. These fuels can be divided intro three categories:

- Natural gas
- Manufactured gas
- Byproduct gas

Natural gas is the only true fossil-fuel gas and is usually trapped in limestone casings on the top of petroleum reservoirs. Natural gas is primarily composed of methane with small fractions of other gases.

The combustion of gas has several advantages as compared to coal and oil.:

- It is probably the easiest fuel to burn and mixes well with air.
- Burns cleanly with little ash.
- Transportation is easy either through pipelines or as liquefied gas (LNG)

One disadvantage is the difficulty to store in large quantities. Some companies have even tried to store gas into large underground cavities.

There are various manufactured gases, such as:

- Liquefied petroleum gas, produced from petroleum distillates, primarily propane and butane.
- Water gas, produced by passing air and steam through a bed of incandescent coke.
- Producer gas, formed by burning low grade coal seams in situ with insufficient air for complete combustion.
- Blast furnace gas, which is a low quality gas which is a byproduct of the steel industry. It is basically produced by burning coal with insufficient air.
- Sewage gas, composed essentially of pure methane, is produced from vegetable and animal wastes.

NUCLEAR FUELS

STEAM PLANTS

Hydroelectric plants are subject to seasonal and multiannual fluctuation of streamflows. The severity of these fluctuations depends on the main source of runoff. Therefore, to ensure a continuous service in some systems, a complementary generation from thermal power stations becomes necessary. The amount and characteristics of the generation in a given interconnected network will depend on the generating capabilities of different plant types feeding the system.

Hydroelectric plants are normally designed and constructed to cover medium and peak load. Base load is generally covered with steam power stations burning fossil fuels. Alternatively, nuclear power stations may also be considered.

When selecting a site for a thermal power plant, following may be considered:

- Availability of fuels
- Disposal of residuals
- Subsoil and land conditions
- Availability of water
- Transportation facilities
- Availability of labor
- Environmental aspects
- Size of the plant

The availability of fuels, either indigenous or imported, plays an important role in the selection of a site for steam power plants. Sites have been selected basically keeping in view the need to reduce costs of operation and transmission. Considering the large amounts of fuels consumed by steam plants, the selected sites are close to the source of fuels.

Disposal of residuals becomes an important aspect when dealing with coal fired plants. The production of ashes may become a difficult problem to handle when the size of the plant increases.

The selected site should have proper bearing capacity to permit the construction and operation of the plant, especially under dynamic (seismic) loading. The land should be also safe against natural disasters, such as floods, landslides, etc. The land should be sufficient to accommodate the plant itself, fuel storage (especially in case of coal fired plants) and colony for personnel.

Large quantities of water are required for condensers, feed water to the boiler, drinking water for the personnel and for the disposal of ashes in case of coal fired plants when hydraulic systems are used. It is therefore required to locate the plant near a source of water which can ensure supply throughout the year.

Proper transportation facilities are needed during construction and later operation of the power plant. Railway lines and roads may be used to transport heavy parts of the plant during the construction period. Proper means of transportation should be considered for the supplies of fuels when the power station is not located near the mine in case of coal or field in case of oil or gas.

Different types of labor force are needed for construction and operation of thermal power plants. Due to their nature, these plants are more sophisticated than hydro stations, requiring qualified personnel to ensure adequate operation and maintenance.

The environmental impact of thermal power station is becoming a serious consideration al over the world. The so-called "green house effect" produced by the emission of CO_2 into the atmosphere has gained great relevance in recent years. Other problems regarding the contamination of the air are related to the increased utilization of coal, especially when sulfur content is high. Other air pollutants besides SO_2 originated in the combustion process are Nitrogen Oxides (NO_x), which are believed to contribute to acid rain problems throughout the world.

In the same manner, the disposition of ashes in case of low grade coals may become an unpleasant source of environmental pollution if not properly handled. The ash is dusty, which makes it difficult to handle, it is hot when discharged from the boiler furnace and may produce poisonous gases and corrosive acids when mixed with water.

The magnitude of the problems faced with the selection of a proper site for a steam power plant is proportionally related to the installed capacity. For smaller size plants, the supply of fuel and water as well as the disposition of residuals may be possible without incurring major costs.

GAS TURBINES

Gas turbines have been known for many years and constitute a very attractive alternative for power generation due to their reliability, freedom from vibrations and ability to produce large powers from units of comparatively small size and weight.

A rapid progress in the development of gas turbines was achieved mainly due to industrial and military needs. One important field of application is in aviation industry, playing a crucial role in the development of modern aircraft. As a matter of fact, the use of gas turbines for power generation is more recent than its use in other fields.

Fast development has been observed in the development and improvement of gas turbines for electric power generation. The development has been mainly with regard to:

- Increase in units capacity, up to 100 MW
- Improved efficiency
- Reduction in cost

Although relatively high in generation cost as compared to other types of power stations, gas turbines are constructed due to their relatively low capital cost, high reliability and flexibility of operation.

DIESEL UNITS

Diesel units are limited in their capacity up to 50 MW and are therefore attractive only to cover small to medium loads.

The diesel plants are more versatile and efficient than any other heat engines of comparable size. Investment costs are comparatively low and the units can be started quickly and brought into service. Diesel units can burn a fairly wide variety of fuels and manufacturing periods are relatively short.

In practice, following uses are given to diesel units:

- Supply of isolated load centers
- Peak load plants, in combination with hydro and/or thermal units
- Mobile plants, for temporary power supply
- Stand-by units, as backup to normal supply
- Emergency plants, when power interruptions may cause damage and/or financial losses
- Starting units, to run the auxiliary equipment of large steam or hydraulic units

Diesel units have been extensively used for rural electrification throughout the world and are now being considered in Pakistan by various industrial groups to cover their electricity demand during the periods of load shedding.

The operation of diesel units is relatively simple and most of the problems appear with the logistics for the supply of fuel and spare parts. These problems become extremely acute in rural areas, especially when the climatic conditions obstruct the access roads.

4.2.6.5 NON-CONVENTIONAL (SOLAR, WIND, WAVES, ETC)

The most important sources are:

- Geothermal
- Tidal
- Wind
- Solar
- Direct energy conversion

4.2.6.6 NUCLEAR

The discovery of the fission of uranium was of tremendous importance as it opened the prospects of using the energy stored in the atomic nucleus for the production of electric energy. Presently, nuclear energy is intensively used in various industrialized nations to produce electric power. Present estimates indicate that fissionable uranium alone contains far much energy than coal and petroleum together.

A special feature in nuclear energy is the high degree of concentration of energy, which exceeds by far that of conventional fossil fuels. For example, one kg of uranium is equivalent to 20 million kWh of heat energy or 2000 Tons of high grade coal.

There is an international controversy about providing nuclear technology to developing countries. Nuclear energy becomes almost inevitable for developing nations with relatively large systems when other sources of generation (hydro and fossil) are inadequate or scarce.

A nuclear power plant can only be economic if a base load operation of at least 75% can be ensured. A proper mix of generating power in interconnected systems, when the available resources permit, should be developed on basis of hydro, thermal and eventually nuclear generation. Nuclear generation may be attractive if the system load is sufficiently large. On the other hand, presently the smallest size of a nuclear power stations ranges between 500 and 1000 MW, although new developments may allow to build units of smaller size. Taking into account these conditions, only a few developing countries with relatively large interconnected systems can realistically consider the construction of nuclear power plants.

Nuclear power plants are highly capital intensive. However, the associated lower fuel costs as compared to fossil fuel based power stations permit the conservation of foreign exchange.

On the other hand, due to lack of sufficiently qualified personnel, developed countries still depend on the technological development in industrialized nations.

Nuclear reactor may be classified according to :

- Neutron energy : fast and thermal reactors
- Fuel used : Natural fuel or enriched uranium
- Moderator : water, heavy water, graphite and beryllium
- Coolant : water, gas, liquid metal and organic liquid

Following aspects may be considered when selecting the most appropriate location of a nuclear power plants:

- Availability of cooling water
- Transportation facilities
- Distance from load center
- Safety
- Disposal of radioactive wastes
- Subsoil and land conditions

Large amounts of cooling water are needed. Therefore, the plant should be located near a large water body. Alternatively, cooling towers will be needed.

Transportation of large parts may be through railway lines or roads. The bridges along the selected route in either case should be capable to resist the loads.

The plants should be located as near as possible to the load centers to reduce transmission losses.

Safety is one of the most important arguments in developed nations with regard to providing developing countries with nuclear technology. After the disaster of Tschernobyl in the Soviet Union, the issue has taken more importance.

The disposal of radioactive wastes is a serious problem associated with nuclear technology in every part of the world. Public awareness in this regard has even led to the adoption of special regulations in developed nations, especially in Europe. The operation of some power stations and the construction of new projects have been canceled.

The risk of radioactive spills requires highly safe structures. The area where the plant is to be constructed should be preferably be placed in regions with low incidence of earthquakes and with good conditions for the foundation of the structures.

COMPARATIVE COSTS AND USEFUL LIFE OF DIFFERENT TYPES OF POWER PLANTS

	Power Range MW	Cost Range US$kW
Steam	0 - 1	2500 – 3500
	1 – 4	2000 – 2500
	4 – 10	1500 – 2000
	10 – 30	1250 – 1500
	30 – 100	600 – 1250
	100 – 1000	400 – 1000
Diesel	50 – 200	1000 – 1500
	200 – 1000	1000 – 1200
Gas Turbines	1 – 10	800 – 1100
	5 - 30	300 – 500
	30 –80	200 – 400
Geothermal	5 – 20	2000 – 50000
Solar	0 – 1	25000 – 50000
Wind	0.005 – 0.200	2500 – 10000

4.2.7 STUDY OF ALTERNATIVES

This chapter concentrates on the application of various computer models with the objective of explaining some of the best known algorithms available to carry out production simulation and economic analysis of expansion alternatives.

The study of alternatives comprises the evaluation of different strategies to cover the forecasted demand within the specified planning horizon, according to the objectives defined and utilizing in the best possible manner the available resources.

In economic terms, the study of alternatives has as objective function the minimization of costs, having as constraints on one side the system requirements and on the other the resources available.

The costs considered in the analysis comprise capital investments for civil works and equipment, operation costs (of special significance in case of thermal power stations) and maintenance costs. Various algorithms and computer programs have been developed to simulate the load dispatch (production) of interconnected hydrothermal systems, which allow the estimation of generation costs in case of thermal power stations.

Additionally, due to the complexity of the problem, various computer models have been developed and are frequently utilized in the formulation and evaluation of alternatives. One well known model is WASP (Wien Automatic System Planning Package) developed by the International Atomic Energy Commission. This model is used in Pakistan by WAPDA's Power Planning Department for studies of system expansion. The WASP model assumes that both load and generation are concentrated at one point and therefore does not consider the transmission system.

Alternatively, GTZ has also sponsored the development and implementation of computer models to carry out capacity expansion studies in various developing countries. These models allow to carry out the analysis with and without consideration of the transmission system.

4.2.7.1 BASIC CONCEPTS

The basic requirement in a capacity expansion planning is the determination of cost associated with a given strategy to cover the forecasted power and energy demand, taking into account also the desired qualitative aspects of the service.

INVESTMENT COSTS
Investment or capital costs are those expenditures required to implement the projects, expand existing facilities, repair components, etc. The determination of the quantity and time distribution of the investments is a basic result of any planning exercise.

OPERATION COSTS
Operation costs in interconnected hydrothermal systems are basically related to the expenditures needed to generate power with thermal power stations. These should also include the cost of operation of auxiliary equipments, which in case of thermal power stations may be significant.

With a deterministic model, the energy not served can only be estimated as deficit and may be somehow quantified by as a fictitious thermal power station, having operation costs equivalent to the estimated cost to consumers of energy not served, whose cost may be estimated on basis of the costs associated with operating small generators to satisfy their power requirements.

MAINTENANCE COSTS
These costs are associated with the preventive maintenance of the equipment. Although difficult to foresee, some provisions may also be made for corrective maintenance based on past experience.

4.2.7.2 LOAD DISPATCH (PRODUCTION) SIMULATION

As part of the analysis, load dispatch (production) simulation is needed to determine the production costs associated with the operation of the different plants in the systems according to the electricity demand, their characteristics and availability.

Besides allowing the quantification of power and energy production, fuel costs are also estimated through the simulation of units dispatch. The Loss of Load Probability (LOLP) and Expected Energy Not Served (EENS) can also be estimated by means of algorithms which take into account the reliability of operation of the plants.

SIMULATION METHODS
Simulation models are very popular in the past due to the relative simplicity in their implementation. The complexity of these models has increased with the consideration of reliability of operation of the power plants.

There is a large variety of models which are being used to simulate the operation (dispatching) of power stations in interconnected systems. For the purposes of this course, two categories of simulation models are considered:

- Deterministic
- Stochastic

DETERMINISTIC METHODS
Deterministic models may be based on daily load curves or duration curves. For planning purposes, the time discretization normally used to calculate power and energy generation and associated costs is one month. The load dispatch algorithms are adjusted accordingly.

When based on daily load curves, a day is assumed as typical for the time period used as a basis for the analysis, i.e. one month. The results of the dispatch obtained are considered representative of the whole period.

Alternatively, the dispatch may be made on basis of load curves, which are calculated for the time periods under consideration, i.e. one month.

Computer program LDISP, Load Dispatch Simulation Program, has been extensively used in various countries to simulate the monthly load dispatch of interconnected hydrothermal systems. The results of the analysis are basically used to prepare the budget requirements for fuels. This program has also been implemented in WAPDA for these purposes.

STOCHASTIC METHODS

There are some limitations in deterministic models to account for the stochastic nature of availability of generation. Hydroelectric power stations are subject to the availability of flows, which vary throughout the year and even during the day due to climatic effects. On the other hand, thermal power stations are also subject to unforeseeable outages due to failure of their components.

Due to above reasons, stochastic methods have gained popularity in recent years. The classical work of Baleriaux et al. (1) has provided the basis for the development of various stochastic algorithms to simulate the load dispatch of hydrothermal systems.

The method based on the Equivalent Load Duration Curve (2), also known in the literature as Cumulative Load Distribution, used in WASP computer model has become a standard in the field.

A computer program, with the name of LOLP, has been especially developed to illustrate the method through examples. The program follows a standard procedure, concoluting the plants available to cover the demand. Details are provided in the corresponding description.

OPTIMIZATION MODELS

These comprised algorithms based on mathematical programming techniques, such as linear and non-linear programming, dynamic programming, mixed-integer programming, etc.

Due to simplicity in the development of algorithms, linear programming has been used frequently to simulate the dispatch of hydrothermal systems. The degree of detail used in the past was mainly limited by the capacity of the computer systems available.

An alternative algorithm to simulate monthly load dispatching is used in computer program LPD. In this case the dispatch of the plants is made through linear programming, which allows a better representation of the way in which the units are required. However, computation times are significantly higher.

4.2.7.3 CAPACITY EXPANSION PLANNING

The definition of how to extend the available capacity of the system to cover expected power and energy demands is normally considered as the planning of capacity expansion of a given electric system. In this context, following aspects are considered:

- What projects to build?
- When?
- Which size?
- What is the associated cost?

The decisions should be based on so-called "criteria of excellence", which provide the elements to determine and select the best alternatives. In this regard, a well established procedure is to select the alternatives in terms of their minimum cost discounted throughout the planning horizon.

Basically the concept of minimum cost leads to a selection of expansion programs strictly based on economic efficiency, if no other considerations are made with regard to the standards to be met by the proposed power stations. These standards may be related to measures and procedures implemented to reduce air and water pollution, protection of the environment, etc.

Other important considerations in developing countries may be the lack of financial means to develop the system according to the forecasted power and energy demand. Under these circumstances, a gap between supply and demand may develop leading to deficits. Especially under these circumstances, great care should be taken in the analysis to ensure a satisfactory solution.

However, in any case should be expected that the lack of reliable data, insufficient knowledge about the system or a poor decision making will be solved by a computer program. Regardless of its complexity, a computer program of this nature is basically a tool and should be used to provide information to gain insight into the problem.

AGGREGATED (LUMPED) MODELS

Aggregated models are those which consider both generation and demand concentrated at a given point. The effects of the transmission network are ignored and the transmission and distribution losses are included as a lump sum in the demand.

In spite of the drawbacks which may be indicated due to the lack of consideration of transmission lines, aggregated models provide in general a reasonably reliable basis to establish a capacity expansion program. The reason for this is that the investments required to develop and operate the generating system are significantly higher than those needed to expand the transmission network.

The following paragraphs provide a description of two computer models available for the analysis of expansion alternatives.

PLANS

Some of the algorithms in this program package were developed and applied in various GTZ projects throughout the world. The package has been further modified and adjusted for this course with the idea to provide a basic tool to understand the basic principles of capacity expansion planning and to carry out analysis with the interconnected system. A detailed description of the computer program is provided.

PLANS is a computer package developed for deterministic as well as stochastic simulation and analysis, <u>on monthly basis</u>, of expansion plans of electric systems, both interconnected and isolated.

The main purpose of the package is to help in the process of evaluation and decision making by giving answer to *what if* questions. For this reason, the expansion sequences are developed interactively and not automatically. Experience has shown that in *real life* there is a finite number of alternatives to be considered in the expansion analysis of electric systems, especially in developing countries. The generation of large number of alternatives may be interesting for academic purposes, but not for practical applications. The reason for this is the fact that there are always relatively few projects which can be realistically implemented within the planning horizons under consideration (20 to 30 years).

Another aspect considered while preparing the computer package was the time required to execute each complete run. Extremely large execution times are not desirable, as the process becomes cumbersome and to some extent unpractical. It should be kept in mind that computer programs such as PLANS are basic tools that assist in the analysis but can not replace the human knowledge and understanding needed to consider all complexities of the problems related to expansion planning. In other words, independently of the sophistication of the models, simplifications are always needed. It is therefore improper to expect that the lack of knowledge of a planner can not be substituted by a computer program.

Heuristic and Dynamic Programming based algorithms for the automatic selection of projects are also available but have not been implemented in PLANS due to the above given reasons.

PLANS has been written in FORTRAN IV (ANSI 77) and runs on minicomputers based on DOS operating system. Minor modifications are needed to run the program on UNIX based computer systems.

The computer package has been developed in a modular form, as schematically shown in Fig. 4.4. The modules, which are basically different computer programs, are interrelated through data files, both temporary and permanent.

In its present form the computer package allows the consideration of generation system. The inclusion of costs of transmission lines can only be made manually directly by editing the data files, however work is in progress to carry out analyses and cost estimates by including one additional module for these purposes.

The computer package has been developed on basis of already existing computer programs developed in other countries through projects sponsored by GTZ, the German Agency for Technical Cooperation. The aim has been to have at disposal tools which can be simple to use and adjust as required. In this regard, there are basically no restrictions on the use of the programs.

The programs were originally developed and implemented for minicomputers which had sufficient capacity to run and execute them. Their implementation on personal computers is now possible through recent developments in the hardware (RAM and disk storage capacity) and software (operating systems and compilers) for these equipments.

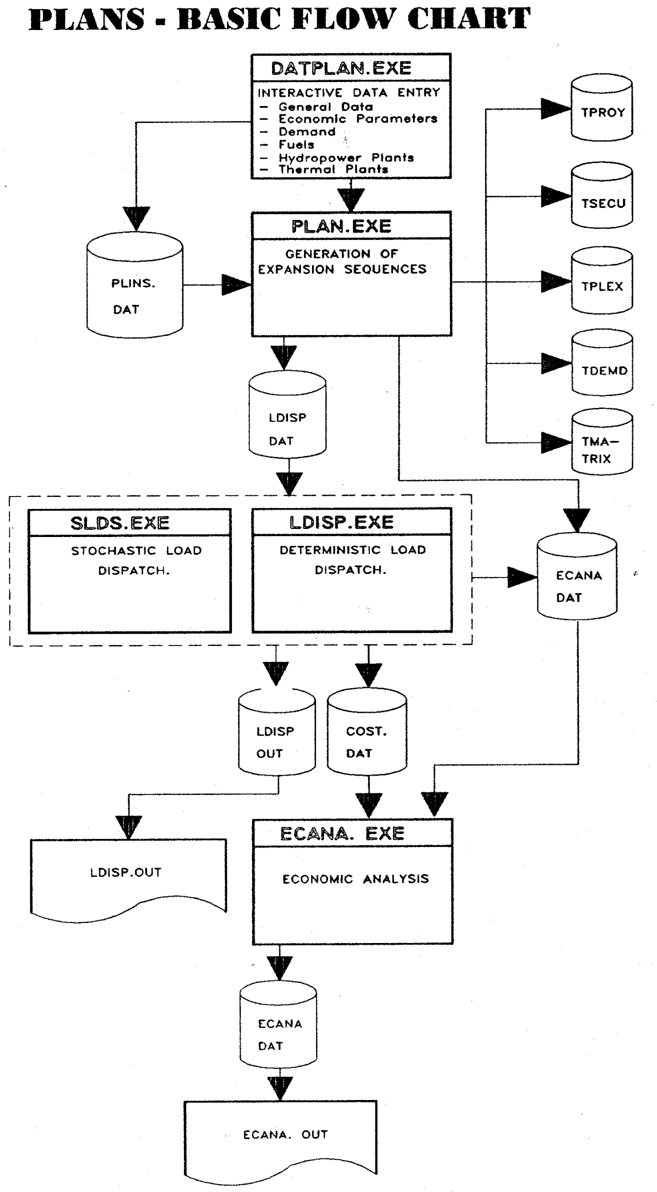

Fig. 4.4 Block diagram of computer program PLANS

Methodology
The programs allow a deterministic simulation of the expansion of electric systems taking into consideration the monthly variations of supply and demand. In terms of supply, variability is mainly due to seasonal availability of power an energy generation from hydroelectric plants. The seasonal variation of demand is represented through simplified monthly load duration curves.

Economic evaluation is made through the analysis of cash flows of capital, operation and maintenance cost.

Project sequencing - Program PLANS
Project timing and sequencing refers to the definition of the time of implementation of the projects aiming at satisfying the demand for power and energy throughout the planning horizon.

With PLANS, the formulation of expansion sequences is possible in two different ways:

- Pre-fixing the projects before program execution

- Selection through interactive execution of the program

Alternatively, a combination of above is also possible, and is the common case. Some projects are pre-fixed based on decisions already made, which is the case of schemes well known. In other cases, especially when dealing with long-term planning, the projects may still be subject to further study and decisions are mostly needed to select certain type of project according to the expected development of the demand.

load dispatch (production) simulation - Program LDISP
Load dispatch (production) simulation is carried out aiming at a minimization of the total costs of generation. The program carries out the analysis for every month and every year throughout the complete planning horizon. Two different algorithms are available, deterministic and stochastic, to simulate energy production.

Presently, the deterministic algorithm used for the load dispatch simulation is based on the Integrated Load Duration Curve (ILDC). This algorithm, includes some simplifications to ensure a fast execution. However, results are normally satisfactory for both system planning and operation planning.

To simulate the dispatch of the plants in a hydrothermal system, the algorithm basically proceeds as follows:

- Dispatch of the hydroelectric plants aiming at a maximum utilization of available energy

- Dispatch of the thermal power stations, sorted according to specific cost of generation from lowest to highest, covering those areas in the curve corresponding to the demand not satisfied by the hydroelectric plants.

For a faster execution, the hydroelectric plants are dispatched aggregated. This is made through an equivalent plant with a capacity and energy output corresponding to the added values of the available plants in the time period under consideration.

Details of the algorithm are given in the corresponding program description.

As an extension to the program, a module to calculate loss of load probability has been added. This allows also the determination of unserved energy, which is then used in the economic evaluation of alternatives.

Economic Analysis - Program ECANA
This program carries out a classical economic analysis. Programs PLAN and LDISP prepare information concerning costs, which is then organized in the form of a cash flow. The program calculates the discounted Net Present Value (NPV) for given rates of return and cost escalation of fuels for thermal generation.

To minimize the requirements for their execution (RAM and disk storage), the programs have been organized according to their function. Therefore, following has been considered:

- Development of expansion sequences keeping in view the need to satisfy the demand for power and energy throughout the planning horizon.
- Determination of capital costs associated with the proposed projects, including the beginning and duration of construction period for a proper account of the phasing of investments in local and foreign currency.
- Estimation of fuel costs incurred in the operation of existing and proposed thermal power plants.

- Economic analysis of proposed expansion alternatives. A sensitivity analysis is needed to evaluate the effect of variable discount rates and escalation of fuel costs.

These basic requirements are accomplished through the sequential execution of the computer programs described in the following paragraphs.

WASP

This computer program was originally developed by the International Atomic Energy Commission and has been adopted as a standard package by the World Bank and other international agencies to evaluate capacity expansion programs in developing countries.

WASP has also been installed in Pakistan and is used on regular basis to update, study and evaluate the expansion programs of the generating system.

A detailed description of the programs is available elsewhere (2,3,4). Annex 1 contains a brief description of the program.

DESAGGREGATED MODELS

Aiming at a more detailed analysis, some efforts have been reported regarding the development of computer models, which may consider the combined development of generation and transmission systems.

Due to their complexity, these models are not included in this course.

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4.2.8 SELECTION AND RECOMMENDATION OF PLAN

Keeping in view that planning constitutes an instrument used to assist in the process of decision making, the result of a planning effort should be translated in a series of recommendations for future actions.

The aspects to be considered in the selection and recommendation of a plan will be thoroughly presented and discussed in this chapter. The chapter will be complemented with a case study using data of WAPDA's system, which will be carried out mainly during the second week of the course.

4.2.8.1 SELECTION CRITERIA

In previous chapters reference was made to the need of ensuring the feasibility of the projects keeping in view technical, economical, financial, social and political aspects. Following the same approach, but in a more complex manner, any proposed plans should satisfy these conditions to ensure its implementation.

TECHNICAL ASPECTS

Technical considerations of a plan imply that the proposed actions are technically sound and feasible. This basically implies that, to develop the plan, all technical aspects have been properly considered.

It is important to ensure that the basic parameters of the plants and projects considered are properly accounted for. These comprise mainly:

- Capacity of plants and projects
- Energy output of plants and projects
- Earliest dates of commissioning of new projects
- Efficiencies and/or fuel consumptions of thermal power stations

The violation of any of these basic parameters will make the plan technically unacceptable, even in case of having deficit of generation.

ECONOMICS

Form the economics viewpoint, a plan is selected on basis of minimum discounted costs. The discounted values, which are determined according to predetermined rates, are the basis to select a given expansion strategy.

Benefits due to the sell of energy are not considered at this stage. The reason for this is that an expansion plan is prepared to cover forecasted power and energy demands, which have been derived considering already the effect of pricing of energy. The expansion sequence is normally prepared in such a way that expected demands are covered.

Special cases may occur when the generating capacity is not sufficient to cover the demand during part or the total planning horizon. This may happen under following circumstances:

- Demand grows too fast
- Deficits already exist
- Projects are not available for implementation
- Retirement or derating of old plants reduce available capacity

The evaluation of the expansion sequences when deficits exist should be carefully made. Obviously, an alternative, which minimizes deficits, may be more expensive than other which allows a gap between supply and demand.

One way of quantifying these effects is to give a cost to the power and energy not served, which in this case corresponds to the deficit. The cost of the unserved power and energy can be estimated on basis of the price to be paid by consumers to provide them with electricity, which may be possible through the purchase and operation of small generators.

The capital or fixed cost may be estimated on basis of the total power deficit, according to the unit cost of installed capacity of small generators. The operation or variable cost can be calculated in the same manner according to the unserved energy.

Both power and energy deficit may vary with the season and the time of the day. therefore, it may be convenient to calculate in accordance with the time discretization adopted to calculate generation costs for the entire interconnected system.

It must be noted that a deficit in the system does not have implications on the balance between supply and demand only. Normally, a deficit is also associated with poor quality of service in terms of reliability, voltage levels, etc. In practice, system components such as generating units, transformers and other elements are operated at maximum capacity, leading to overloading, poor efficiencies and insufficient maintenance which finally leads to damage and outages.

FINANCE
Financial viability of an expansion sequence is determined on basis of the expenditures and revenues to develop, operate and maintain the system. This aspect of the evaluation has become very critical in developing countries in recent years, basically due to the problems associated with the repayment of loans. A discussion on these problems is outside the scope of this course.

A sequence may be economically feasible but financially unfeasible if the expected revenues cannot cover the costs.

SOCIAL
This refers to the social acceptance of a given strategy in terms of quality of service, cost of service, environmental impact, etc. Social acceptance is defined on basis of following considerations:

- Are consumers willing to pay for the service?
- Will consumers be willing to accept the quality of service to be given?
- Are consumers willing to accept the environmental impact of the proposed strategy?

The cost of service is directly born by consumers through the tariff structure. However, not always can the revenues of electricity sales cover the costs required by the proposed plan. The alternative in this case is to adopt subsidies, which may come from different sources, local and foreign. However, if subsidies are financed locally, the costs must be covered by and/or at the expense of other sectors of the economy, provided that surplus exist.

The problem of a high cost of service can be socially unacceptable by the consumers:

- When the cost is relatively high and has to be covered only through power sales
- When development in other sectors is restricted to obtain subsidies for the power sub sector

It is generally accepted that the supply of electric energy is needed to promote development. However, supply alone may not be sufficient if the service does not have sufficient continuity and reliability.

Another consideration in this discussion is the effect of environmental impact of the proposed plan. Presently there is a generalized movement towards protection of the environment. The emissions of pollutants from thermal power stations are being restricted to reduce greenhouse and other negative effects in the atmosphere. All these measures have as a consequence that the cost of electric energy will most likely become more expensive.

When a plan stresses on the utilization of thermal power stations, the question is whether consumers will accept sacrifices either reducing their power demands or paying a higher cost for the energy in order to protect the environment.

POLITICAL
Evidently, if the strategy is not socially accepted, it will hardly be politically feasible. However, other political considerations may be related to:

- Conflicts of interests between affected groups in the allocation of costs and/or benefits

- Emphasis of government on certain projects
- International lobby through banks or other organizations in favor of certain technologies

4.2.8.2 IMPLEMENTATION PLAN

The results of a plan requires the implementation of certain actions which will lead to the satisfaction of power and energy demand. These actions comprise the development of infrastructure and other activities which require availability of funds and personnel. The evaluation of the implementation plan should be made on basis of qualitative and quantitative considerations.

Quantitative aspects are concerned with the coverage of power and energy demand throughout the planning horizon. These include also the capital, operation and maintenance costs of the system.

On the other hand, qualitative aspects are related to the continuity and reliability of the service provided to the consumers. If deficits occur, most likely the system breaks down frequently as its components are prone to fail due to overloading, overuse and improper maintenance.

The quality of service has a price and decision are to be made with regard to the standards to be adopted and the manner to cover the associated costs.

INFRASTRUCTURE

This includes the construction and/or erection of elements needed to provide the electric service to the consumers, delivering the energy from the source to the end users.

GENERATION

With regard to the generating units, the implementation plan should provide the guidelines concerning the actions to be taken, such as:

- Improvement of existing plants
- Implementation of new projects

The selection should be based on the technical characteristics of the plants and the associated construction, operation and maintenance costs.

TRANSMISSION

The recommendations with regard to the transmission system may include the construction of new lines related to new generation projects, as well as the improvement and extension of the network to cope with the growing demand.

When dealing with new generation projects a basic analysis is to establish whether the project remains competitive after inclusion of costs of corresponding transmission lines. This aspect is more relevant for sites located at a certain distance from the interconnected transmission network. However, even some projects in the vicinity of the existing transmission system may require to reinforce the existing lines to carry the additional capacity generated by the new project.

On the other hand, the expansion of the transmission system require always certain works, which may include:

- Improvement of existing grid aiming at the solution of short-term problems
- Reinforcement of circuits to cope with growing loads
- Construction of new lines

DISTRIBUTION
The development of the distribution system is normally not included directly in a system expansion program. However, the requirements to extend the distribution networks have to be considered while preparing demand forecasts.

The demand at end user level grows through:

- Increased consumption of already connected customers
- Connection of new customers within already electrified areas
- Connection of new customers through extension of electrified areas

FINANCING
There are various sources of financing available for project implementation. However, conditions may vary depending on the type of source, nature of project, etc. among the most important aspects to consider are:

- Interest rates
- Duration of grace periods, if any
- Lending period
- Form of payment (installments/year)

If interest rates are relatively low and grace periods long, the loans are classified as "soft". These loans are usually given in limited amounts, and the interest rates may not even compensate the inflation rates.

When the international market dictates terms and conditions, the loans are classified as "commercial".

LOCAL FINANCING
Local financing refers to the funds available through local sources, which may include organizations inside and outside the power sector.

Local financing may be through public and/or private sector.

FINANCING THROUGH INTERNATIONAL AGENCIES
These sources of financing are related to agencies operating at regional and worldwide level. The best known international agencies operating in Pakistan are:

- The World Bank
- Asian Development Bank
- Economic European Community

BILATERAL (GOVERNMENTAL) FINANCING
Industrialized nations and some oil producing countries have created their own agencies to provide financial assistance to less developed countries. These loans are normally agreed between the donor country through the agency and the beneficiary, therefore the name bilateral.

The terms and conditions of these loans are quite variable and normally have to be negotiated between the interested parties. Some of these loans may also be part of general purpose financing packages provided by lending countries on special conditions, regarding interest rates and grace periods (soft loans). The only problem with these loans is that some firms and agencies in industrialized nations use these mechanisms to obtain contracts with certain advantages, as the favourable conditions become some sort of export subsidy for the manufacturer.

SUPPLIERS CREDITS

These are loans provided or arranged by manufacturers. The terms and conditions and in most of the cases on commercial basis. These loans may be used to finance part or the complete project.

If the complete project is financed through suppliers credits, the project is executed on "turn key" basis. In this case, the suppliers/contractors are expected to construct the complete project according to a previously agreed cost, defined on lump sum basis. With this arrangement, the risk due to unforeseeable conditions at site are taken by the suppliers/contractors. Provided that the specifications for civil works and equipment are well prepared, the decision on a turn key solution should be based on a careful analysis of the profitability of the project.

PERSONNEL

The implementation of any plan must be carried out by personnel of different disciplines and qualifications. The continuity of personnel involved will depend on the time required to carry out the various activities.

WAPDA'S PERSONNEL

WAPDA's personnel are expected to participate at various stages of work, covering activities from planning through execution, commissioning and finally operation of the projects. However, personnel may not be sufficiently experienced to carry out works in some areas. On the other hand, some problems may arise or new technologies may be introduced for which specialist's advise is required.

In any case, the implementation program should take into consideration the scope of work and capabilities of the personnel within the institution. This will also serve to provide the guidelines to define:

- Type and amount of work to be undertaken by the organization's personnel
- Mode of operation if personnel from other institutions/organizations is engaged
- Training requirements

ENGINEERING SERVICES

Engineering services are always needed in every power utility to carry out specialized works. These services may comprise local and foreign individuals and firms.

There is a long tradition in WAPDA working with local and foreign consultants. The in-house capacity is not completely developed to carry out all required works regarding planning, design and execution of projects. This may be due in part to certain directives in the institution which have not properly allowed the development of these capabilities.

EXPERTS FROM MANUFACTURERS

These type of personnel are needed during erection of equipment and in some cases to carry out very special repair works. The charges for the services of this personnel during erection is already included in the cost of the equipment and may be free of charge during the period of guarantee of the equipment. However, services for special repair works may be charged by manufacturers after termination of the guarantee period.

4.2.8.3 STRATEGIES

In previous paragraphs, emphasis has been given to the supply aspects of expansion programs. These have been based on the development of infrastructure through the implementation of projects in order to cover the forecasted power and energy demand. Under these conditions the demand is expected to grow according to certain patterns dictated by

However, these are not the only option available to the planners and system operators. The most important alternative is to introduce methods and procedures to control the growth of the demand. This alternative is known as "load management" and has as a basic target the control of some or all consumer groups in the system. This may be achieved through a selective pricing according to consumer type, season of the year, time of the day, etc.

Other measures are to reduce the quality or even the continuity of the service. This may be achieved through power cuts (load shedding), reduction in frequency, etc.

LOAD MANAGEMENT

The concept of load management can be better applied if the system is operating without deficit. If the supply is restricted, some demand management techniques may not be suitable any more. Under these circumstances, pricing remains as the most efficient alternative to manage the load.

TARIFFS

The tariffs applied depend on the type of consumer and are affected by the total energy consumption and the load factor of the consumers.

Independent of the structure of the demand, in large interconnected systems tariffs should be designed to cover the following items:

- Recovery of capital invested for generation, transmission and distribution
- Recovery of running costs, which may include;
    - Operation
    - Maintenance
    - Billing
    - etc
- Satisfactory profit

generally speaking, tariffs have the following form:

$$T = ax + by + c$$

where,

T = total amount of bill for period under consideration
x = maximum demand, in kW
y = energy consumption, in kWh
a = rate per kW or maximum demand
b = energy rate per kWh
c = constant amount charged to consumers

Following are some well known tariff schemes, which are basically variations of above formula:

<u>Flat Demand Rate</u>. This type of charging is the simplest normally adopted in rural areas and depends only on the connected load and fixed numbers of hours of use per month or year. It is used when metering is not available and has hence the form:

$$T = ax$$

<u>Straight Line Meter Rate</u>. This type of charging depends on the amount of energy consumed. The amount billed is directly proportional to the energy consumed and has the form:

$$T = by$$

The disadvantage of this system is that the consumers not using energy will not pay, although some costs are incurred to provide them with the service, from power station through transmission and distribution grids.

Block Meter Rate. This system is based on the fact that the fixed costs spread over a greater number of units when generation increases. Therefore, the unit cost of energy decreases with increasing consumption. The general structure of this scheme is as follows:

$$T = b_1y_1 + b_2y_2 + b_3y_3 + ... + b_ny_n$$

where,

$$b_1 < b_2 < b_3 <.. b_n$$

$$y = y_1 + y_2 + y_3 + ... + y_n$$

The levels for y_1, y_2, y_3, etc are defined according to the characteristics of the system, both in terms of available facilities and structure of demand.

Marginal Cost Pricing. Rates based on marginal cost pricing have been adopted by power utilities in some industrialized countries. Mainly due to increasing energy and environmental costs, have generated interest on marginal cost pricing, especially with regard to "peak load" pricing. In recent years the system has also gained wide acceptance in the World Bank and associated financing agencies. It is quite clear that a "clean" kWh costs more than a "dirty" one, both in terms of fuel and capital costs.

Marginal cost pricing implies basically that the consumer should be charged for the service according to the cost incurred in providing it. This means that the consumer should face a rate structure that accurately reflects the cost per kWh he imposes on the system each period of the day.

Various studies have been carried out in Pakistan to establish tariffs on basis of marginal cost pricing. The most recent one (1,2) is expected to be implemented in the near future.

OTHER MEASURES

Other measures are mainly related to a relaxation of the quality levels, basically the system frequency. By doing so, the system load in MW may be automatically reduced.

LOAD SHEDDING

Load shedding in this case refers to the action of disconnecting loads due to insufficient generating capacity to cover the demand. This is an alternative of a country unable to cope with the power and energy demand and deficits occur. The reasons for this may be:

- Fast growing power and energy demand
- Lack of managerial capacity to implement the projects
- Lack of natural resources
- Unavailability of feasible projects

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