ELECTROMECHANICAL

FEATURES

VOLUME V

CONTENTS

FIGURES

SECTION 1
INTRODUCTION AND OVERVIEW

Scope of Electromechanical Report

This volume covers the selection, spatial requirements, cost, and representative manufacturers of the major equipment items and systems which comprise the electromechanical functions of a small hydroelectric power plant. The historical record of cost increases in equipment is presented for escalation of the cost component of the foregoing items to a time period beyond the July 1978 base used in this volume. The upper limits of small hydroelectric projects, as defined herein, are operating heads up to 100 feet and flow rates producing an output of up to 15,000 kW of power. The lower limits are a function of available equipment and the economics of developing power at the site.

Definition of Electromechanical Equipment

Electromechanical equipment is considered to be the equipment and systems required to develop the energy, either potential or kinetic, available in impounded or flowing water, to convert it to electric energy, to control it, and to transmit it to a regional power grid. The major equipment items are the hydraulic turbine, the electric generator, and a switchyard consisting of a transformer, circuit breaker and switchgear. Included are supporting systems which control and protect these major equipment items. Maintenance facilities such as a crane for lifting, which may be required, are also considered in a broad definition of electromechanical equipment.

Dependent upon the type and capacity of the hydraulic turbine and electric generator, the cost of the electromechanical equipment can vary from one quarter to one half of the total small hydroelectric power additions cost. When the cost of transmission lines and rehabilitation of the impoundment structure is included to the total project cost, the ratio decreases.

The selection of some equipment, primarily the generator, is dependent on the type of hydraulic turbine selected. Other equipment, such as transformer, switchgear and electrical protection systems are examples of equipment not dependent on the type of hydraulic turbine used.

Limitation of Data

The data provided herein regarding cost and dimensions were obtained from manufacturers, federal agencies, engineering consultants and contractors. The data was analyzed and factored to represent reasonable costs to be used for the intended purpose of this volume, which is feasibility level cost estimates. Generally, the cost data presented should be considered the mid-point in a band of costs varying as much as plus or minus 10 percent.

There are significant factors which can cause the costs of equipment to vary that are not controllable. It is not unusual to have competitive bids for turbines and generators vary by 25 percent. These variations can occur for several reasons. Whenever standardized units are proposed by a manufacturer, their cost should be less then a custom-made unit, because a custom made unit usually includes some development engineering costs. The exchange rate of the dollar is directly related to the cost of foreign-made equipment. The final selection of the type of turbine/generator and other mechanical equipment should be made by totalling firm bid prices from manufacturers and the estimated powerhouse civil/structural cost with due consideration to guaranteed hydraulic efficiences and anticipated life.

Power Equation

Power can be developed from water whenever there is available flow which may be utilized through a fall in water level. The potential power of the water in terms of flow and head can be calculated with the following equations:

$$hp = (Q \times H) / 8.815$$

where: hp is theoretical horsepower available
Q is quantity of water flowing through the hydraulic turbine in cubic feet per second
H is available head in feet

In terms of electrical output the above equation becomes:

$$kW = (Q \times H \times E)/11.81$$

where: E is the overall efficiency of the hydropower plant. For general estimating purposes, E is normally taken to be 0.85.

Functional Differences Between Large and Small Hydroelectric Power Plants

It is the general practice in the design of modern hydropower plants to include adequate controls in the generation equipment to enable the unit to maintain the system frequency in the event the power plant and its local distribution system become electrically separated from the regional power grid. For small hydroelectric plants which are typically very small in comparison to the generation capability of the regional grid, there are cost savings in the governoring system if the turbine-generator speed control system does not include frequency regulation of the electric system. Under these latter conditions an electric separation from the regional grid would shut down the small hydroelectric power plant.

Furthermore, for smaller hydropower plants, the duplication of transmission lines leading from the power plant to the connection with the grid is not necessary. The loss of one small power plant would not normally cause any impact on the system but the savings realized by not duplicating the transmission line could significantly effect the economic feasibility.

Smaller hydroelectric power plants can also be designed with less flow control than larger plants. The flow of water to most turbines is controlled by a set of gates called wicket gates. The wicket gates, which are controlled by signals from the governor, regulate the flow of water into the turbine and control the amount of power produced. Where it is not important to control the amount of power produced or regulate the flow for hydrological reasons, wicket gates can be eliminated, reducing the first cost of the turbine by about 10 percent, and also providing a reduction in maintenance costs.

Figures 1-1 and 1-2 show a comparison of a new and an old small hydroelectric power plant project.

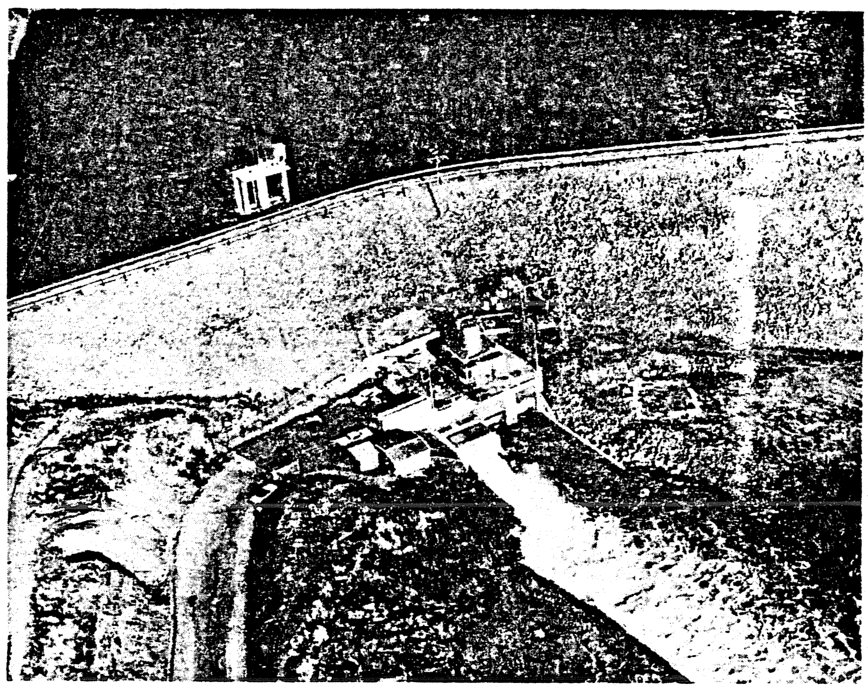

Figure 1-1. McSwain Power Plants located on the Merced River, California with a capacity of 10,000 KW. Constructed in 1969 (Courtesy of Merced Irrigation District).

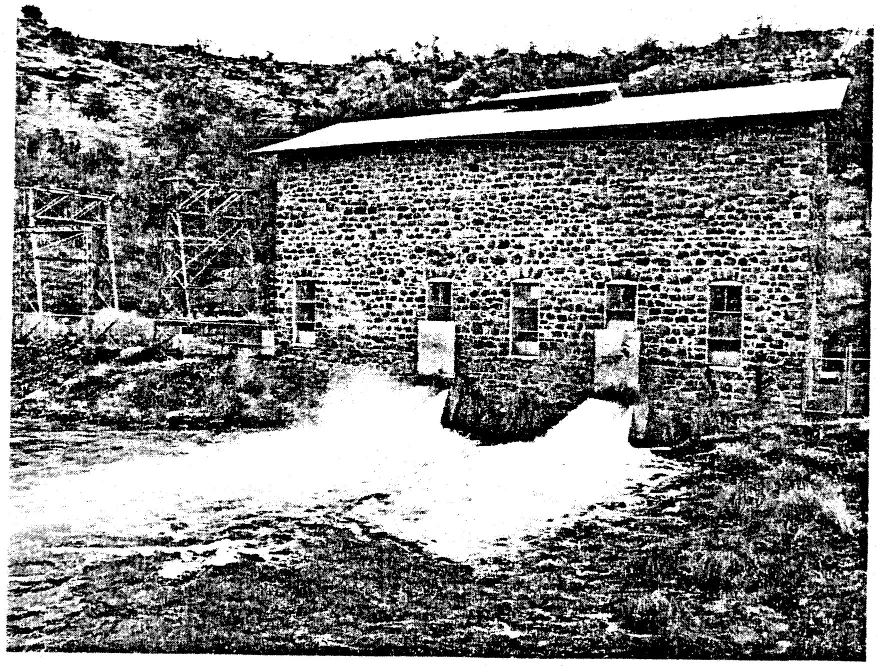

Figure 1-2. South Power Plant located on Bottle Creek, California with a capacity of 4,000 kW. Constructed in 1910. (Courtesy of Pacific Gas and Electric Company).

SECTION 2
ELECTROMECHANICAL FEATURES

General

The major electromechanical components of a power plant are the inlet valve, turbine, draft tube, draft tube gates, generator, control and protection equipment, and substation for transformation of the power to the transmission line voltage. In terms of spatial requirements and costs, the major items are the turbine and generator. Other miscellaneous plant equipment include the crane, station light and power systems, fire protection systems, heating and ventilating equipment, potable water system, and sanitary facilities. Most of the traditional miscellaneous equipment for larger hydroelectric projects can be either eliminated or reduced in scale for smaller, unattended hydropower projects.

General Considerations for Selection

Economic vs. Actual Life. In the selection of electromechanical equipment, differences between economic and actual life are important in the determination of the project feasibility. The economic life is the period of time to retire the bonds or to retrieve the capital required for construction. Bonds with a forty year retirement period would indicate an economic plant life of forty years. However, this does not properly credit the actual life of a hydro facility. A turbine/generator unit, properly maintained, may last over 75 years and consideration of a capital investment credit at the end of economic life should therefore be given.

Technical Considerations. Small hydro plants have generated the interest of a number of turbine and generator manufacturers in both the foreign and domestic market. The advantage of having foreign suppliers is the competitive aspect they introduce to the domestic marketplace as well as innovative technology. The disadvantage is the communication gap that may exist when spare parts are needed or technical problems in operation must be resolved. Although the economics of foreign equipment may prove attractive, consideration for future problems must be evaluated in the selection of equipment.

Another technical consideration is the speed of rotation of the turbine and generator. Under low head conditions, the turbine speed is generally below 450 r/min, which is considered a low speed. A low speed generator is larger in diameter than a high speed machine of the same capacity. By selecting a gear driven speed increaser, it is possible to couple a low speed turbine to a generator operating at several times the speed of the turbine. The higher speed generator would cost less to manufacture, weigh less, reduce the structural requirements and decrease the building size. Although this reduces the cost of procurement and construction, the speed increaser represents a loss in efficiency of one to two percent and a potential increase in maintenance cost.

Reaction turbine runners are subject to pitting caused by cavitation. For further discussions on cavitation refer to USBR Engineering Monograph No. 20-1976. Damage to the runner from cavitation can be avoided by proper selection of the speed of the turbine and the distance the runner is set above or below the tailwater surface. Selection of these parameters primarily have an effect on the cost of the turbine/generator and powerhouse excavation. This variation in cost for a typical installation is within the accuracy of the estimated costs presented in this volume. The dimension and cost data presented in this volume is based upon the centerline of the runner being set at approximately the minimum tailwater elevation. If site excavation costs are unusual it is suggested that turbine manufacturers be contacted for recommendations of speed and setting elevation to avoid cavitation.

Design Trends for Small Hydropower Installations. Industry is responding to the needs of the small hydropower plant market. Equipment manufacturers are standardizing the sizes and capacities of small units. Such applications are particularly applicable for the bulb-type and the tube-type predesigned turbine and generator units.

For a manufacturer, standardization is the preparation of functional control diagrams and physical layouts which may be readily adapted to a range of job site conditions. The purpose is to reduce engineering costs and establish the criteria applicable to a specific range of power plant sizes. Another application is the establishment of predetermined modes for unit start-up and the reduction of requirements for control equipment such as governors and synchronizing equipment. Standardization represents cost savings and an increase of project feasibility.

Methodology for Selection of Unit and Determination of Cost

The methodology by which the turbine/generator and accessory electromechanical equipment for a small hydropower plant is selected and its cost determined is described in the following paragraphs. The steps are shown graphically on Figure 2-1. The selection process is a trial-and-error process and two or more selections may be carried through this procedure at the same time. The final selection is made by combining all costs, including civil features of the powerplant and improvement of the impoundment, then comparing the annual cost to the amount of energy generated.

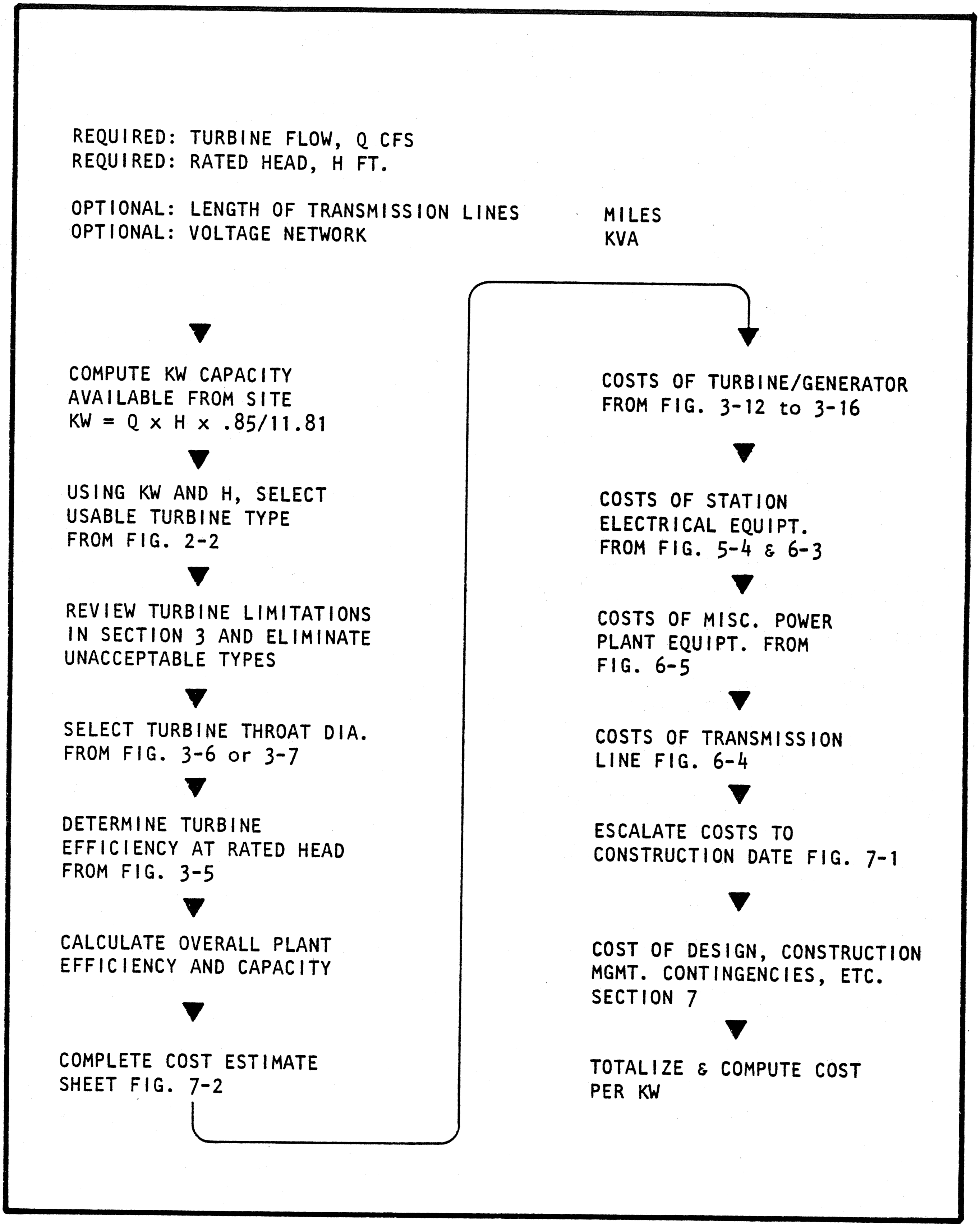

Figure 2-1. Turbine selection methodology

Collect Site Data. The basic data which must be considered in the selection of a hydraulic turbine are the design flow of water and the net head on the turbine. If the results of the study are to include transmission line cost, the other data needed to complete the electromechanical cost estimate include location and voltage of the nearest transmission line with the available capacity to handle the power from the project. Additional data which would be desirable include condition of the water, variation of water level in the impoundment, variation of tailwater level with flow and climatic conditions for the site. The collection of this data is further described in Volume III, Hydrologic Studies.

Obtain Effective Head. The effective head is the static head, the difference between the level of water in the impoundment and the tailwater level at the outlet, less the hydraulic losses of the water passage. The effective head must be used for all power calculations. The hydraulic losses can vary from essentially zero from flume-type turbine installations to amounts so significant for undersized outlet conduits that the energy potential of the site is seriously restricted. The hydraulic losses in closed conduits can be calculated using the principles set out in general hydraulic text books. In addition to conduit losses, an allowance for a loss through the intake structure should also be included. In general a hydraulic loss of one velocity head (velocity squared divided by 64.4) or greater would not be uncommon. The hydraulic losses through the turbine and draft tube are accounted for in the turbine efficiency curves.

Select Turbine/Generator. From the turbine design flow and maximum effective head, the kilowatt capacity of the unit can be computed by the power equations. Note that with the installation of multiple turbines, the turbine design flow should be divided by the number of units to give the flow per unit. The installation of multiple turbines should be considered in order to obtain higher efficiency over a wide range of flows. If multiple units are selected, all of the units should be equivalent, same capacity and same manufacturer, in order to reduce the required spare parts inventory.

The efficiency to be used in the preliminary sizing should be 85 percent. Based upon the kW capacity of the unit and turbine net head, the type of turbine (or turbines) can be determined from Figure 2-2. This graph was developed from data available from turbine manufacturer and information contained in public and private utilities publications. Section 3 contains pertinent information relative to the type of turbines shown on the figure, including general information and the limitations of operation of turbines relative to various flows and head.

Select Turbine Throat Diameter and Other Dimensions. Modern reaction turbine design has evolved through the trials of various dimensions and shapes in models which are tested in hydraulic laboratories. The critical dimension which dictates the amount of discharge capable from a turbine is the throat diameter, i.e. the diameter immediately below the runner of a Francis turbine or the tip diameter of a Propeller turbine. The throat diameter is a function of the type of turbine, effective head and capacity and may be estimated by use of the appropriate chart in Section 3. All other dimensions of the turbine may be estimated by use of the figures given in Volume VI - Civil Features. These dimensions will vary with different manufacturers' designs; however the data given are suitable for preliminary sizing.

Determine Cost of Turbine/Generator. Given the net head and kW capacity, the cost of the turbine/generator, including transportation and installation, can be determined by using the procedures described in Section 3. In employing cost data, reference is made to Section 1 of this volume relative to the limitations of data. The data may be further modified to reflect the user's experience with respect to items that may be special to the area, such as unusual labor rates or special transportation charges.

Select Performance Curves for the Overall Plant Efficiency. The overall plant efficiency is the turbine efficiency times the generator efficiency times transformer efficiency times an efficiency factor to account for station use and average station deterioration. The turbine efficiency is explained in Section 3. The generator and transformer efficiency is described in Sections 4 and 5. The efficiency often selected for average station use and deterioration is 98 percent. For a small hydroelectric project, where the flow and head remain relatively constant, and overall plant efficiency of 85 percent is a reasonable value.

For plants where the flow and head vary over a wide range, monthly, weekly, or possible daily operation schedules with use of the performance curves of the selected units may be required to obtain a reasonable estimate of the annual power production. If the flow varies over a wide range, two or more units are often more cost effective because of the improved efficiency characteristics of a multi-unit installation.

Select Control and Protection Equipment and Determine Cost. There are options for the selection of control and protection equipment, including type of governor and degree of operational control for the unit, and amount and degree of protection for the equipment. These options and the cost differences are discussed in Section 5.

Select Miscellaneous Power Plant Equipment and Determine Cost. The selection of miscellaneous power plant equipment is discussed in Section 6. The options include a crane, heating and/or ventilation equipment, sanitary facilities and a potable water supply. The latter two items depend upon whether the station is attended or unattended. The selection criteria may include the remoteness of the site and the owners preference for providing such facilities. Consideration may be given to a separate building to house these facilities not required for actual plant operation.

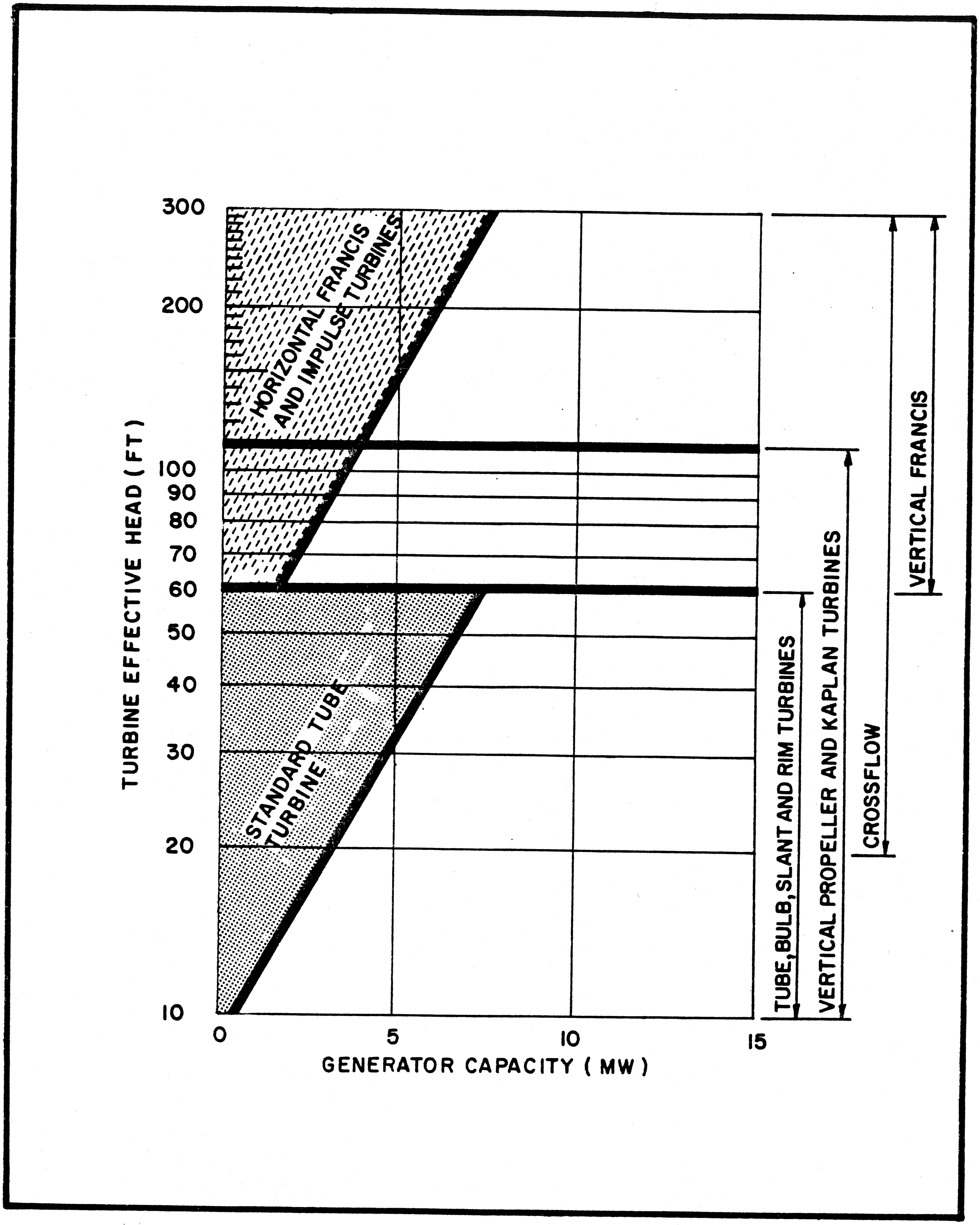

Figure 2-2. Turbine operating range

Select Transformer, Switchyard Equipment and Transmission Line Sizes and Determine Costs. Section 6 includes parameters for the selection and cost determination of the station transformer, switchyard equipment and transmission line to the connecting grid. The generator voltages vary from 480 volts from small units to 13,800 volts for larger units. Where the transmission voltage is uncertain, it is suggested that a voltage step-up to 34,500 volts be assumed. Consideration should be given to the type of terrain travelled as noted in the cost data.

Addition of Indirect Costs. In the preparation of an estimate for the electromechanical equipment, additional indirect costs need to be considered as outlined in Section 7. These indirect costs are escalation of construction and equipment prices and development costs. The costs of construction and equipment provided herein are at the July 1978 cost level and should be escalated to date required for either the reconnaissance or feasibility study. The development costs include expenditures for license and permit applications, preliminary and final design, construction management and administration. The development costs are provided as a proportion of the direct electromechanical equipment cost. Section 7 also provides a proportion of the estimated cost as related to the electromechanical equipment for annual operation and maintenance of the hydropower plant.