SECTION 4
ELECTRIC GENERATORS SELECTION AND COST GUIDELINES

Classification of Generators

General. The electric generator converts the mechanical energy of the turbine into electrical energy. The two major components of the generator are the rotor and the stator. The rotor is the rotating assembly to which the mechanical torque of the turbine shaft is applied. By magnetizing or "exciting" the rotor, a voltage is induced in the stationary component, the stator. The principal control mechanism of the generator is the excitor-regulator which sets and stabilizes the output voltage. The speed of the generator is determined by the turbine selection, except when geared with a speed increaser. In general, for a fixed value of power, a decrease in speed will increase the physical size of the generator.

The location of the generator is influenced by factors such as turbine type and turbine orientation. For example, the generator for a bulb type turbine is located within the bulb itself. A horizontal generator is usually required for a tube turbine and a vertical shaft generator with a thrust bearing is appropriate for most Francis turbine installations.

Conventional cooling on a generator is accomplished by passing air through the stator and rotor coils. Fan blades on the rotating rotor assist in the air flow. Depending on the temperature rise limitations of the winding insulation of the machine, the cooling may be assisted by passing air through surface air coolers which have circulated cold water as the cooling medium. On both indoor and outdoor installations the generator and associated cooling equipment and piping are enclosed in a housing, usually fabricated of steel, with entrance hatches and with a top hatch for an emergency exit (outdoor only). Indoor installations provide additional plant security but add an additional cost to the structure. Outdoor housings are generally accommodated with crane rails on the generator deck to provide for removal of the machine during maintenance. A photograph of a typical vertical, hydroelectric generator is shown in Figure 4-1.

Synchronous. A synchronous generator is so named because it is synchronized to the system voltage and frequency before the breaker device which connects the generator to the system is closed and, when connected, continues to operate at synchronous speed.

The excitation of the generator is achieved by impressing a direct current (dc) source across the rotor field coils and creating a magnetic field within the stator which induces a voltage potential in the stator coils. Present day designs employ a static excitation device which converts an alternating current (ac) source to a dc source via solid state circuitry. The static system has replaced the shaft-driven dc excitation generator and comparatively costs less, has a quicker response time and accommodates discharge of the field energy without a field discharge resistor upon a sudden disconnect of the unit from the system. However, for generators of 5,000 kW or less, a brushless shaft driven exciter may still be used in lieu of a static excitation system. The brushless exciter is a rotating ac generator with rectifiers on the main shaft to produce dc current for the field.

The voltage regulator functions as an automatic control device. It senses machine voltage and compares it to a set point. As the generator load changes, the voltage regulator adjusts the machine excitation to hold the generator voltage constant.

The exciter-regulator generally consists of one modular unit. It primarily affects generator reactive power output, power factor and voltage levels. The equipment is used in conjunction with the synchronizing equipment in the starting sequences of placing the generator on-line. Once the exciter-regulator brings the machine voltage up to system voltage and the synchronizing equipment matches frequency and phase with the system, the generator may be connected to the power grid. Small machines are frequently started and brought up to rated speed without excitation, the breaker closed and excitation applied to pull the generator into step with the system. This procedure eliminates the cost of the synchronizing equipment.

Induction. The major difference between an induction and a synchronous generator is that the induction generator obtains its excitation from the power grid.

The general method of getting the plant on-line is to start the generator as a motor with the turbine runner spinning "dry" and then open the wicket gates of the turbine to load the unit. The generator then begins to operate as a generator.

Present-day costs for induction generators are somewhat less than for synchronous generators of the same rated output. However, commercially available induction generators are generally limited to capacities of less than 2,000 kW. For the purposes of the preliminary feasibility study, synchronous machines should be used.

The choice of generator, synchronous or induction, is a function of application. An induction generator has a fixed power factor which if operating into a small power system can be a disadvantage because other generators in the system will be required to provide the reactive component for the operation of the induction generator. Synchronous generators can vary the power factor and contribute reactive power into the system. The proper adjustment of reactive components of synchronous generators can be utilized to reduce losses in the system.

Selection should be based on a case by case analysis of the power grid into which the generator will contribute power.

Procedure for Selection of Generator

General. With a Francis turbine, a vertical or horizontal configuration is possible. The orientation becomes a function of the turbine selection and of the power plant structural and equipment costs for a specific layout. As an example, the Francis vertical unit will require a deeper excavation and higher power plant structure. A horizontal machine will increase the width of the power plant structure yet decrease the excavation and overall height of the unit. It becomes apparent that generator orientation and setting are governed by compatibility with turbine selection and an analysis of overall plant costs.

Dimensions. Three factors affect the size of generator. These are orientation, kVA requirements and speed. The turbine choice will dictate all three of these factors for the generator.

Figure 4-2 lists dimensional information on vertical generators rated at 4160 volts which is the rated voltage

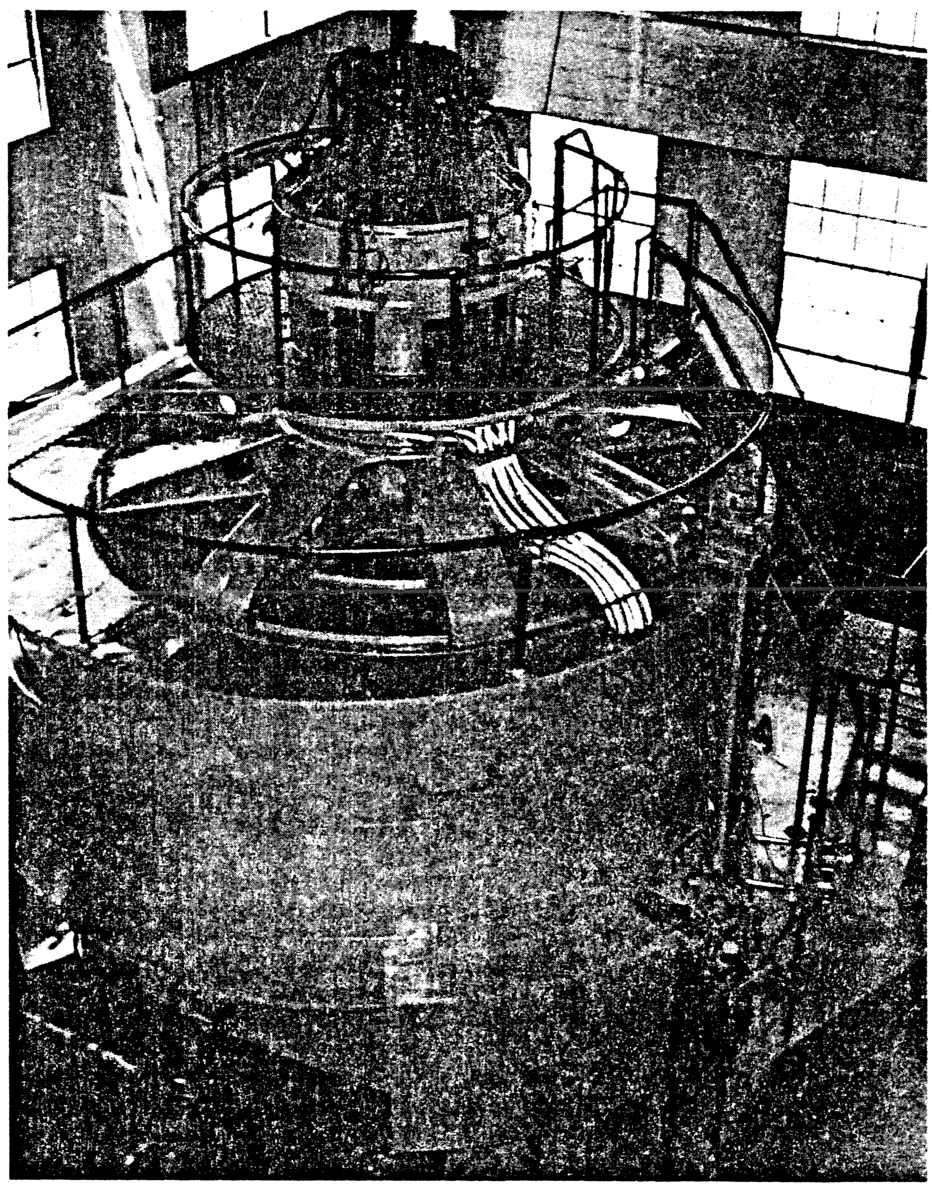
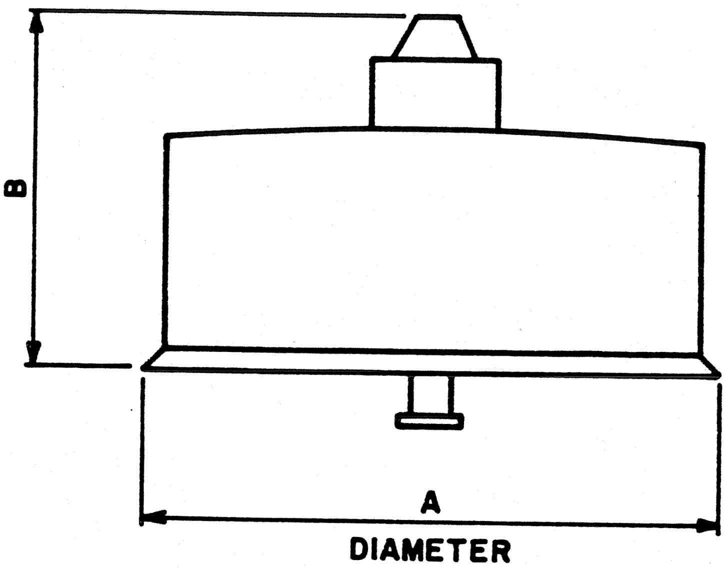


Figure 4-1.
Vertical indoor generator, Kern Canyon Power Plant on the Kern River, California. Capacity 8,480 kW. (Courtesy of Pacific Gas and Electric Company).



RATING (MW)	A (in)	B (in)
0.5	80	40
1	85	50
2	95	75
5	125	120
10	145	145
15	180	180

NOTES:

1. All values represent median sizes for varying head conditions (0-300 ft.).
2. Data based on 3-phase generators, 60 cycles, 0.9 power factor and 4160 volts.
3. For units above 5MW, several extra feet should be added to the diameter if surface air coolers are used.

Figure 4-2. Dimensions for generators, vertical configuration commercially available. All dimensions shown represent synchronous generating equipment.

The size of the generator for a fixed kVA varies inversely with unit speed. This is due to the requirements for more rotor field poles to achieve synchronous speed at lower r/min.

Generator Efficiencies. The efficiency of an electrical generator is defined as the ratio of output power to input power. Efficiency values for commercially available generators are included in Section 3. There are five major losses associated with an electrical generator. Various test procedures are used to determine the magnitude of each loss. Two classes of losses are fixed and therefore independent of load. These losses are (1) windage and friction and (2) core loss. The variable losses are (3) field copper loss, (4) armature copper loss and (5) stray loss or load loss. (Fink and Carroll, 1968)

Windage and friction loss is affected by the size and shape of rotating parts, fan design, bearing design and the nature of the enclosure. Core loss is associated with power needed to magnetize the steel core parts of the rotor and stator. Field copper loss represents the power losses through the dc resistance of the field. Similarly, the armature copper loss is calculated from the dc resistance of the armature winding. Stray loss or load loss is related to armature current and its associated flux. Typical values for efficiency range from 96 to 98 percent. This efficiency value is representative throughout the whole loading range of a particular machine; i.e., the efficiency is approximately the same at 1/4 load or at 3/4 load.

Cost Data. Generator costs vary with kVA capacity, speed and configuration. Cost will increase with an increase of kVA or a decrease in speed. Vertical generators are more costly than horizontal generators due to the addition of a thrust bearing for vertical units.

A refinement in costs would compare indoor versus outdoor installations. The indoor generator has a lower generator housing cost; however, this reduction is outweighted by the additional building structure costs. This examination is considered in the Civil Features discussed in Volume VI.

Cost data for the generators is included with the turbine cost data in Section 3.

Generator Manufacturers. The source of generator data concerning dimensions, cost and operating characteristics is the generator manufacturers. The manufacturers are continually adapting designs to new market criteria. With the increased interest in this area, generator manufacturers have come forth with new generator designs to accommodate small hydro conditions. Activity on both foreign and domestic markets is presently very active.

A partial list of generator manufacturers for small hydroelectric generators is shown in Exhibit II at the end of this volume.

SECTION 5

GENERATION CONTROL, PROTECTION EQUIPMENT AND TRANSFORMERS

Hydroelectric Plant Control

General. The governor is the primary controller of a small hydroelectric plant. The governor may be actuated by manual operation, by float level control in the waterway or by the flow of water in a conduit. Each method provides control for starting and loading the unit.

The generator is controlled through the excitation and voltage regulation equipment. In coordination with the synchronizing equipment, these systems allow for unit start-up, and voltage and power generation control when the unit is on the line.

The central location for plant control is the main control board. From it emanates the complete operation and monitoring of all plant equipment. Together with the plant switchgear and storage energy system, normally batteries, the above are the predominant control systems for small hydroelectric plant operation.

There are several differences in the control systems required for large versus small hydroelectric installations. A comparison of the two sizes of installation indicates that the primary descriptions of the above control systems are representative for both classes. In large plants, the complexity of the regulation equipment (e.g., governor, synchronizing equipment, excitation gear) will be greater since slight increments in turbine gate position or generator field adjustment may result in large increments of power swing relative to the power grid. Small hydroelectric units do not create such an impact on the system and thereby require less costly and complex equipment. The other area where a difference occurs is in the horsepower of the auxiliary pumps, storage battery capacities and protective systems. Large hydroelectric plants employ larger sized control systems simply because the auxiliary systems are larger.

Main Control Board. The function of the main control board is to control and monitor all plant functions. In small hydroelectric plants, often unattended, a primary function of the control board is to give indication of plant function status after a remote alarm has occurred so that an operator may be dispatched to determine the nature of the alarm. From this display the operator can determine the nature of the malfunction, and can then follow established operating instructions for handling the plant malfunctions and often restart the unit.

The control board consists of indicating meters, control switches, lights, annunciators, mimic arrangements, interposing relays, protective relays and recording instruments. The indicating meters provide information on voltage levels, current levels, watts, vars, temperature and unit speed. Indicating lights show status, such as "pump on - pump off" or "valve open - valve closed". The annunciators display specific alarm or malfunction conditions throughout the plant. Generally the annunciator points are grouped by function. One layout often used has the annunciators partitioned into generator, turbine and transmission line functions. The annunciator may be accompanied by a local alarm and facilities for initiating remote alarm. Protective relays are mounted in a separate area of the control board and are visible from the front for inspection of relay targets. Interposing relays are often mounted behind the control board for ease of interwiring within the board. Recording wattmeters, varmeters and voltmeters in addition to flow and water level recording meters are mounted in the vicinity of the protective relays.

The configuration in design and layout is arbitrary and dependent on operator logic and system conformance. Note that the control switches are mounted with corresponding indicating lights, indicating meters and the annunciator sections. This arrangement is quite common. Relays and recording devices are grouped together. The typical control board layout includes a walk-in configuration. The whole panel layout may be set up for front view if this is deemed feasible. Figures 5-1 and 5-2 illustrate an old and new control board arrangement. Both boards are still in operation.

Generator Control

Synchronization and Voltage Regulation. The synchronizing equipment allows the generator breaker or line breaker to be closed when the generator voltage is in phase and frequency with the system voltage. This function may be performed manually with use of a synchroscope or automatically employing speed matching and automatic synchronizing relays. For small units automatic synchronizing equipment may be eliminated.

The voltage regulator works jointly with the static excitation equipment. After the field has been excited to achieve system voltage and the generator is synchronized to the system, the voltage regulator assures that the set point voltage is automatically maintained. A voltage adjustment device is provided to set the desired generator voltage.

Generator Breakers and Line Breakers. Generator breakers and line circuit breakers are the link that connects the generator to the power grid. The generator breaker closing occurs when the unit is in synchronism with the power grid. These breakers also act as an interrupting or tripping mechanism to disconnect the unit from the system when an abnormal condition or a normal shutdown takes place.

Breakers are classified by type, voltage class, continuous rated current and interrupting capacity. Types of breakers include magnetic, air blast, gas, oil and vacuum and are indicative of the medium in which the electrical arc is extinguished. The distinction between the generator breaker and the line circuit breaker is that for multiple unit arrangements with a single step-up transformer, a separate low voltage breaker is required for each generator. Some single unit plants eliminate the generator breaker and connect the plant to the system with the line circuit breaker. See Figure 5-3 for a typcial one-line diagram of a single unit plant.

Generator breakers for small hydroelectric installations are commonly air blast or vacuum type, metal-clad units rated at 4.160 kV. The interrupting capacity is dependent on fault calculations which determine system and generator contribution to a fault. Metal-clad units can be supplied with associated metering and instrument transformers.

The line circuit breaker is located on the high voltage side of the step up transformer in the switchyard. Vacuum and gas type are being installed more frequently due to decreased maintenance costs. However, many utilities still standardize designs for small installations around the oil type unit. Standard voltage levels are 15,500, 38,000, 48,300, 72,500 and 121,000 volts.

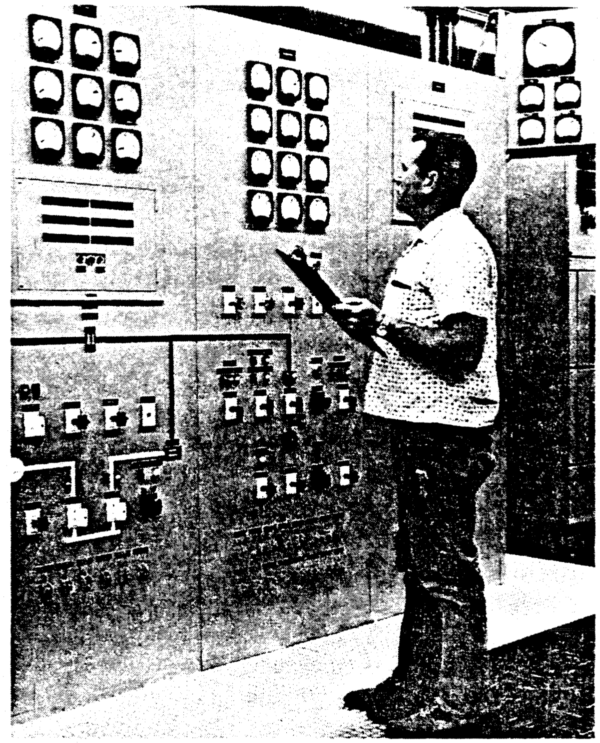


Figure 5-2. Control board for the New Exchequer Power Plant which was installed in 1969. (Courtesy of Merced Irrigation District)

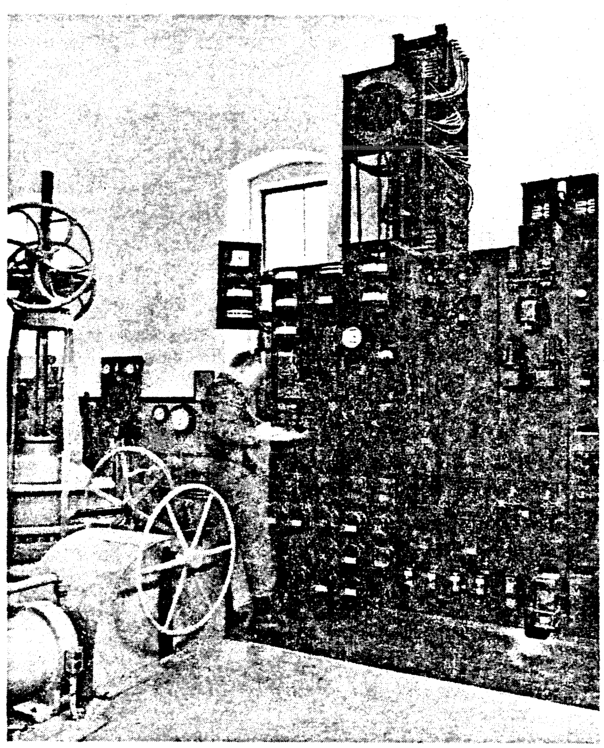
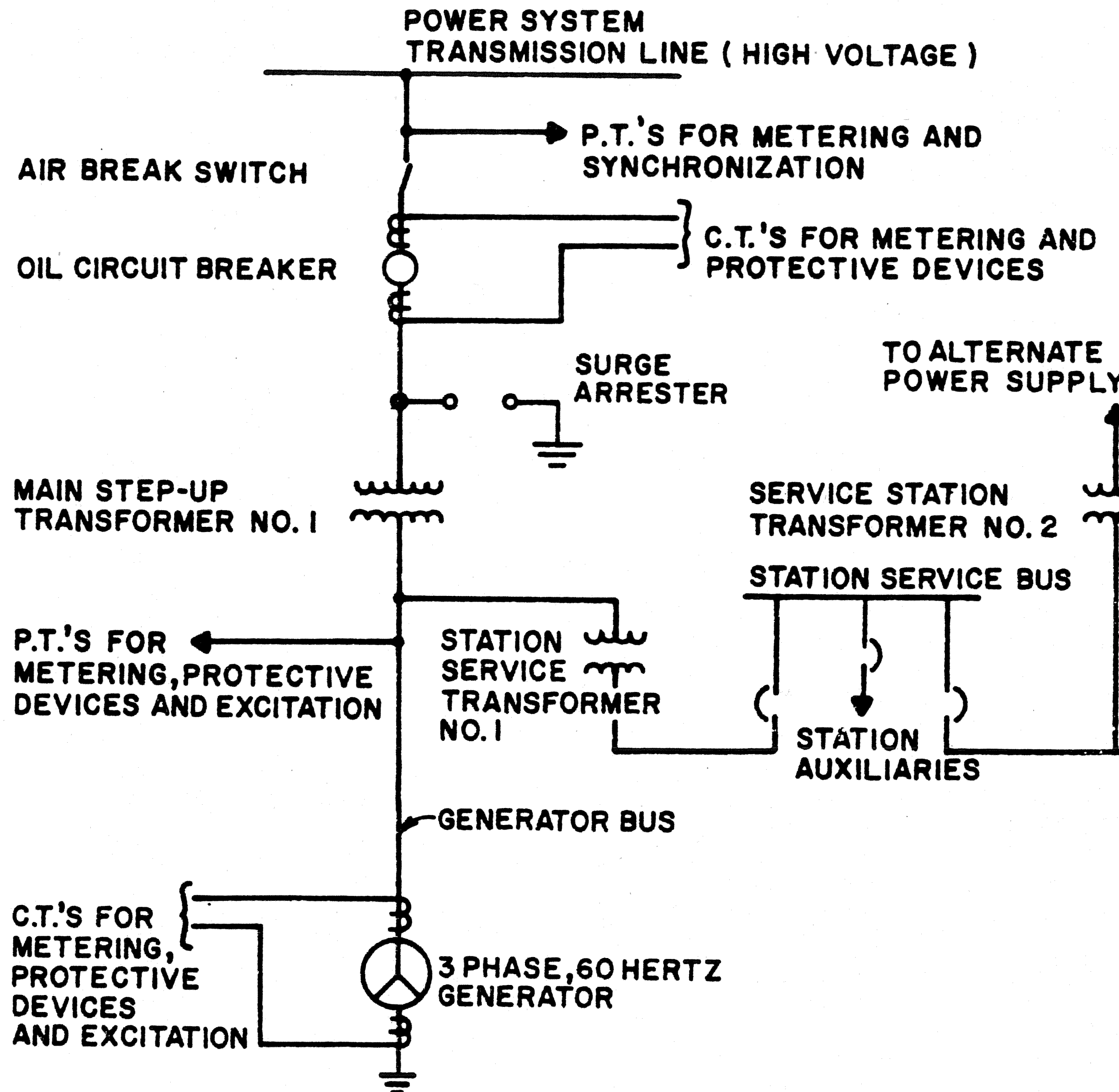


Figure 5-1. Control board for South Power Plant, installed in 1910 and still in operation. (Courtesy of Pacific Gas and Electric Company)

For all aforementioned breakers, control cabinets and consoles are available for the circuitry required to close and trip the breaker. Bushings come with provisions for instrument transformers. Options include relaying equipment and key interlocks.

Unit Starting. The method for starting the unit is regulated by the governing system. The governor controls speed and loading of the turbine. After allowing an initial flow of water through the turbine to achieve breakaway of the turbine runner, the speed regulation and matching equipment begins a feedback network to adjust governor speed and to check system speed. Once the speed adjustment is achieved and the voltage is regulated, the unit is connected to the system. The function of the governor is then to control load on the unit by positioning the gates to regulate flow of water to the turbine runner.

Starting the Unit by Motoring. An alternative means of unit starting is to start the generator as a motor. Induction generators are started by this method. If a synchronous generator is to be started by this method it requires that a damper winding be designed into the machine to handle starting requirements. There are some additional requirements to this system which offset its advantages in economy and ease of operation.



NOTES:

1. C.T. and P.T. refer to Current Transformer and Potential Transformer respectively.
2. For two or more units, a single main step up transformer may be employed; each unit will require a separate load side generator breaker (4.16kV).

Figure 5-3. Single unit one-line electrical diagram

These requirements include the need of a seal water system to cool the turbine seals during starting or motoring and additional metering to measure power flow into the generator. This measurement must be figured into the net power production of the plant.

Governor and Load Control Equipment. Large hydroelectric installations are equipped with hydraulic-mechanical or hydraulic-electric governors which regulate speed. These governors are capable of regulating the speed of the turbines with a gate control deadband of less than 0.02 percent. Small hydroelectric installations generally have little effect on the frequency of the power grid and may be installed without speed regulation governors which result in a cost savings. Gate control equipment is generally part of the equipment furnished by the turbine manufacturer and the estimated costs are included in the turbine generator cost curves.

For small hydroelectric installations, non-speed-regulating governors may be either hydraulic or electric-operated and their function is to bring the turbine to near synchronous speed for start-up, to regulate load after synchronous speed has been achieved and to shut down the unit during both normal and emergency conditions. The units must be equipped with mechanical speed switches and an independent energy source which will shut down the turbine in the event of load rejection or loss of station power. When hydraulic systems are used, an air-oil accumulator is used as an independent energy source. When electric operators are used, a dc battery system is used.

In cases where load regulation is not required, the turbine is equipped with an inlet valve which must be able to shut the unit down under emergency conditions. The power to close the valve can be provided by a hydraulic accumulator system, a battery system or a weight trip lever device.

Station Equipment and Protection Systems

Relaying Equipment and Surge Protection. An important part of hydroelectric plant operations deals with safety and protection. In particular, short circuits and ground faults within the plant must be monitored and corrective action must be initiated to prevent injury to personnel or damage to equipment.

Two types of protective devices are the protection relays and the surge protection arresters. The relays examine time-current relationships and operate when the voltage and current characteristics lie outside of the pre-calibrated settings. An example is the generator differential relay which senses a fault within the machine itself. Its operation initiates emergency shutdown of the unit. The purpose is to immediately arrest any further damage to the equipment and to alert the local operator or a remote control center to the condition. Surge protection is required to restrict any line surges from the system or any surges in voltage that have not been properly contained by the station lightning arresters. The surge arresters are physically located as close to the generator terminals as possible. The surge equipment prevents insulation damage and flashover on the generator windings.

Protection relays often cost in the range of several hundred dollars. They are flush mounted on the main control board to allow the display of relay targets. The targets indicate which phase of the three-phase system activated the relay. The settings of the protective relays are based on voltage-current information and time characteristics. Settings must be coordinated so that the closest relay to the fault activates first and the next one up the line represents the back-up. In most cases, this information is coordinated with the operator of the power grid.

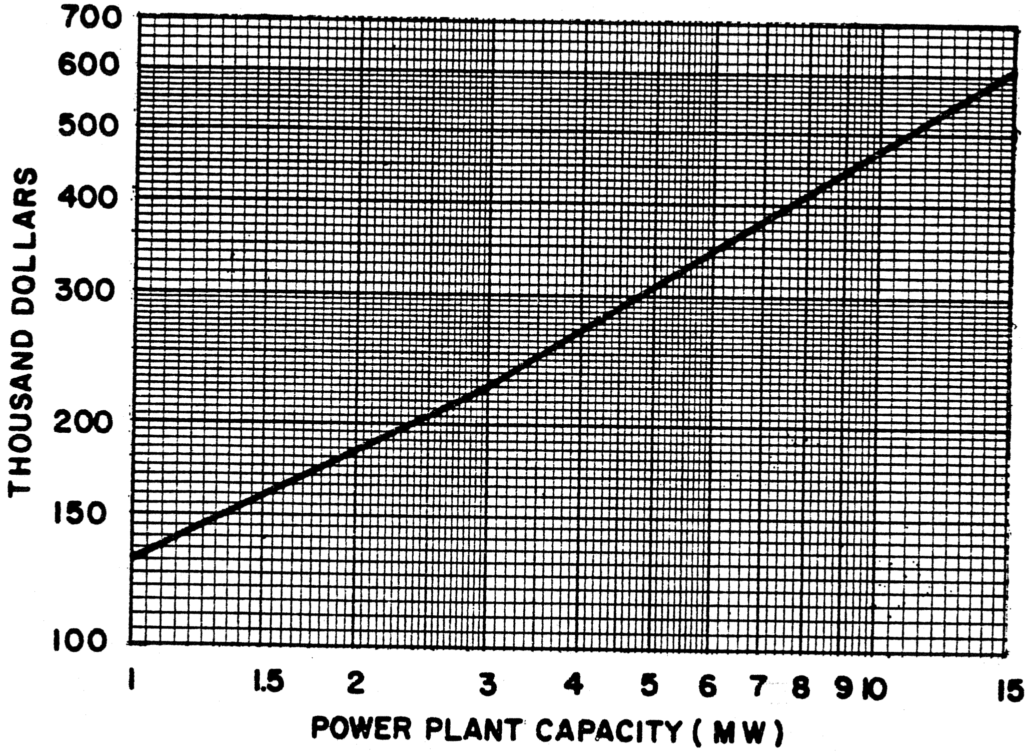
Fire Protection. A $C0_2$ fire protection system is employed in the generator housing assembly and general plant area. The purpose of the generator $C0_2$ system is to extinguish fires that occur within the generator housing. A bank of cylinders for both initial and delayed discharge is actuated by $C0_2$ thermal switches. Portable extinguishers are positioned about the plant to contain local fire hazards. Steam or water may be used in place of $C0_2$, but both require that the generator be disconnected from the bus and the excitation system before the fire protection system is activated. A further advantage of $C0_2$ is the fact that it is harmless to the insulation. A common physical configuration is a bank of cylinders against a wall with a discharge header pipe to the generator housing.

Small hydroelectric installations may not warrant automatic fire systems. Local hand-operated $C0_2$ extinguishers may be suitable. The costs for fire protection is included as an item in Miscellaneous Power Plant Equipment, Section 6.

Cost Data. Station electric equipment includes station switchgear, battery system, station service transformer and equipment, lighting, protection system, control board, cable and conduit. These systems represent a fixed expenditure of plant cost regardless of turbine and generator selection. Figure 5-4 illustrates the dollars vs. MW for the range of small hydroelectric plants.

Transformers

General. The power transformer is a highly efficient device to step the voltage from generation level to transmission level. Efficiencies are generally in the range of 99 percent. For small hydroelectric installations, a single, two winding, oil-filled substation type transformer is required. The main tank is pressurized with nitrogen to monitor rupture of the vessel and with loss of pressure to cause an alarm to sound. The bus entry to and from the transformer is accomplished by porcelain bushings, which may be supplied with current and potential transformers for metering, relaying and instrumentation. A terminal cabinet is located on the side of the transformer. Its function is the termination of auxiliary devices such as sudden pressure relays, over-temperature devices, and cooling fans and pumps. The cooling system consists of fin-type radiators which



NOTES:

1. Major Equipment is listed below:
   a. Battery and Battery Charger
   b. Station Switchgear
   c. Station Service Transformers
   d. Bus, Cable, Conduit and Grounding
   e. Main Control Board
   f. Lighting System
2. All items applicable to FERC Account No. 334
3. Costs include freight and installation.
4. Costs shown are for a single unit plant. For multiple units a cost for generator breakers and additional controls must be added. Add $20,000 + $58,000 x (n-1) to the cost of a single unit plant of the same total kW capacity. (n = number of units).
5. Cost Index is July 1978.

Figure 5-4. Station electrical equipment costs

depend strictly on convection. To augment natural cooling, fans or fans combined with oil circulating pumps may be employed. A further refinement of cooling can be accomplished with oil-to-water heat exchangers. This method, however, requires that the coolers be operated at all times. Small hydroelectric installations are normally limited to open air transformers with forced air cooling only for extremely warm days or short term overload conditions.

Cost Data. The main variable for transformer cost is the capacity of the unit for power transfer (kVA). Voltage levels are the next variable in cost as higher voltage requires more insulation material. Each transformer is provided with a control cabinet and sudden pressure relay. It is assumed the low voltage of the hydroelectric generation will be 4160 volts. Several high side voltages are presented. Transformer costs are included in switchyard costs given in Section 6.

SECTION 6

SWITCHYARD, TRANSMISSION LINES, AND MISCELLANEOUS TOPICS

General

The switching and delivering of power to some distant point represents the final link to the power grid. Although sometimes disregarded in preliminary feasibility assessments, the length of transmission of the power may be an economic constraint that seriously affects project feasibility.

Switchyard

The switchyard is comprised of line circuit breakers, disconnect switches, transformers, structures, buswork and miscellaneous power plant equipment. The arrangement of this equipment should allow for the future movement of circuit breakers and other major equipment into position without de-energizing existing buses and equipment. For single unit small hydroelectric installations, the switchyard will consist of the generator bus, step-up transformer, a disconnect switch, a line circuit breaker and a take-off tower. Station transformers, excitation transformers, and surge and metering cubicles may also be included in the switchyard to decrease floor space requirements in the powerhouse structure. Another alternate arrangement would have the metal-clad (enclosed in cabinets) generator breakers located in the switchyard. A typical arrangement drawing for a single unit plant is shown in Figure 6-1. Multiple unit switchyards may be similarly arranged as long as electrical protection and a means for isola tion is maintained between individual generators by use of generator breakers.

The location of the switchyard with respect to the powerhouse is dependent on soil conditions, space requirements and topography. Where geographically feasible, the best location of the switchyard is close to the powerhouse structure. This eliminates costly extension of the generator bus and reduces power losses in the bus. A photograph of a typical switchyard for a hydroelectric power plant is shown in Figure 6-2. Note that the plant is shown under construction.

Cost Data. The costs presented are for single unit switchyards. Cost data reflects the installed cost for level of transmission up to a maximum of 115 kV. Cost data relative to site preparation and clearing, foundation, structures and fencing of the switchboard area is provided in Volume VI. See Figure 6-3 for cost data.

Transmission

Reduction of line losses is the key to optimum transfer of power. For the potential developer of a small hydroelectric plant, transmission facilities may be the responsibility of the purchaser of the power. Thus the developer will only need to coordinate the outgoing take-off structure with the positioning of the incoming transmission line.

However, some projects will require that the developer also be responsible for transmission to some point at which an intertie to the transmission grid can be made. This construction then must be included in a cost analysis to determine the economic viability of the project. Consideration of right-of-way for construction of the transmission line and siting of the line l also must be taken into account.

The physical equipment for a transmission line includes conductors, poles, supporting guys, insulators and connectors. Wood pole line construction is quite applicable for the range of transmission levels discussed herein. The nominal values of transmission voltage considered in this study are 13,800, 34,500, 69,000 and 115,000 volts. (Alcoa Aluminum Overhead Conductor Engineering Data, 1960).

Cost Data. Figure 6-4 illustrates cost data for transmission lines of up to 30 miles and at voltages typical for small hydroelectric plants. The cost data has been developed from data supplied by the U.S. Department of the Interior. These costs reflect open, level terrain and favorable foundation conditions. The figure also indicates a procedure for increasing the costs when more adverse conditions are present.

Miscellaneous Power Plant Equipment

Small hydroelectric installations are generally operated and monitored from a remote location and therefore designed to house only the generation equipment. Heating, ventilating and air conditioning and waste systems for human habitat are normally not required. During infrequent maintenance periods, bottled water and portable toilet facilities may be provided. The estimated costs for miscellaneous equipment contained in this volume reflect minimum equipment for average site conditions and consist of the following:

Ventilation. A central blower located in the roof or end walls with temperature control to actuate when ambient temperature rises above 74 degrees F is provided. Filtered air inlets near floor at generator level are also included.

Water System. Duplex pump system with strainers is provided for water-cooling requirements of the turbine and generator. The water is taken from the penstock or tailrace. The cooling water system should operate independently of the plant generating equipment. No water cooling system for generator ventilation is included in the costs data.

Crane. A permanent powerhouse crane is not recom-

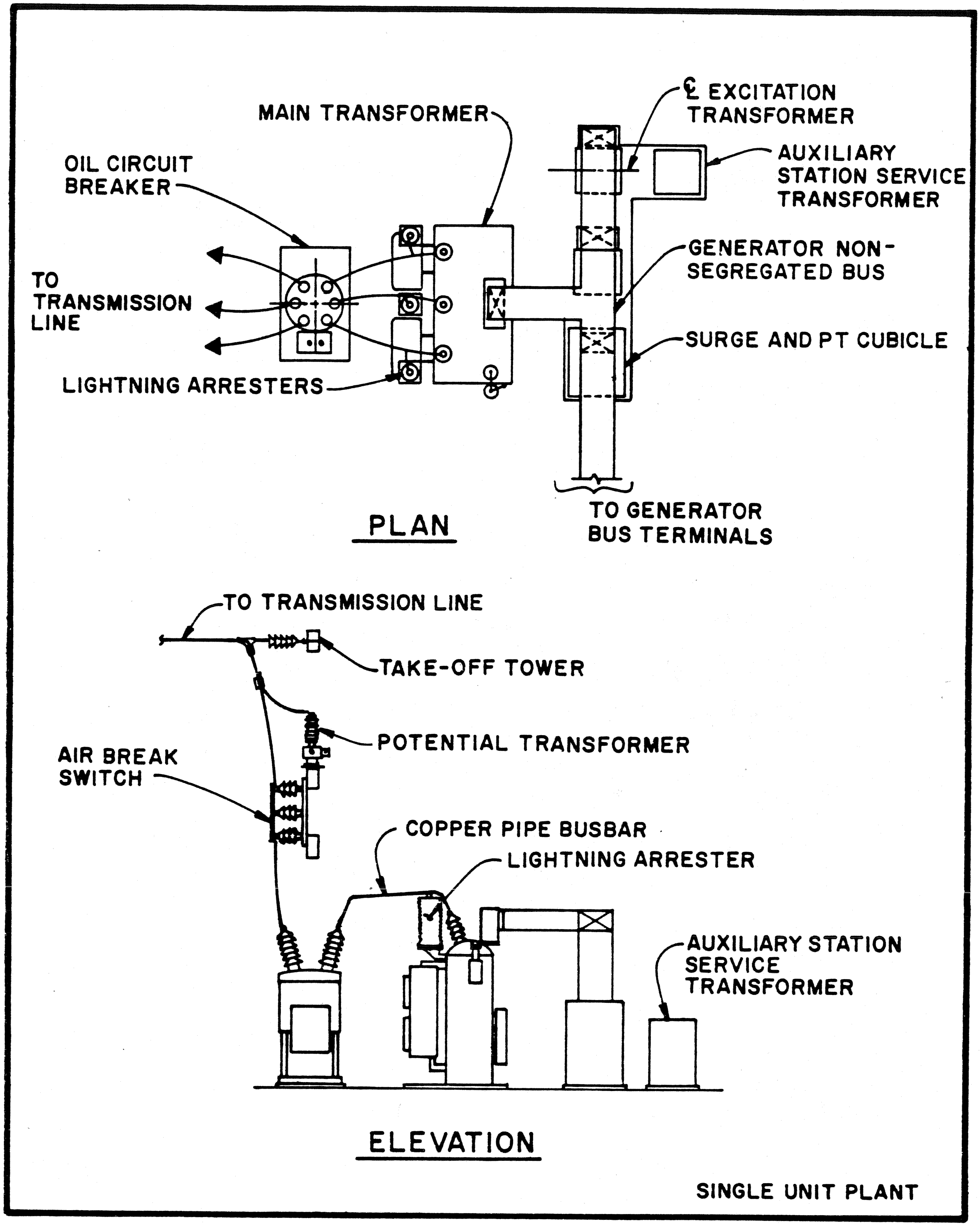


Figure 6-1. Typical arrangement of a switchyard

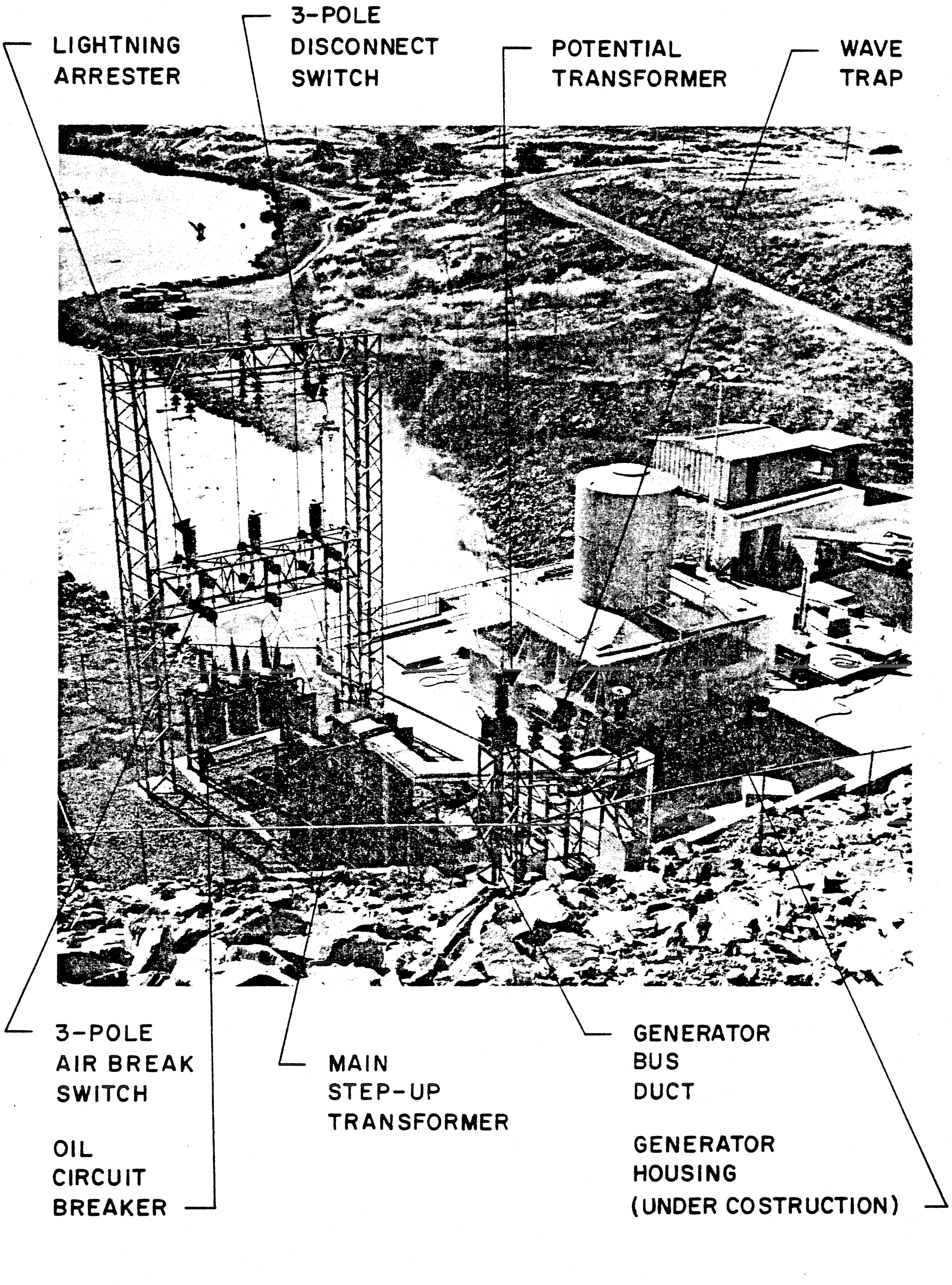
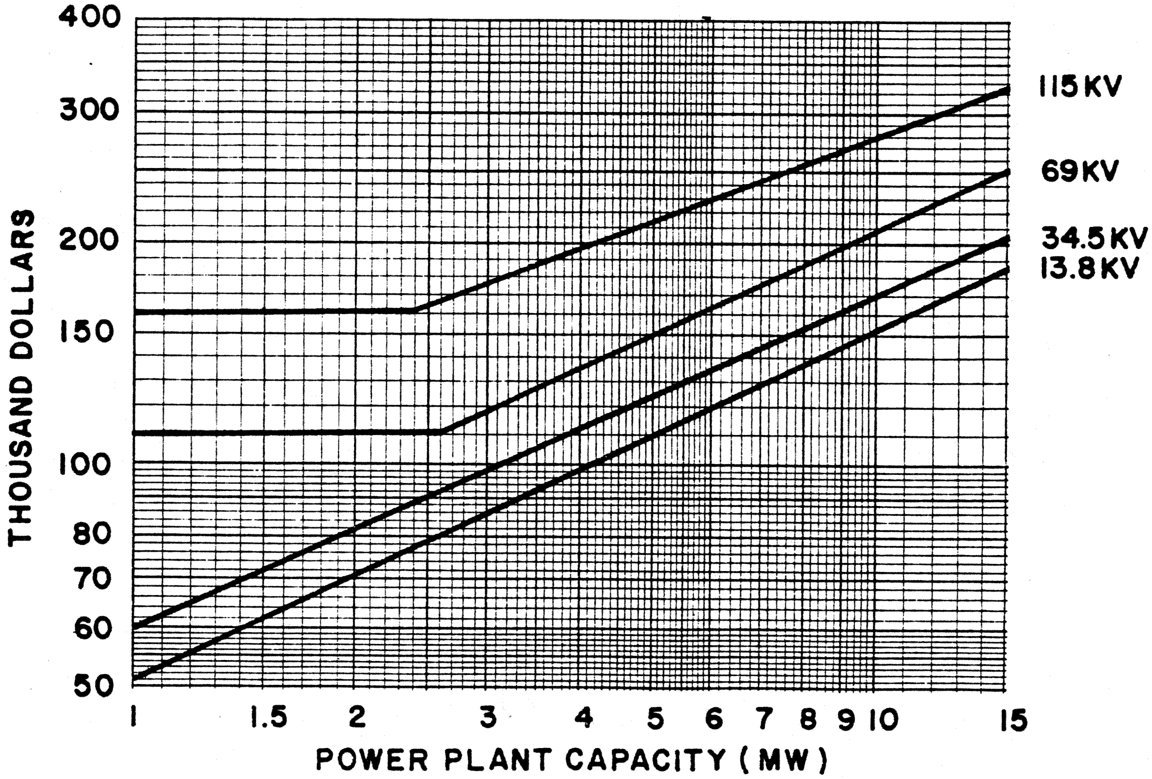


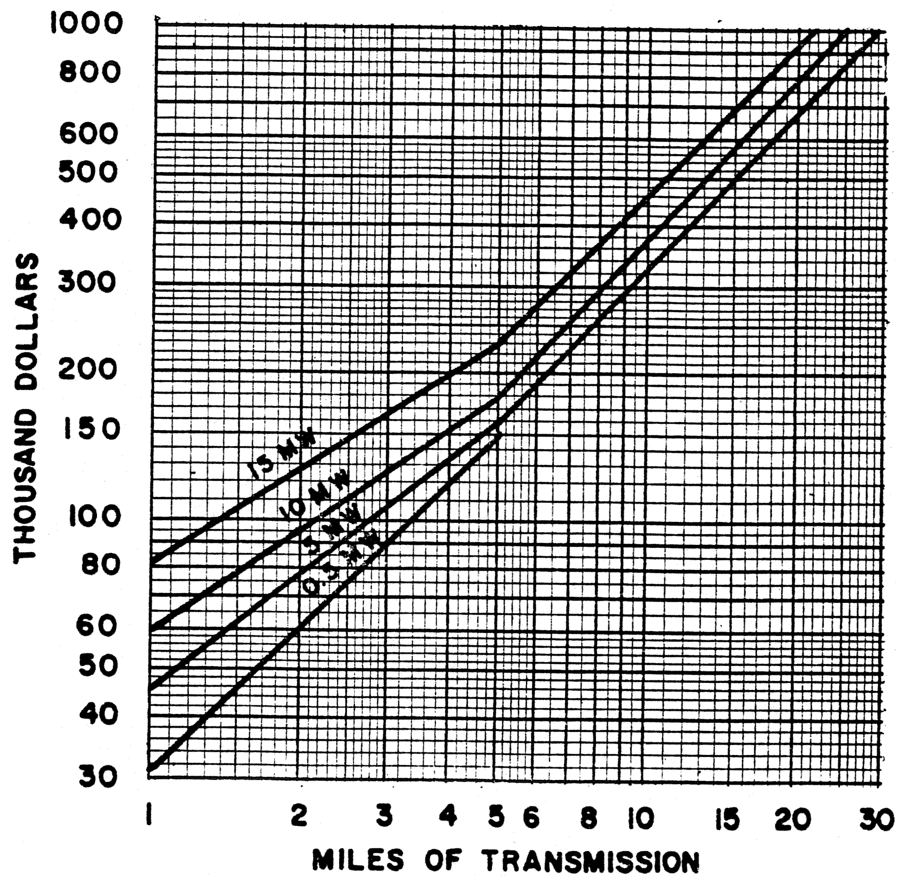
Figure 6-2. Switchyard for McSwain Power Plant. (Courtesy of Merced Irrigation District)



NOTES:

1. The major Equipment is listed below:
   a. Main Step-up Transformer
   b. Line Side Oil Circuit Breaker
   c. Lightning Arresters
   d. Air-Break Switches
   e. Bus work
2. Costs include 25 percent for freight and installation.
3. Foundations and Switchyard structures are covered in the Civil Features (Volume VI).
4. Above costs reflect a design of 45 feet of generator buswork. For extension beyond 45 feet, use a factor of $200 per foot for generator buswork.
5. Cost index is July,1978.

Figure 6-3. Switchyard equipment costs



NOTES:

1. Direct Costs are for Prairie Construction and favorable foundation conditions.
2. Costs should be increased for areas with more difficult access (up to 50 percent for swampy or mountainous areas).
3. Costs should be increased for unfavorable foundation conditions (up to 50 percent for swampy or rocky areas).
4. Direct Costs include normal construction road costs but do not include any contingencies, land and rights, relocations or clearing and access roads.
5. It is not feasible to transfer 500 kW more than 5 miles because of line loss of power. A limiting distance of efficient transfer should be calculated for values up to 5000 kW to ensure that a design be feasible.
6. Cost index is July, 1978.

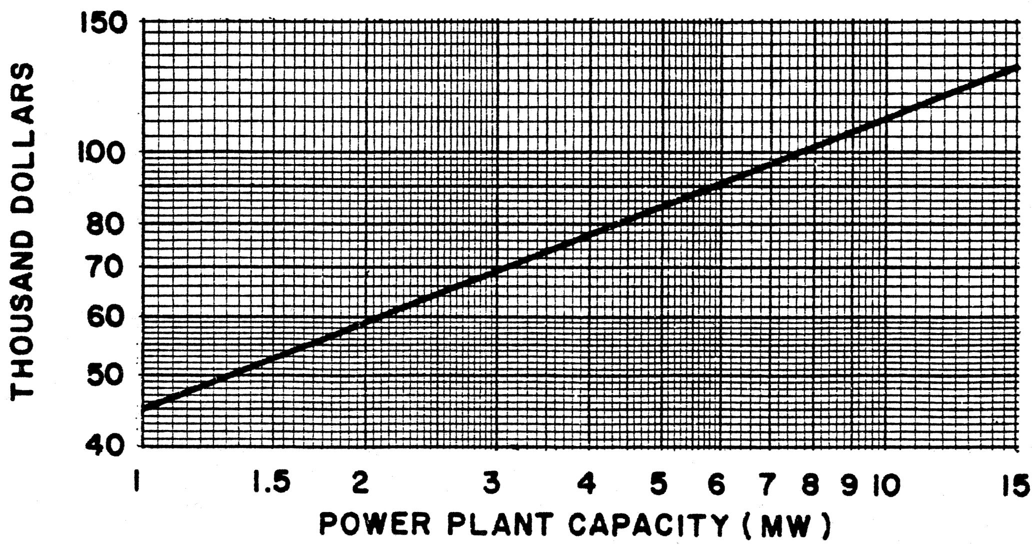
Figure 6-4. Transmission line costs

mended for small hydroelectric plants. Due to size and cost of equipment, it is considered more economical to bring in portable equipment for major plant overhauls. Provisions for a portable gantry crane for larger power plants should be provided. This would include crane rails embedded in the generator deck and a power connection. Appropriate hatches should be provided for access to all movable machinery.

Miscellaneous. An eye wash bath and a ventilating fan for battery area are required for safety of the workers.

Fire Protection System. The fire protection system included in the cost is for a detector operated CO_2 system for extinguishing fires in generator housings and for hand held portable extinguishers for other fire protection.

Cost Data. Figure 6-5 contains data for estimating the cost of miscellaneous power plant equipment. The costs contain only the minimal equipment as described in the previous paragraphs. For an attended station with facilities for operators and maintenance personnel, the costs should be increased by a factor of 2 to 3.



NOTES:

1. The Major Miscellaneous Power Plant Equipment is listed below:
   a. Ventilation Equipment
   b. Fire Protection Equipment
   c. Communication Equipment
   d. Generation Bearing Cooling Water Equipment
2. Communication equipment includes alarm and communication facilities for unattended operation of unit; further cost figures should be obtained for very remote locations or integration with complex communication networks.
3. All figures shown include a 15 percent factor for freight and installation.
4. Cost index is July, 1978.

Figure 6-5. Miscellaneous power plant equipment costs

SECTION 7
COST SUMMARY

Additional Cost Considerations

This section will provide a cost summary and describe additional factors which should be considered in the preparation of an estimate for the electromechanical equipment of a small hydropower plant. These factors include escalation, development costs, and annual operation and maintenance costs.

Escalation. The costs for the electromechanical features described in the previous sections were given as July 1978 bid prices. In order to determine the equipment costs after that date, the previously presented costs must be excalated to the desired future date. The bid price, escalated to the desired future date, may be determined by use of the U.S. Bureau of Reclamation indices. These indices are published quarterly and indicate constructuion cost trends. The quarterly publication is known as *Construction Cost Trends* and can be obtained from any USBR regional office. In the Sacramento region, the publication can be obtained by writing the Bureau at 2800 Cottage Way, Sacramento, CA 95825, Attn: M.P. 200. The indices are also published quarterly in *Engineering News Record.*

In order to determine escalated costs, it is first necessary to plot all up-to-date indices on the graphs provided in Figure 7-1. After plotting the indices, the resulting curve should be extrapolated to the desired future date. The extrapolation should be an extension of the latest trend in the indices. After extending the curve, the appropriate index should be picked off for the desired future date.

Once the index for the desired future date is known, it is then possible to estimate the equipment cost for that date. The equipment costs obtained from previous sections of the report should be multiplied by the index for the desired future date, then divided by the July 1978 index. The resulting figure is the facility bid price, escalated to the desired future date.

Contingency. A contingency allowance should be added to the escalated prices to cover the unknown items and items omitted which would normally be covered with a more detailed cost estimate. Contingency is also considered an allowance for possible cost increases do to unforeseen conditions. This allowance is normally taken to be 10 to 20 percent of the escalated prices. The percentage used should reflect upon the confidence level of the data used.

Engineering, Construction Management and Other Costs

Once the escalated construction cost has been determined, it is necessary to estimate the engineering, construction management and administration costs, sometimes referred to as development costs or indirect costs. These costs include expenditures for feasibility study, license and permit applications, preliminary and final design, construction management, and administration. A multiplier of 20 percent should be applied to the total escalated construction cost, including contingencies, to estimate these development costs.

For a more detailed breakdown of these development costs the following percentages, applied to escalated constructuion costs plus contingencies, may be used:

Feasibility Study	2%
License and Permit Applications	2%
Preliminary Design	3%
Final Design	6.5%
Construction Management	5.5%
Administration	1%

The above percentages are for electromechanical costs only, hence the multipliers should be applied only to electromechanical bid costs. Not included in the above development costs are interest during construction, legal fees and financing fees. These omitted costs will be covered in Volume II which describes economic and financial considerations.

Operation and Maintenance Costs

Operation and maintenance costs for small hydropower plants are difficult to forecast accurately. The costs are directly related to the site and owner's capability to perform the operation and maintenance function. The amounts which are suggested to be used in this report are based on those published by the U.S. Bureau of Reclamation and are updated to reflect recent experience.

Operation and maintenance costs as described herein, include the items listed below.

Insurance. The Government is basically a self-insurer, however, for a commercial installation, coverage is required for fire and storm damage, vandalism, property damage and public liability. Insurance can also be purchased for major mechanical or electrical damage. This latter insurance is not usually considered for small hydropower installations.

Routine Maintenance and Operation. An amount must be budgeted to cover the costs of manpower, wages, services, equipment and parts utilized in the normal operation and maintenance of the hydroelectric plant.

Interim Replacement. During the life of a hydroelectric project, miscellaneous equipment and facilities will wear out and require replacement. This replacement is in addition to those routine replacements

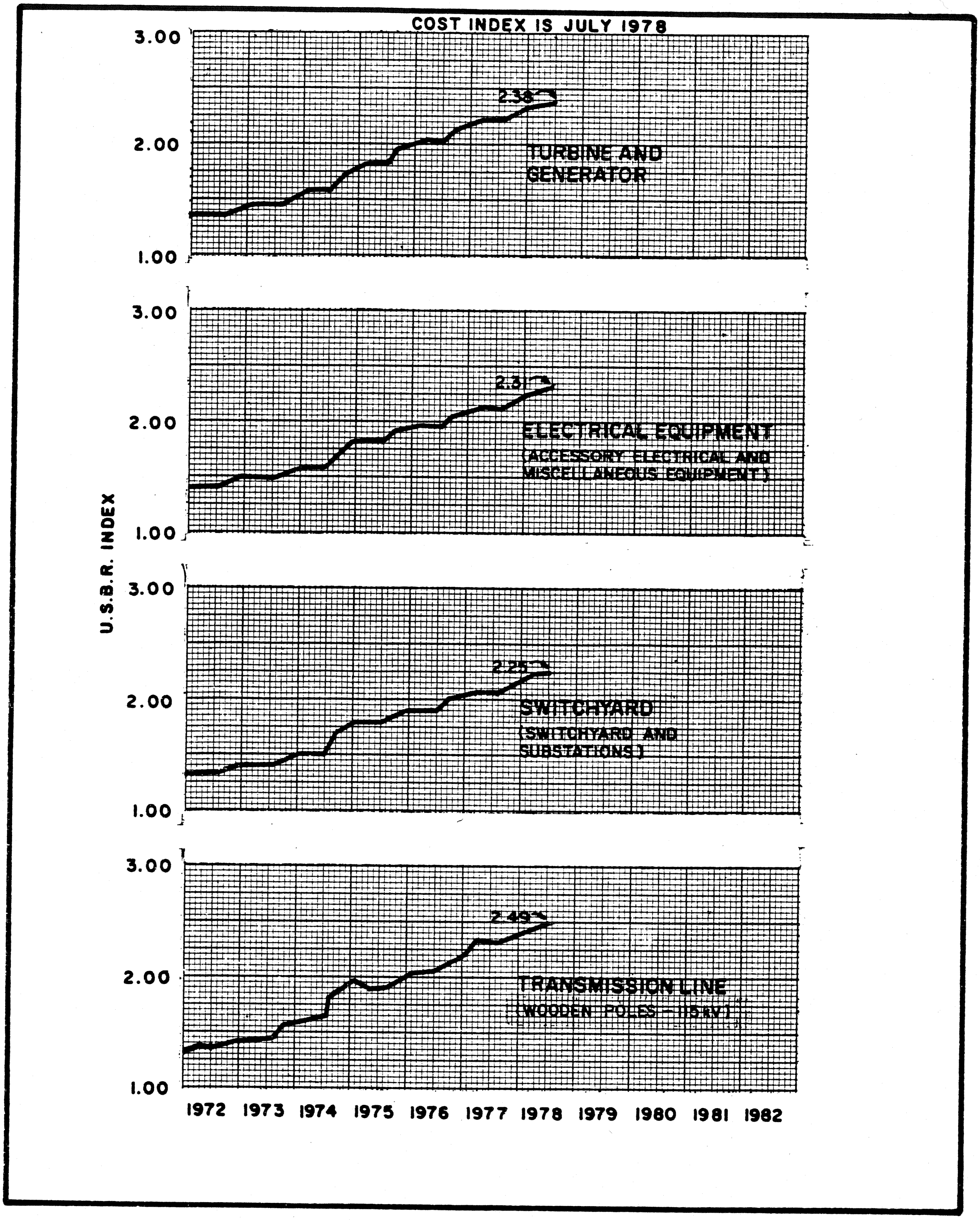


Figure 7-1. Escalation Costs

covered in normal plant maintenance. A sinking fund should be established for these interim replacements. For the most preliminary studies, the yearly deposit into this sinking fund should be taken as 0.1 percent of total construction cost plus contingencies.

General Expenses. The final portion of operation and maintenance costs are made up of those expenditures for administration fees and other miscellaneous costs required during project operation.

Total Annual Cost. The total annual cost of operation and maintenance expenses can be estimated by multiplying the investment cost, i.e., escalated bid price, contingencies and development costs, for plant facilities, by 1.2 percent. The resulting amount will be the estimated cost for operation and maintenance of the hydroelectric plant for the first year of operation. The annual operation and maintenance costs will increase with time, corresponding to inflationary trends. The current annual increase for operation and maintenance costs is taken to be 6-1/2 percent.

There are two final comments to be observed in determining the operation and maintenance costs of hydroelectric plant electromechanical facilities. First, the annual costs for operation and maintenance should never be estimated below a certain minimum amount, approximately $20,000 in 1978 dollars. Second, the multiplier given previously, 1.2 percent, should be used only if the owner can integrate the operation of the small hydropower facility with other related operations. If the operating entity will operate and maintain only the small hydropower facility under consideration, a multiplier of 2 to 4 percent should be used to determine annual O&M costs.

Manpower Allocation for Studies. The allotment of time for the preparation of feasibility studies for small hydroelectric power plants varies depending upon site conditions and degree of depth of the study. As a general rule of thumb, however, approximately ten man-days should be allocated for the electromechanical portion of the study. Of that total, approximately 10 percent would be spent by a lead Hydroelectric Engineer with experience in Hydropower or electromechanical projects. An experienced Mechanical Engineer would spend approximately 35 percent of the man-hour allocation, and an experienced Electrical Engineer would spend approximately 25 percent. The remainder of the man-hour allocations, approximately 30 percent, would be spent by a designer and draftperson, familiar with engineering calculations. For more complex sites, or if substantial text is required, the required manpower will increase. Guidelines have been established by various professional organizations which indicate that feasibility studies should cost between one and two percent of the total project costs. The larger percentage is applicable to more complex installations.

Cost Summary

Figure 7-2 is a cost estimate summary sheet for the electromechanical components of a small hydroelectric power plant. Account numbers have been assigned to correspond with the account number assigned by the Federal Energy Regulatory Commission. Each item is referenced to the chart as section of the report providing cost data. The cost data contained in this report is adequate for indication as to the feasibility of a potential hydroelectric power site. As indicated pre viously, actual prices on equipment should be obtained whenever possible for a final feasibility determination.

COST ESTIMATE SHEET

PROJECT ______________ PLANT CAP. ______________ MW DATE ______________

JOB NO. ______________ ANN ENERGY ______________ MKWH BY ______________

ACCOUNT NO.	DESCRIPTION	QUANTITY	UNIT COST	COSTS JULY 1978	Escalation Factor	COSTS DATE
333	WATER WHEELS, TURBINES AND GENERATORS TURB. TYPE GEN. TYPE RATING MW FT. D_2 FT. INSTALLAED COST (FIG 3-12 TO 3-16)					
334	STATION ELECTRICAL EQUIPMENT TRANSFORMER, LIGHTING ARRESTOR, AIR BREAKER SWT, GEN. BREAKER AND LINE OCB (FIG. 6-3)...................... BATTERY SYS., STA. SWT GEAR, STA. SER. TRANS.,BUS,CABLE CONDUIT, GRD., CONTROL BD., LIGHTING SYS., FREIGHT AND INSTALLATION (FIG. 5-4)............................					
335	MISC. POWER PLANT EQUIPMENT VENTILATION, FIRE PROTECTION, COOLING WATER, COMMUNICATION SYS., FREIGHT AND INSTALLATION (FIG. 6-5)..					
350	TRANSMISSION LINE LENGTH MI VOLT. KV (FIG. 6-4)..............					
COST PER INSTALLED KW				SUB TOTAL		
	CONTINGENCY (%)					
				SUB TOTAL		
	ENGINEERING, CONSTR. MG. & OTHER COSTS (20%)					
	TOTAL INSTALLED COST					

Figure 7-2. Cost summary sheet

REFERENCES

Alcoa Aluminum Overhead Conductor Engineering Data, 1960, Section 5, p. 79-83.

Fink, D. G., and Carroll, J. M., 1968, *Standard Handbook for Electrical Engineers,* Section 6.

U. S. Army Corps of Engineers, *Reservoir System Analysis for Conservation HEC-5C,* Computer Program 723-X6-L2500.

United States Department of Interior, Bureau of Reclamation, *Selecting Hydraulic Reaction Turbines, Engineering Monograph No. 20,* 1976.

EXHIBIT I

TURBINE MANUFACTURERS

Name/Address/Offices	Type Manufactured
Allis Chalmers Corp. Hydro Turbine Div. P.O. Box 712 York, PA 17405 (U.S.A.)	Francis, Impulse, Kaplan, Propeller, Tube, Slant and Standardized Tube
Axel-Johnson Corp. 1 Market Plaza San Francisco, CA. 94105 (Sweden-U.S.A.)	Francis, Impulse, Kaplan, Propeller, Tube and Slant
Barber Hydraulic Turbines Ltd. 65 Queen St. West Toronto, Ontario, Canada 195H2195 (Canada)	Vertical, Horizontal and open flume Francis-Packaged Hydro Units
Bell Hydropower 3 Leather Stocking St. Cooperstown, N.Y. 13326 (U.S.A.)	Crossflow
Charmilles Krupp International Inc. 550 Manaronek Ave. Harrison, NY 10528 (Switzerland)	Francis, Impulse, Kaplan, Propeller, Tube, Slant
Dominion Engineering P.O. Box 220 Montreal, Canada (Canada)	Francis, Kaplan, Propeller, Bulb and Tube
Fuji Electric Co. Nissho-Iwai American Co. 700 So. Flower St. Los Angeles, CA 90017 (Japan)	Francis, Kaplan, Propeller and Standardized Bulb
General Electric Co. 55 Hawthorne St. San Francisco, CA 94105 (U.S.A.)	Francis, Kaplan and Propeller
Hitachi America Ltd. 100 California St. San Francisco, CA. 94111 (Japan)	Francis, Kaplan, Propeller and Bulb
Independent Power Developers Rte. 3 Box 285 Sandpoint, Idaho 83864 (U.S.A.)	Impulse and Propeller
Kvaerner-Moss Inc. 800 - 3rd Ave. New York, N.Y. 10022 (Norway)	Francis, Impulse, Kaplan, Tube and Slant-Standardized Units

James Leffel & Co. 426 East St. Springfield, Ohio 45501 (U.S.A.)	Francis, Impulse, Kaplan, Propeller and Open Flume.
Mitsubishi International Corp. 50 California St. San Francisco, CA 94111 (Japan)	Francis, Kaplan, Propeller, Bulb, Slant and Tube
Neyrpic Alsthon-Atlantic 50 Rockefeller Plaza New York, N.Y. 10022 (France)	Francis, Impulse, Kaplan, Propeller, Bulb, Slant and Tube
Noble Automated Systems Inc. 226 Phelan Ave. San Jose, CA. 95112 (U.S.A.)	Impulse
Ossberger Turbines F.W.E. Stapenhorst Inc. 285 Labrosse Ave. Pt. Claire, Quebec H9R1A3 (Canada)	Crossflow
Siemens-Allis Utility Sales Operation P.O. Box 89000 Atlanta, GA. 30338 (U.S.A.)	Bulb
Sulzer Bros. Inc 1255 Post St. San Francisco, CA. 94109 (Switzerland)	Francis, Impulse, Kaplan, Propeller, Bulb, Slant and Tube
Voest-Alpine 1923 Magellan Dr. Oakland, CA. 94611 (Austria)	Francis, Impulse, Kaplan, Propeller, Bulb, Slant and Tube
Westinghouse Electric One Maritime Plaza San Francisco, CA. 94111 (U.S.A.)	Bulb

EXHIBIT II

GENERATOR MANUFACTURERS

ASEA Inc.
4 New King Street
White Plains, New York 10604
(Sweden)

Beloit Power Systems
555 Lawton Avenue
Beloit, Wisconsin 53511
(U.S.A.)

Electric Machinery Manufacturing Company
800 Central Avenue
Minneapolis, Minnesota 55413
(U.S.A.)

General Electric Company
1 River Road
Large Motor and Generator Department
Schenectady, New York 12345
(U.S.A.)

Hitachi America, Ltd.
100 California Street
San Francisco, California 94111
(Japan)

Ideal Electric
330 East First Street
Mansfield, Ohio 44903
(U.S.A.)

Kato Engineering Company
1415 First Avenue
Mankato, Minnesota 56001
(U.S.A.)

Westinghouse Electric Corporation
Hydro Generator Department
700 Braddock Avenue
East Pittsburgh, Pennsylvania 15112
(U.S.A.)

Siemens - Allis
P.O. Box 2168
Milwaukee, Wisconsin 53201
(U.S.A.)