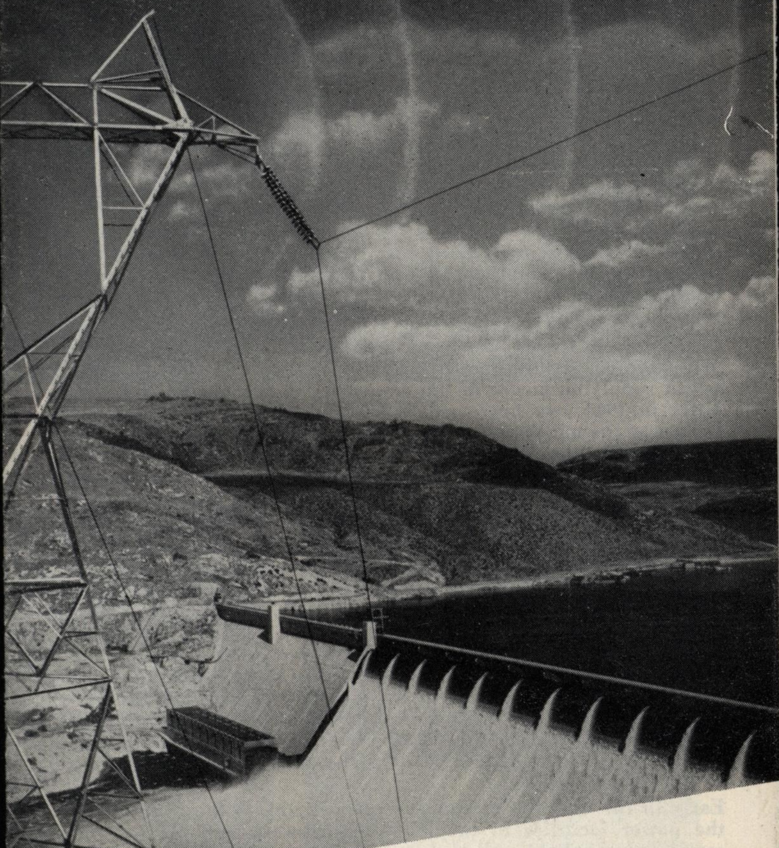
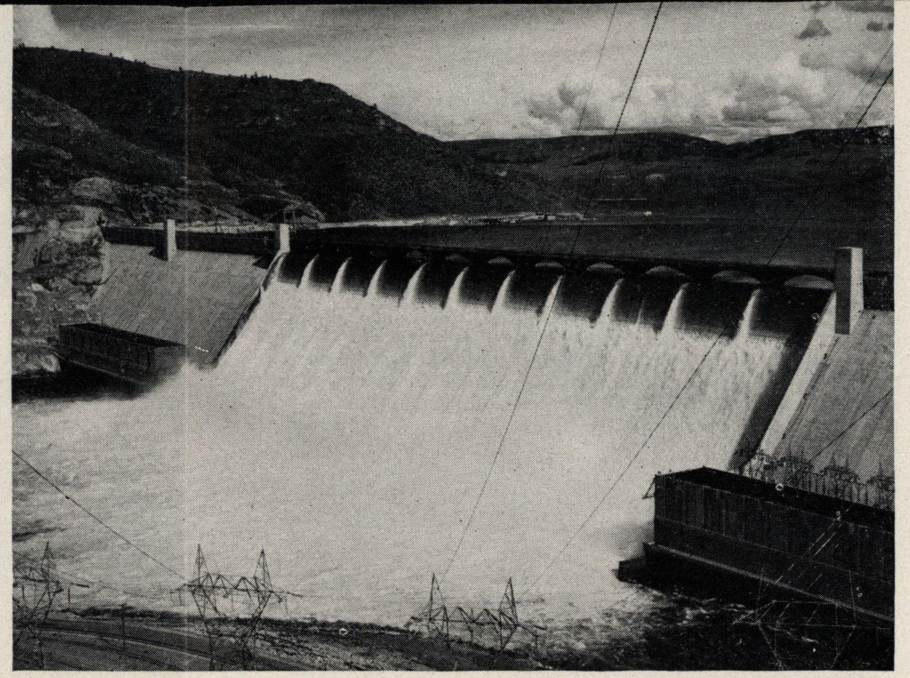
Electric POWER from the COLUMBIA BASIN RECLAMATION PROJECT



UNITED STATES
DEPARTMENT OF THE INTERIOR
J. A. KRUG, *Secretary*
BUREAU OF RECLAMATION, Michael W. Straus, *Commissioner*

POWER FOR WAR AND PEACE



Grand Coulee Dam

SEVERAL times during World War II the power plant at Grand Coulee Dam was the world's greatest power producer, running for weeks with all generators overloaded continuously. Peak loads exceeded 962,000 kilowatts. Outputs were frequently close to 22 million kilowatt-hours a day, and more than 600 million kilowatt-hours a month.

The first commercial delivery of power from Grand Coulee Dam was made on March 22, 1941, when, as an emergency measure, two 10,000-kilowatt generating units, designed to carry only local loads, were connected to the 234-mile transmission lines joining Grand Coulee and Bonneville Dams, to help fill the pressing demand for electricity for defense industries, particularly for the production of aluminum. On the first of October 1941, the first of the large generating units to be completed replaced the smaller units in commercial service.

Shortly after war was declared (January 24, 1942) a second large generator was ready for service, and on April 7, 1942, the third began supplying power to war industries in the Pacific Northwest. Early in 1943, two borrowed 75,000-kilowatt generating sets, built for use at the uncompleted Shasta Dam in northern California, were carrying wartime overloads in the power plant at Grand Coulee, and later in the same year the number of large units was increased to five. The sixth of the large generators added its output to the wartime power supply on February 11, 1944.

Three Government agencies participated in the war power program in the Pacific Northwest—two power producers and one distributor. The producers were the Army Engineers, who built and operate the dam and power plant at Bonneville near Portland, Oreg., and the Bureau of Reclamation, which built and operates the Grand Coulee Dam and power plant. The distributor of power from the two great Government power plants on the Columbia River is the Bonneville Power Administration. It built and operates the Government power transmission system which interconnects the Government power plants with each other and with the load centers near Spokane, Portland, Seattle, and Tacoma. It is the great wholesaler of power in the Pacific Northwest.

Early in the war, for the purpose of utilizing to the fullest extent the power facilities in the Pacific Northwest, and making their service more reliable, all the power systems, public and private, in Washington, Oregon, Idaho, western Montana, and northern Utah were interconnected to form the Northwest Power Pool. When operating separately, each system had idle equipment, for use in emergencies only, and each was dependent for its output on the stream flow and water storage facilities in its own territory. Each had been designed to serve ordinary domestic and municipal purposes, and industries operating on a peacetime basis. The needs of war industries increased greatly the demands for power, and lengthened the working day—in some industries to 24 hours.

Through the Northwest Power Pool surplus power in one area can be made available in some other area where there is a deficiency, either because of water shortage or because of heavy demands for power. Interchange of power also reduced the amount of steam power used during the war, and saved large quantities of critical fuel oil and coal. The Government-owned power plants and high-voltage transmission system constitute a "backbone" for the huge interconnected system. The plant at Grand Coulee Dam is by far the largest plant in the system. It is well situated, near the center of gravity of the system, and can send its power to the east, south, or west, wherever power is needed. During the war, the plant at Grand Coulee was the only one in the pool with sufficient water available to run it full time, throughout the year, with a full load.

A large part of the output of the Government plants at Grand Coulee and Bonneville went directly into war work, especially into the production of light metals and the rolling of aluminum. Power for the atom-smashing plant of the Hanford Engineer Works was supplied from the power plant at Grand Coulee Dam. However, much of the output was supplied to municipal and private power systems, where it was distributed to shipyards, airplane plants, tank factories, machine shops, and to hundreds of shops and factories, large and small, engaged in producing war matériel.

Now that the war is over, the huge power facilities at Grand Coulee Dam can be turned to the constructive work of peace. They will supply water for irrigating more than a million acres of potentially irrigable land in the Columbia Basin, where thousands of returned war veterans may find homes. Power from these facilities will be available to light and heat homes, and through use of electrical appliances and machinery, save labor in the home and on the farm. The huge generators are ready to develop our rich mineral resources, and to serve factories and industries, all working for the benefit of the people. As the demand for power increases, more generators will be installed, until the full capability of this project is utilized.

Sensitive Instruments Control Production

Power producers, unlike manufacturers of merchandise, cannot carry spare goods in stock to cover temporary underproduction or to meet a sudden demand; they must produce power to order, instantly, on the closing of a switch, and production must be reduced instantly when the demand is reduced. Electrical pressure (voltage) and the frequency in alternating-current circuits must be held very close to standard values. Intricate, sensitive, automatic regulating devices are required.

When many generators are supplying power to a network, it is the practice to set the governors of all but one or two of them so that each will supply power to the network at a uniform rate. Since the demand for power varies constantly, the governors on one or more of the generating units feeding the network are made highly sensitive to speed changes, and consequently to changes in load. Automatically, the governors regulate the flow of water to the corresponding turbines, increasing the water supply to the turbine runners as the load increases, and reducing it as the load diminishes, and so maintaining normal frequency and generator speed.

The generating unit that handles the fluctuations in the load performs another important function; it regulates the speed of all of the other generators in the network, and, incidentally, the speed of all of the electric clocks in the area served by it. Electric clocks are really not clocks at all; they have in them no time-measuring devices like the hair springs and balance wheels of watches or the pendulums of clocks; and they cannot keep time on their own resources. They are only electric motors running in step with the generators that drive them, and turning clock hands at a rate determined by the generator speed.

In order that the generators, and consequently the electric clocks in the area served, will turn at the right rate, the Grand Coulee power plant is provided with a master clock, which is compared with naval observatory time four times each day by means of short-wave radio time signal, and is corrected if necessary. The error is seldom more than a few tenths of a second, but correction for even such small errors can be made by turning dials on the control board.

The master clock is of unusual design. It contains the essentials of a clock—a source of power to make it go, a time-measuring device, and a mechanism to turn hands to indicate the passage of time—and to tell time if the clock is set correctly. But it differs in detail from ordinary clocks and watches—a storage battery takes the place of springs and weights as prime mover, a tuning fork vibrating 60 times a second measures time, and a small synchronous motor turns the clock hands at a rate fixed by the tuning fork vibrations. A feeble pulsating electric current generated by the vibrating fork is "amplified" by vacuum tubes like those in a radio set, that is, the vacuum tubes have the effect of releasing energy from the storage battery in pulsations timed by the tuning fork. Thus, the tuning fork times the clock motor.

As a means of keeping the generators running with actual clocklike regularity, electric impulses from the master clock are delivered to a "time-error indicator" on the control board, which also receives electric impulses from the "regulating" generator. If the generators run ahead of or lag behind the rate set by the clock, the electric impulses received from the generator and the clock cause the hand of the time-error indicator to show, in tenths of a second, how much the generators (and the power consumers' electric clocks) are fast or slow with respect to the master clock.

Whenever the time-error indicator shows the generators to be ahead of or behind the master clock, a second intricate instrument, the "load and frequency controller"—actuated by the time-error indicator—adjusts the turbine governor, and admits more or less water to the turbine wheel, to change slightly the turbine speed and to bring the generators in the power plants and electric clocks on the power network back into correct time relation with the master clock.

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Enabling power purchasers to tell time by electric clocks (if the owners set them correctly) is really a minor function of the intricate and highly sensitive instruments in modern power plants. Their really important functions are the regulating and the protecting of numerous, and perhaps widely scattered, electrical generating units, with the promptness and accuracy of which men are not capable, to the end that a continuous and dependable power supply may be available for industrial and domestic uses in time of peace, and for defense in time of war.

Creating World's Largest Power Plant

Each large generating unit at the Grand Coulee Dam includes a vertical-shaft turbine rated 150,000 horsepower. Water from the reservoir is admitted to a turbine through an 18-foot steel penstock embedded in the dam, entering first the turbine scroll case (1), which is a spiral water passage around the cylindrical wheel chamber. The scroll case, 51 feet wide, and weighing 291 tons, was embedded in reinforced concrete while under an internal water pressure of 145 pounds per square inch.

Power is derived from the turbine by the reaction of swiftly flowing water on the curved vanes of the 16-foot turbine wheel or runner (2), a single steel casting weighing about 60 tons, set inside the scroll case. When the turbine carries its rated load, water passes through it at the rate of 141 tons a second, moving at velocities of about 12 miles per hour in the penstock, nearly 20 in the scroll case, and in excess of 50 as it leaves the scroll case through a 34-inch annular opening, and enters the runner. Passing downward through the runner, the water enters the draft tube, and is discharged downstream at a velocity of less than 5 miles per hour.

The turbines are set low, near the river's low-water level, so that the turbine and draft tube are practically always under pressure. Generators are set on concrete piers over the turbines, above normal high-water levels.

Connecting a turbine and generator is a shaft 44 inches in diameter, more than 70 feet long, and weighing about 200 tons. (3) Its three sections are connected by means of 75-inch flanges, held together by 5.75-inch bolts, made oversize, and shrunk by chilling in dry ice before they can be put in place.

Governors Maintain Precise Speed

The speed of modern generating units is regulated so closely that electric clocks, running in synchronism with them, are reliable timekeepers. As the load on a generator is increased, it tends to slow down; and it does, in fact, slow down very briefly and very slightly before gates can be opened and more water can be passed through the turbine to carry the added load and to maintain the normal speed.

The flow of water through a turbine is controlled by adjusting the positions of a series of rectangular wicket gates inside the turbine casing, overlapping each other like the slats of a venetian blind, and set around the water wheel, in the gap through which water flows out of the scroll case to the runner.

A governing mechanism (4), driven in exact synchronism with the generator, includes a pair of revolving "flyballs," which droop if the generator slows down, or swing outward if its speed is increased by a reduction in generator load. In so doing, they move a sensitive pilot valve, and cause oil under a pressure of 250 pounds per square inch to move the pistons in two large cylinders. Through them the governor adjusts the openings between the wicket gates and admits more or less water to the turbine runner, as may be required to maintain the rated speed.

The action of the governor may be made responsive to a change of one one-hundredth of one percent in the generator speed.

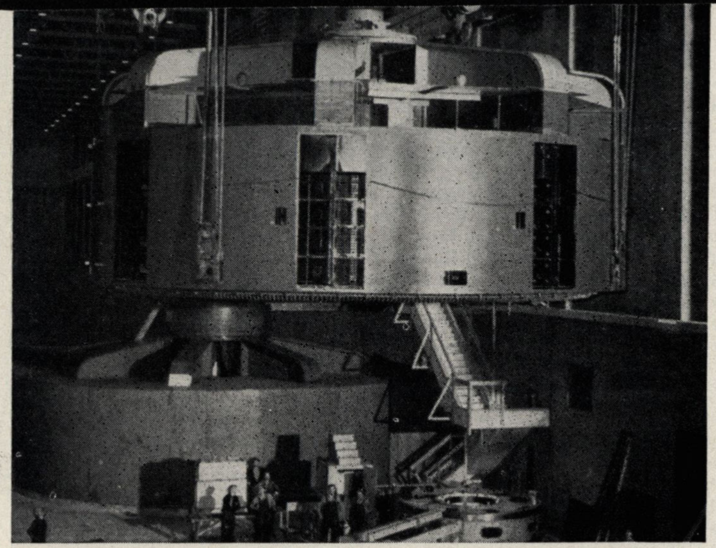
Generators Assembled at the Dam

One of the two large essential parts of a generator is the stator (5), a cylindrical structure 37 feet in diameter and nearly 10 feet high. Each stator was shipped from the factory in four 68-ton sections. Here the sections were assembled in unoccupied turbine pits, and coils were placed across the joints. The coils are made of heavy copper bars, insulated with mica, asbestos, and glass tape, and are set in slots in the laminated steel magnetic core of the stator.

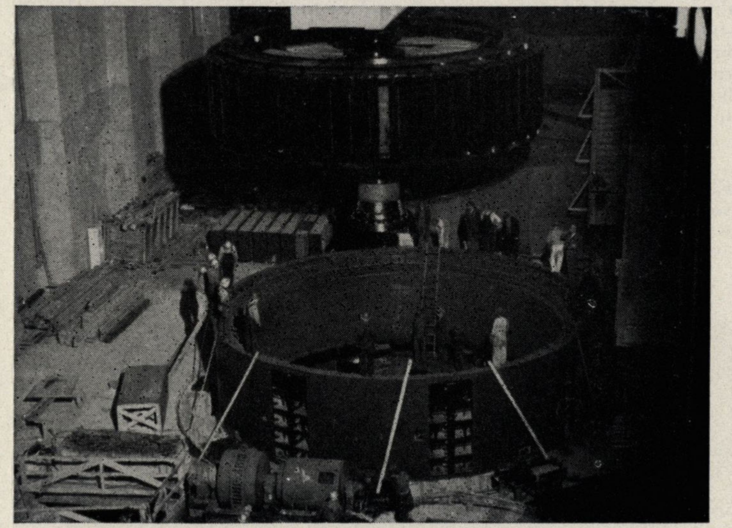
Heaviest of the generator parts is the rotor (6), a 587-ton mass of steel and copper, which revolves inside the stator. In assembling it, the 31-foot section of shaft was set on end on an accurately leveled, finished casting, and the 60-ton cast steel spider, its hub expanded by heating, was lowered in place upon it.

Around the ends of the spider arms, a rim 20½ inches thick radially, and 79 inches high, was then built up of steel plates, one-eighth of an inch thick. Lugs on the plates engage rectangular slots in the ends of the spider arms, to transfer the turbine's driving force from the spider to the rim. Keys driven in the bottoms of these slots, after the massive rim had been expanded by electric heating, made the rim tight upon the spider after cooling.

Sixty powerful electromagnets, each weighing two and a quarter tons, were then attached by dovetail connections to the outside surface of the rim. By shifting across the coils in the stator the powerful magnetic fields which this revolving group of magnets projects into the stator core, the power output of the turbine is expended in generating electricity in the stator windings.

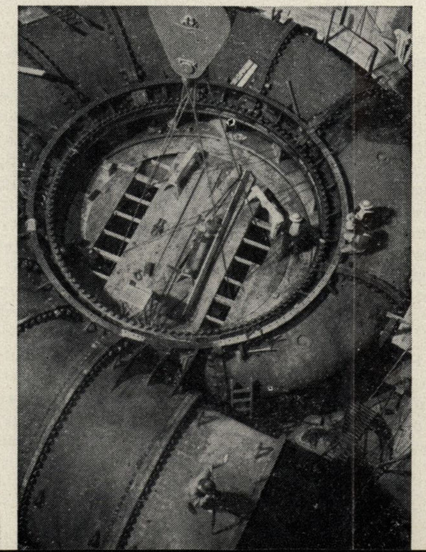


(7) *Placing stator*

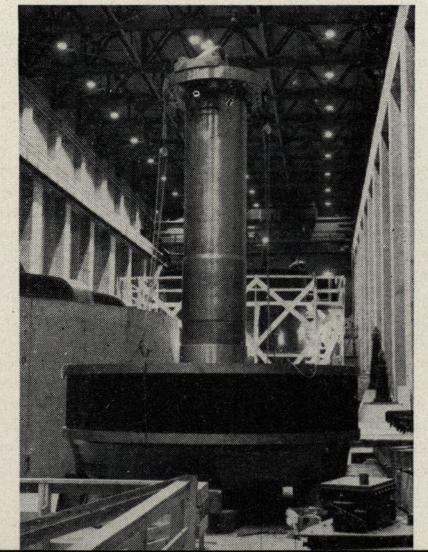


(8) *Placing rotor*

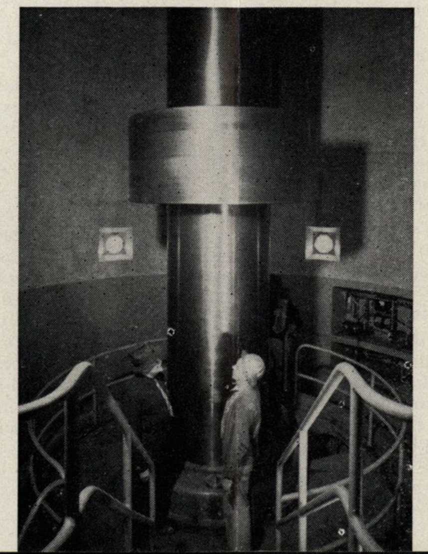
(1) *Turbine scroll case*



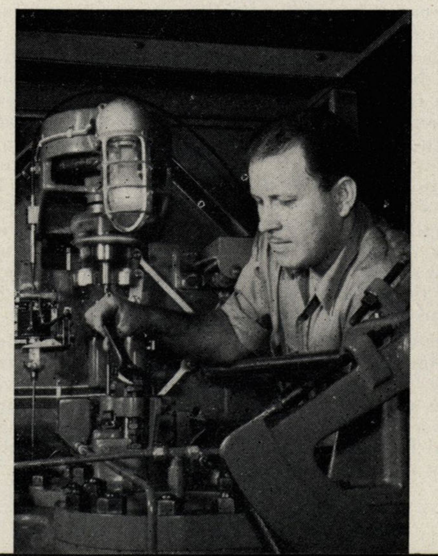
(2) *Turbine water wheel*



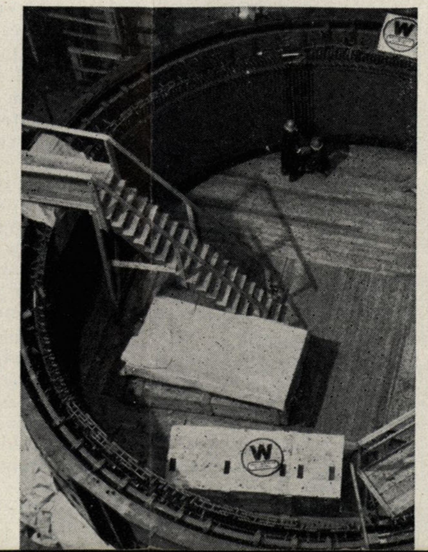
(3) *Turbine shaft*



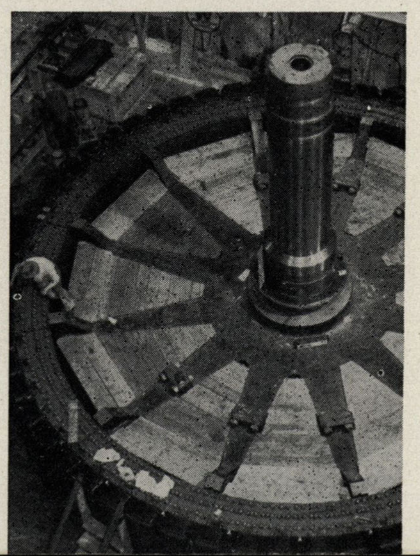
(4) *Turbine governor*



(5) *Generator stator*



(6) *Generator rotor*



Before a stator was moved from the assembly floor to its permanent location (7), an upper generator bracket, consisting of eight radiating cantilever beams attached to central steel rings, and weighing 160 tons, was set down upon it, and bolted in place to stiffen it. Then the two 350-ton bridge cranes let down their four large hooks, lifted the 430-ton combination from the assembly floor, and set it down on the base prepared for it.

After a stator was shifted slightly, if necessary, to make it exactly concentric with the turbine shaft, and was secured in that position by dowels and bolts, a rotor (8) was moved into place by the two bridge cranes, using a 65-ton equalizer between the cranes and rotor, to distribute the 650-ton load evenly among the four crane hooks.

Thrust Bearing Carries Huge Load

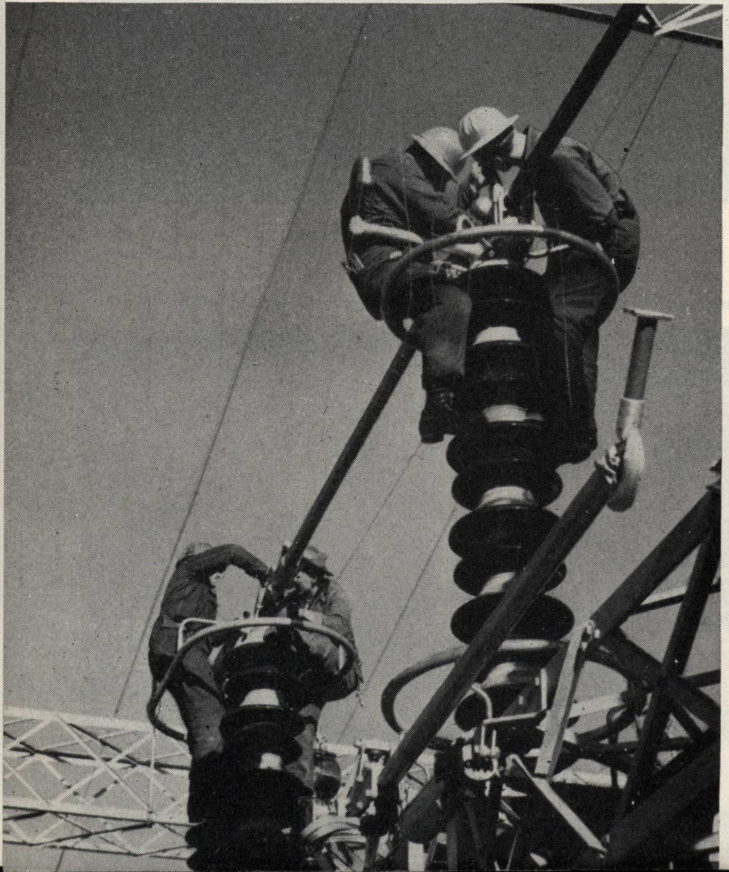
A heavy guide bearing, supported on the turbine casing, just above the runner, and two lighter guide bearings, one above and one below the rotor, restrain the shaft from lateral movement. They carry no vertical load.

All the rotating parts—rotor, shaft, and turbine runner—are suspended from a thrust bearing (9) on the top of the generator.

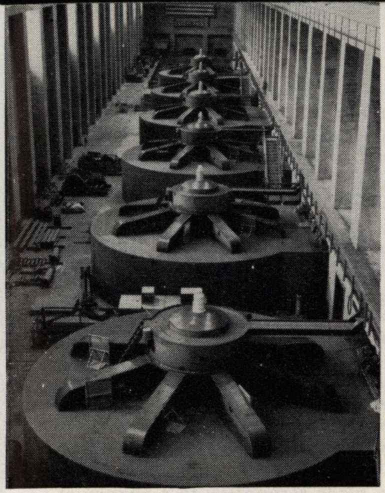
The thrust bearing consists of an 8-foot cast-iron ring (the thrust runner) mounted on a cast-steel thrust collar which is attached to the upper end of the rotor shaft, and eight stationary babbit-faced steel thrust blocks, supported on pivots on the generator's upper bracket. The highly finished down-turned face of the cast-iron thrust runner is carried on a thin film of oil between it and the upturned babbitted faces of the thrust blocks. The entire bearing is immersed in a bath of water-cooled oil.

Voltage Stepped Up for Transmission

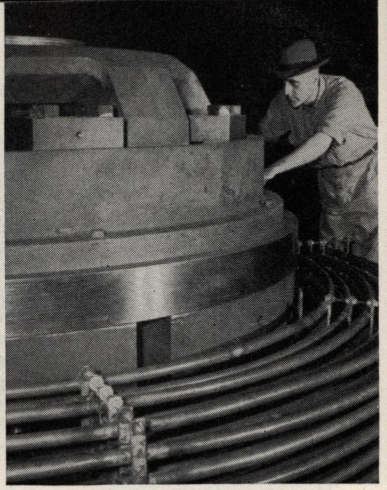
Electrical energy, generated at 13,800 volts, is stepped up to 230,000 volts for long-distance transmission, in groups of three 36,000-kilowatt transformers. Each transformer is 12 feet wide, 20 feet long, and 29 feet high over insulators, and each weighs 125 tons when charged



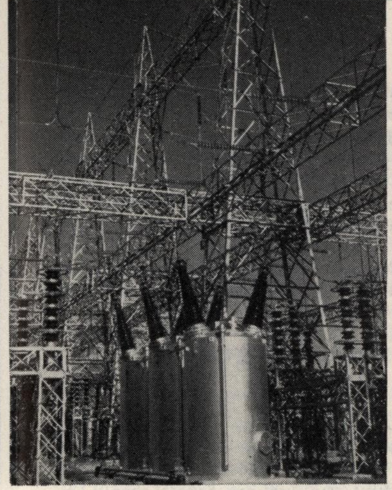
Disconnecting switches



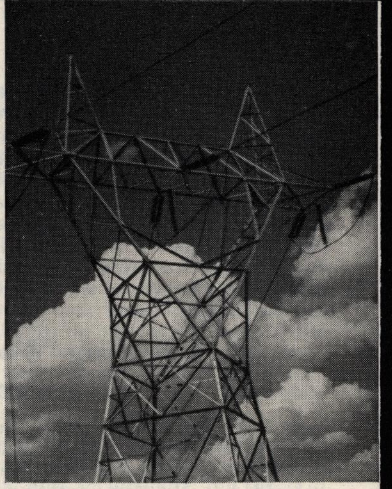
Generator room



(9) Thrust bearing



(10) Switchyard



Transmission line

with 14,500 gallons of insulating oil. The transformers were too large and too heavy to be shipped in finished form.

At the dam, the two sections of a transformer case were assembled and welded together; braces used in shipping were removed; and after assembly was complete, a 28-inch vacuum was drawn on the case to remove air and moisture, 54 tons of filtered oil were put in, and nitrogen was added to fill the space above the oil.

High tension lines from the transformers are carried on steel towers over the powerhouse and up the canyon walls to a switching yard, where facilities are provided for interconnecting generating units and transmission lines (10).

River Development For Food and Power

Personal and economic security and political power have always been based on rich and varied natural resources, and have nearly always been centralized in areas which possessed, or controlled, rich natural resources, and were occupied by industrious, ingenious, courageous people.

Most important of all natural resources is productive land, for man must be fed, clothed, and housed with products of the soil. Second in importance among natural endowments are sources of energy adaptable to man's use, for agriculture is largely, and industry is almost completely, dependent on power.

Americans live well, and far above the world's average present or attainable standard of living, partly because they have great natural resources and many machines, but chiefly because they have power enough to run many machines. Power provides many of the necessities and conveniences of peacetime life, and many of the absolute necessities for victory in war.

One of the chief sources of hydroelectric power is from the racing waters of the Columbia River harnessed at Grand Coulee Dam. The Columbia falls 1,290 feet in its 600-mile course across the State of Washington, from the Canadian boundary to tidewater, near Portland, Oreg., about a hundred and forty miles from the sea. The tremendous weight of the river's flow, falling through so great a distance, is one of America's greatest economic assets because of the millions of horsepower it supplies. Great quantities of power will be procurable from the Columbia River long after the shrinking of American oil and coal resources has made power from fuel expensive, if not scarce. In the meantime, we can live better, and can economize in the use of our dwindling fuel resources by developing arable land and hydroelectric power by means of the river.

The 10 dams proposed by the Army Engineers for the development of the Columbia will utilize about 92 percent of the fall of the river within the United States. How much power can be developed at each site that is suited to the building of a dam depends upon the height of the dam that can be built there without backing the river up against the next dam upstream, and upon the size of the river at that point, that is, upon the "head" and the "flow" there.

Except in the case of rivers like the Niagara, which is the outlet of a system of enormous lakes, the flow of a stream varies widely from year to year, and from season to season. The Great Lakes almost completely equalize the outflow through the Niagara River from the great area which they drain, partly because the tributary streams are not all high or low at the same time, but principally because of the enormous area of the Great Lakes, which enables them to store or to discharge great quantities of water without changing much in depth, that is, without changing much the force which causes the discharge from the lakes to take place. In a small way, hydroelectric engineers imitate the Great Lakes drainage system by forming reservoirs on streams they develop. Lakes—preferably broad and long—make the best reservoirs, because in them low dams at their outlets store much water with very little increase in depth.

Every stream goes through high- and low-water seasons. Most streams in the United States have their high-water periods in the spring, are low in late summer and fall, and may be high in winter because of rains, or low when their little tributaries happen to be frozen during widespread cold periods. The Columbia is unique in having its high-water period extend through the summer, thus making water and power for use in irrigation available entirely from surplus flood water. That peculiarity is due to the fact that the Columbia drains timbered mountainous areas, some of which contain deep snow deposits, and extensive ice fields which may be remnants of an ice cap that covered thousands of square miles in western Canada, thousands of years ago. The ravages of summer heat are repaired each year by the snowfalls of winter, making the ice fields serve as reservoirs to store the heavy precipitation of winter and release it in the summer. The high water in the Columbia is too high, and the low water is too low to suit hydroelectric engineers. Those extremes are the causes of two handicaps to water-power plants.

If one should build a power plant large enough to utilize the maximum flood water of a stream, there would be a deficiency of water, and part of that plant would stand idle at all times most years, and during most seasons of every year. If, instead, a power plant should be built for the minimum flow, much water would run to waste all of the time, almost every year. Any run-of-the-river power plant with a capacity between those extremes is troubled one way or the other, or both ways. To relieve such situations partially, water storage facilities on a power stream are desirable. Under ideal conditions, the reservoir or reservoirs should be sufficiently large to impound flood waters, and so to exercise complete control over the lower river—that is, to equalize the flow throughout the year, as the Great Lakes do through the Niagara River. Boulder Dam, on the Colorado River, has realized that ideal.

If a stream were to be developed for power alone, by means of a number of reservoirs, dams, and power plants, we would have to solve only the problems of developing power projects in economic order, and distributing the costs of the whole development among them; but the systematic development of a river is seldom made for one purpose alone, and we have the problems of distributing costs among a variety of beneficiaries.

On western rivers, combinations may include irrigation, power development, and industrial and domestic water supplies, as well as flood control and navigation, in so-called multiple-purpose projects, the costs of which, if reimbursable, must be allocated to the several beneficiaries directly, or if not reimbursable, must be distributed over the taxpayers of the country. Generally, the costs of irrigation and power projects are charged to beneficiaries, and the costs of flood control and aids to navigation are paid out of public funds.

The development of the Columbia River to the greatest economic and social advantage will be influenced not only by the variations in the yearly run-off from its drainage basin, but by the variations in flow within each year, by the quantity of waters that can be stored in high water and released in low-water seasons, by the heights to which dams can be built at different proposed sites, by the peculiarities of high-head and low-head dams, and by the distances of the various proposed dams from existing and potential power markets. Economic and engineering investigations and reports made by the Bureau of Reclamation and other Government agencies will form a sound basis for development plans.

Power—Basis of Progress and Security

Grand Coulee Dam is the dominant engineering feature of two enterprises which are of the greatest significance to the economic future of the Pacific Northwest and the Nation. It is to be the means of adding a million acres of farm land to the meager agricultural resources of the Pacific Northwest, and thousands of small-town and farm homes to the sparsely populated Far-West States; and it is the largest and most important of the 10 dams by which the energy of the greatest power stream in North America is to be made to serve the people of the Nation.

Most potent of the agencies that have made the fruits of his inventions and discoveries widely useful to man are scientific knowledge, intellectual daring, and abundant cheap energy; and possibly the greatest of these, in these days, is cheap energy. It is the great multiplier and extender of man's efforts. Given all our mental powers, all our brilliant ideas, all our wisdom and daring, all the findings of science, all the schemes of the inventors, all our raw material, all our physical vigor, and all our manual skill, the people of this country would still have to live in a relatively crude and insecure environment, as millions do elsewhere in the world, if we did not have, also, abundant cheap power. Even our form of Government would be different, and probably our personal freedom would be greatly restricted.

Energy from burning fuel and falling water aids us in taking crops from the soil and minerals from the earth, in processing and transporting them, and in distributing them as foodstuffs and miscellaneous industrial products.

Energy, in excess of that necessary for mere subsistence, gave man the leisure in which to develop and promote civilization, the means of increasing his economic wealth, and the means of operating a democratic government large enough and strong enough to protect itself against aggression. Both progress and national security are based on power.

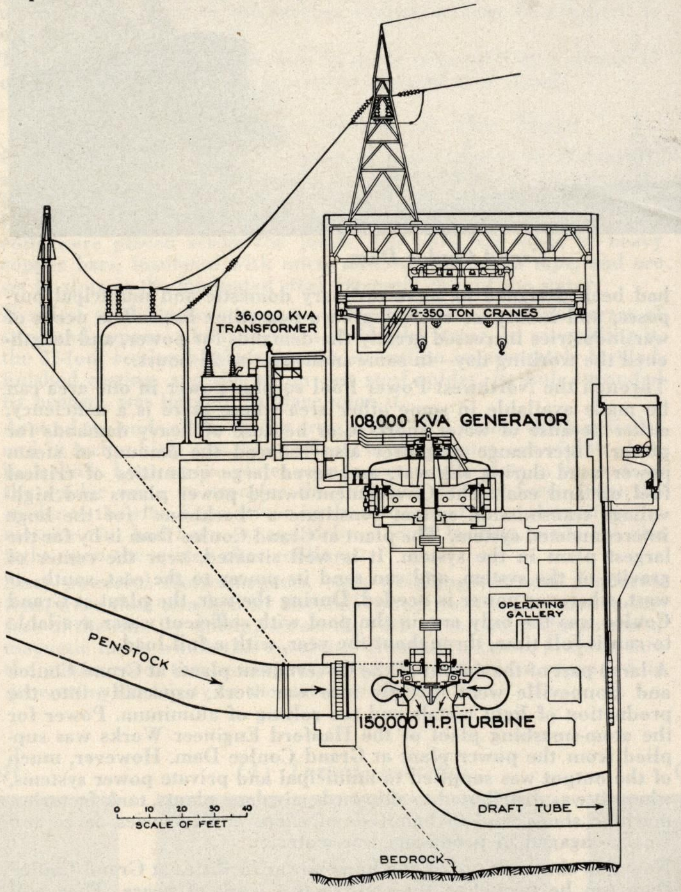
There seems never to have been a time when use could be foreseen for all the power that American builders of power plants were preparing to generate, yet the demand for power has grown steadily with the increase in the supply and with the reduction in cost. Electricity has given us artificial light to an extent never dreamed of in the days of candles and oil lamps. Electric lights and household conveniences are the most obvious contributions of electricity to our comfort, but they are not its greatest contributions to our well-being. Applications of electricity to mining, metallurgy, manufacturing, and transportation have been responsible for great advances in prosperity and in our standards of living.

It was never, in the past, possible to forecast precisely the quantity of power that people would use, nor the rate at which the demand would develop. It is not possible to do so now; but the appetite for the products of industry is insatiable, and more uses will be found for more power as rapidly as it becomes available at low cost. Hydroelectric energy is wealth gained without the loss of irreplaceable fuel resources.

Power Plant at Grand Coulee Dam

The completed power plant at Grand Coulee Dam will be the largest in the world, containing ultimately 18 turbines of 150,000 horsepower, rated capacity, driving an equal number of 108,000-kilowatt generators, and three 14,000-horsepower turbines driving 10,000-kilowatt generators, a total rated capacity of 2,742,000 horsepower in turbines and 1,974,000 kilowatts in generators. In service, the generating units have proved themselves capable of carrying 125,000 to 130,000 kilowatts. Nine large generating units will be installed in each of the two powerhouses, one located on each side of the spillway.

The 10,000-kilowatt station-service units supply power for the operation of exciters, heaters, blowers, pumps, cranes, elevators, lights, and other equipment in the power plant and dam, and all electricity required in the Bureau's village, Coulee Dam.



The large units are to supply power for pumping water for irrigation and will continue to furnish power for transmission to consumers on the Bonneville-Grand Coulee distributing system. The largest individual consumers are producers of aluminum, and other metals and alloys used in defense and peacetime industries.

The first six large generators installed in the west powerhouse are arranged for connection to long-distance transmission lines or to 65,000-horsepower synchronous motors which will drive huge pumps when the irrigation phase of the project is developed. Since ordinary types of motor-starting equipment are not adapted to such large motors, the first six large generators are separately excited with energy from the station-service units so that one of the generators, starting from rest with an energized field, can bring up to speed with it the two pump motors to which it will be connected electrically.

For sale by the Superintendent of Documents, Washington 25, D. C.
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