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Existing Federal hydroelectric plants could increase power production by modernizing turbines to increase efficiencies and capacities and by modernizing generators to increase capacities. Findings/Conclusions: Increasing hydroelectric power production will increase the Nation's energy supply, displace consumption of nonrenewable fuels by fossil-fuel powerplants, reduce pollution, increase Federal revenues, and displace or delay construction of alternate power sources. Detailed analysis at each powerplant is needed to determine what modernization improvements might be made and if they would be cost effective. At present, the agencies do not have a system to make sure that opportunities are identified and acted upon. Recommendations: The Secretaries of the Interior and the Army and the Chairman of the Board of the Tennessee Valley Authority should: identify opportunities to improve hydropower production through equipment modernization, implement those that are economically justified, and consider making changes before the end of the equipment's useful life; include in the economic analysis the value of oil or coal consumption displaced and, either directly or indirectly, the value of maintenance costs reduced by installing new equipment; include feasible turbine and generator modernization in their overall hydroelectric power expansion plans; and develop systems to make sure that future technological improvements are recognized and considered for implementation in existing systems. (Author/SC)

UNITED STATES
GENERAL ACCOUNTING OFFICE

Power Production At Federal Dams Could Be Increased By Modernizing Turbines And Generators

Existing Federal hydroelectric plants could increase power production by modernizing turbines to increase efficiencies and capacities and by modernizing generators to increase capacities.

Increasing hydroelectric power production will (1) increase the Nation's energy supply, (2) displace consumption of nonrenewable fuels by fossil-fueled power plants, (3) reduce pollution, (4) increase Federal revenues, and (5) displace or delay construction of alternate power sources.

Federal agencies that operate hydroelectric plants should evaluate existing plants to identify and act on these opportunities.

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UNITED STATES GENERAL ACCOUNTING OFFICE
WASHINGTON, D.C. 20548

ENERGY AND MINERALS DIVISION

B-125042

Secretaries of the Interior and the Army
Chairman of the Tennessee Valley Authority

This report discusses how power production at Federal dams could be increased by modernizing turbines and generators.

This report contains recommendations to you on pages 10 and 11. As you know, section 236 of the Legislative Reorganization Act of 1970 requires the head of a Federal agency to submit a written statement on actions taken on our recommendations to the House Committee on Government Operations and the Senate Committee on Governmental Affairs not later than 60 days after the date of the report and to the House and Senate Committees on Appropriations with the agency's first request for appropriations made more than 60 days after the date of the report.

Mor' Canfield, Jr.
Director

UNITED STATES
GENERAL ACCOUNTING OFFICE

POWER PRODUCTION AT FEDERAL DAMS COULD BE INCREASED BY MODERNIZING TURBINES AND GENERATORS

D I G E S T

At some existing Federal power plants potential exists to increase hydroelectric power production by

--modernizing turbines to increase their efficiencies and capacities and

--modernizing generators to increase their power producing capacity.

It may be cost and energy effective to the Nation for agencies to modernize hydroelectric machinery. Increased hydroelectric power production displaces oil and coal consumption, thus contributing to energy conservation and pollution reduction; it may also displace or delay construction of alternate power sources and increase Federal revenues.

Opinions vary among agency engineers, manufacturers' engineers, and independent engineers as to the extent of increases that can be gained and whether evaluation and implementation of opportunities is worthwhile. Engineering estimates of increased efficiency for plants that might be improved vary from 1 to 2 percent to 5 to 10 percent.

At existing plants where worn out turbine and generator components have been replaced with modern components, efficiency and capacity increases were possible through design improvements. In these instances efficiencies have been increased as much as 3 percent and capacities increased as much as 36 percent.

The increases from design improvements were of such importance that replacing components at other plants, before they wear out, may be economical.

The three Federal agencies having major hydroelectric power operations--the U.S. Army Corps of Engineers, the Department of the Interior's

Bureau of Reclamation, and the Tennessee Valley Authority--do not have systems to evaluate these opportunities and in the past have not studied such opportunities on a system-wide basis.

Detailed analysis at each power plant is needed to determine what modernization improvements might be made and if they would be cost effective.

GAO recommends that the agencies evaluate opportunities to improve hydropower production and act on those that are economically justified. The value of displaced fossil-fuel consumption by increased hydropower production should, we believe, be considered in the evaluation.

C o n t e n t s

ABBREVIATIONS

GAO	General Accounting Office
TVA	Tennessee Valley Authority

CHAPTER 1

INTRODUCTION

About 15 percent of the Nation's electric-generating capacity 1/ is hydroelectric and about 40 percent of this hydroelectric capacity is Federally owned.

Three Federal agencies have major hydroelectric operations--the U.S. Army Corps of Engineer (Corps), the Department of the Interior's Bureau of Reclamation (Bureau), and the Tennessee Valley Authority (TVA). As of July 1, 1975, these agencies operated 152 hydroelectric power plants with an average annual output of about 124 billion kilowatt-hours.2/ About 206 million barrels of oil would be needed to produce an equivalent amount of electricity.

Hydroelectric power is produced by channeling dammed water through turbines, which drive generators that produce electric current. The current is then sent over high-voltage transmission lines to points of use.

Water released through a turbine applies force against turbine blades. The turbine blades drive a shaft which turns an electric generator. The generator converts mechanical energy into electric energy producing electric current. Each step in this energy conversion process affects the efficiency of conversion and reduces the energy output of the system. Efficiency is the ratio of output energy to input energy. In hydroelectric plants, it is the amount of electric energy produced compared to the energy released to the turbines. Thus, the combined efficiencies of each system component is the system's overall efficiency. Improving the efficiency of any one component will increase the system's overall efficiency.

Turbine design depends on the conditions under which it is used such as reservoir levels, water flow, and power demands. Therefore, most turbines are specifically designed to meet the conditions at the dam site.

1/Rated power output of a turbine, generator, or power plant.

2/One kilowatt-hour = 1,000 watt-hours.

SCOPE OF REVIEW

We made our review at the Bureau of Reclamation's Mid-Pacific region, Pacific Northwest region, and Engineering and Research Center; the Corps' Headquarters and North Pacific Division; and at TVA offices in Tennessee. We interviewed agency officials and engineers at each location and reviewed pertinent agency program documents, records, correspondence, and reports. We also contacted several manufacturers' engineering representatives, as well as several independent engineers experienced in hydroelectric machinery, for information and technical opinions.

CHAPTER 2

OPPORTUNITIES TO INCREASE HYDROELECTRIC POWER PRODUCTION AT EXISTING FEDERAL DAMS BY MODERNIZING TURBINES AND GENERATORS

Technological advances since the 1930s, when the Government first became substantially involved in hydroelectric power, have resulted in improved turbine and generator designs and materials. Because of these advances, potential exists at some Federal hydroelectric plants to increase power production. These increases can be achieved by modernizing turbines and generators to improve plant efficiency and maximize power production.

The Bureau of Reclamation, the Corps of Engineers, and TVA make improvements in existing turbines and generators when major components fail or deteriorate. However, because of the long useful life of the components and the Nation's increased energy needs, it may now be worthwhile to make efficiency and capacity improvements before the turbine and generator components wear out.

The three agencies have not identified and evaluated the potential to increase power production in their power systems through turbine and generator modernization, and have not established review systems to identify the advantages of implementing technological advances at existing dams.

Bureau, Corps, and TVA officials agreed in concept that efficiencies and capacities may be increased at some plants by modernizing turbines and generators. However, the Corps believes that it is too expensive and that opportunities for improvements are slight at its dams. A Corps official said the best opportunities to increase efficiencies and capacities would be at dams where operating conditions have changed. Bureau and TVA officials agreed that it would be worthwhile to make preliminary studies to identify potentials. Officials of all three organizations agreed that their agencies have no existing system to review technological improvements, and that studies should be made to determine the potential to increase power production through modernization. As a result of our discussions with the Bureau, instructions were issued to field offices to investigate the financial feasibility of (1) increasing plant efficiency by replacing turbine runners, (2) increasing power plant output by increasing the operating capacity of the generators, and (3) any other methods of increasing efficiency and output.

Each power plant must be individually evaluated in detail by skilled engineers to determine whether any improvements can be made. Improving capacity in turbines may require capacity improvements in both the generator and auxiliary equipment to utilize the increased capacity. Thus, an evaluation of benefits and costs can be made only after careful engineering analysis at each location.

TURBINE EFFICIENCIES AND CAPACITIES CAN BE IMPROVED

One way to improve plant efficiency is to improve the capability of its turbines.

Although efficient when compared to other energy producers, older hydraulic turbines usually were not of optimal design because of the state of the art of turbine hydraulics, engineers' inexperience in designing turbines, and lack of tools to make precise calculations. From the early 1930s to the early 1950s, engineers gradually improved turbine designs as they gained knowledge and experience and as they improved analytical techniques. As computers became available, further design refinements were possible. By 1970 the state of the art in turbine hydraulics had advanced so that significant efficiency and capacity improvements, according to manufacturers, are possible in many older turbines by replacing runners 1/ and other components with more modern ones.

Opinions varied among agency engineers, manufacturers' engineers, and independent engineers as to the extent of increases that can be gained and whether evaluation and implementation of opportunities would be worthwhile. Engineering estimates of increased efficiency for plants that might be improved varied from 1 to 2 percent to 5 to 10 percent. Engineers could not give general estimates of capacity increases because increases vary too much with each plant's design and particular operating conditions.

Engineers cited the following improvements that individually, or in combination, could greatly increase turbine output.

--Increasing maximum efficiency through more modern runner designs.

1/Runner--the rotating assembly of a hydraulic turbine that includes the turbine's blade.

--Correcting turbine designs to match actual water conditions. (Some plants were built based on projected water conditions that did not materialize; thus, the turbine design is not properly matched to the water flow.)

--Changing the designs of runners where operations have changed to providing peak load power, so that best efficiency occurs nearer maximum output.

--Restoring deteriorated runners.

--Increasing turbine capacity for better efficiency at high load points.

--Replacing adjustable-blade propeller runners with fixed-blade propeller runners where head 1/ variation is normally within about ± 5 feet. Fixed-blade runners have higher efficiency than adjustable-blade runners for such a small head range.

--Installing improved wicket gates, 2/ self-lubricating gate bearing materials (which also reduce maintenance), seals, and stay rings.

--Using improved aerating techniques (pumping air behind seals to improve water going through turbines instead of around them).

Corps engineers said that perhaps the best potential to increase turbine efficiency and capacity is at plants where operating conditions have changed from those of the ori inal design.

Examples of improved efficiency and/or capacity by runner replacement

The following examples illustrate efficiency and capacity improvements that are achievable by modernizing

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1/Difference in the height of the water at the reservoir level (level behind the dam) and at the point where the water enters the turbine. The greater the distance the water falls before it hits turbines the greater the energy.

2/Mechanical gates at the periphery of the turbine runner that control the amount of water delivered through the turbine.

turbines. We believe the increases resulting from design improvements are of such significance that replacing components before they wear out may be economical, especially at plants now being used to produce peak load energy.

Hoover Dam - Operated by the Bureau of Reclamation

Hoover Dam is an example of demonstrated efficiency and capacity increases. In 1970 the Bureau replaced four turbine runners at Hoover, because they were in poor condition and required excessive maintenance. Field tests before and after the new runner installations showed that efficiency improved 6 to 7.5 percent over a broad range of gate openings. Bureau and manufacturer's engineers attribute much of the improvement to restoration of the deteriorated condition but say that perhaps 1 to 2 percent is due to design improvements. However manufacturer's tests show that performance could be considerably improved due to possible design changes, capacity increased up to 10 percent, and efficiency at previous maximum horsepower increased up to 8.6 percent.

A Bureau official in the Lower Colorado region projected efficiency increases of about 4 percent for the other turbines if runners are replaced. He estimated a 4-percent increase would produce an extra 140 million kilowatt-hours of electricity each year.

This extra electricity, if it displaced oil, would save about 233,333 barrels of oil a year (at 600 kWh/barrel).

Shasta Dam - Operated by the Bureau of Reclamation

Shasta Dam is an example of potential efficiency increases. Mid-Pacific region engineers studied Shasta turbines in 1975 and determined peak efficiency could be improved about 3 percent--2 percent due to turbine design improvements and 1 percent from matching the turbine to actual water conditions. According to a region official, turbine modernization for Shasta has been submitted for consideration in the regional budget proposal but has not yet been included because higher priority items have taken precedence.

Fort Peck Dam - Operated by the Corps of Engineers

Fort Peck Dam is an example of potential capacity increases. Engineers at the Corps' Omaha District told us they have recently completed a study of the Fort Peck Dam in Montana. The study indicated that runner replacement could increase turbine capacity from 5 to 12 percent at both high and low reservoir water levels.

Wilson Dam - Operated by TVA

Capacity increases possible at a peaking 1/ plant have been demonstrated at Wilson Dam. TVA recently replaced runners on 8 of 21 Wilson Dam units because they were in poor condition and studies indicated improvements could be made. New runners increased turbine rated capacities about 16 percent on four units and about 31 percent on the other four units.

Pickwick Dam - Operated by TVA

Pickwick Dam is another example of potential efficiency increases. Cursory examination of turbine data by TVA engineers showed that two turbines, installed at later dates than the first four units, had 5-percent higher maximum efficiency and 6.7-percent higher test efficiency under the same operating conditions. The engineers said that further study would be required to determine what efficiency improvements could actually be made, but they thought this dam showed promise for improvements. The manufacturer is evaluating the designs to determine whether these improvements are possible.

Fontana Dam - Operated by TVA

Fontana Dam is an example of potential efficiency increases at a peaking plant. Discussions with TVA and the turbine manufacturer's engineers indicated that, based on cursory examination of turbine data, the units' maximum efficiencies could be improved about 1 percent by more modern design. The manufacturer's representative indicated that efficiency might be improved 5 to 6 percent by shifting the best efficiency point toward full gate output. Because this is a peaking plant where turbines are often operated near full gate, in our opinion, a 5- to 6-percent increase at that point would be significant.

Canadian dams

Abitibi Canyon Dam is an example demonstrating considerable efficiency and capacity improvements. In 1976 a Canadian electric utility began replacing the runners on four of five turbines at the Abitibi Canyon power plant in Ontario. Comparison of the design efficiency curves of the old and new runners shows substantial improvements. For the same water flow through the turbines at full gate,

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1/Operating a power plant to meet peak power demands (fluctuations on the basic daily power demand). This usually means providing maximum power for a limited period.

the turbines should produce 11.4 percent more power at 8.8 percent more efficiency, and their maximum power should increase 36 percent.

The utility projects an increased power production of 145 million kilowatt-hours a year due to the changes. This energy increment is equivalent to about 242,000 barrels of oil a year.

Similar improvements were made at Chats Falls power plant on the Ottawa River where gains of 90 million kWh a year are expected.

GENERATOR CAPACITIES CAN BE INCREASED

Another way to increase plant capacity is to increase the capacities of its generators.

The capacity of many older generators can be increased by replacing their stator coils. 1/ Generators built before computers made more precise designs possible often had excessive insulation to make sure they met specifications. Today better insulating materials take less space in the generator. By replacing the old stator coil windings, more core material can be used in the stator because of the extra room.

Federal agencies are aware of this potential and are rewinding generator stators to increase capacity as windings fail. However, according to agency engineers, windings have about a 35-year life expectancy. This means that many overdesigned windings still have perhaps 10 to 15 years of remaining life. We believe that having extra capacity for a long period of time which is possible by rewinding now, should be of considerable value and worth investigating, especially at peaking plants and plants where outputs are limited only by generator capacity.

Examples of generator capacity increases

The following examples demonstrate the amount that generator capacity can be increase by rewinding stator coils.

1/A "stator" is the stationary part of a generator containing electromagnetic coils ("windings") from which an electric current is produced as the rotating element passes it.

Shasta Dam and other Bureau of Reclamation dams

Shasta Dam's generators were originally rated at 75 megawatts. 1/ They were rewound to 83.6 megawatts, and later three generators were rewound to 95 megawatts. The Bureau is now planning to rewind Shasta generators to about 125 megawatts. A manufacturer's representative said they could be rewound to 150 megawatts each if improvements are also made to uprate turbines and drive shafts.

The Bureau has rewound for increased capacity at several other dams. For example, Grand Coulee units have been rewound from 108 megawatts to 125 megawatts, and Davis Dam units from 45 megawatts to 48 megawatts.

Officials at the Bureau's Pacific Northwest region indicate that units at Hungry Horse Dam will be rewound from 71.3 megawatts to 90 megawatts when the windings eventually fail.

TVA dams

From 1944 to 1976, TVA rewound stators when windings failed on 41 of their 109 hydrogenerators. This resulted in an average 14.3-percent capacity increase in 29 of the generators, for a total increase of 129,760 kilowatts.

1/One megawatt = one million watts or 1000 kilowatts.

CHAPTER 3

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

At all three agencies potential exists to increase power production by modernizing hydraulic turbines to increase efficiency and capacity and by rewinding generator stators to increase capacity.

It may be both cost and energy effective to the Nation for the agencies to make improvements before the end of the equipment's useful life. Detailed analysis of each dam is needed to determine what modernizations might be made and if they would be cost effective. Presently, the agencies do not have a system to make sure that opportunities are identified and acted upon.

Complex engineering knowledge is required to determine in detail the benefits and costs of modernizing turbines and generators. The Secretaries of the Interior and the Army and the Chairman of the Board of the Tennessee Valley Authority need to identify opportunities for modernization of hydroelectric machinery and identify costs and benefits in detail.

We believe modernizing existing equipment is worth considering as an alternative or an addition to expanding power operations at existing dams.

RECOMMENDATIONS

We recommend that the Secretaries of the Interior and the Army and the Chairman of the Board of the Tennessee Valley Authority:

--Identify opportunities to improve hydropower production through equipment modernization, and implement those that are economically justified, and consider making changes before the end of the equipment's (or its components') useful life.

--Include in the economic analysis, (1) the value of oil or coal consumption displaced and (2) either directly or indirectly, the value of maintenance costs reduced by installing new equipment.

--Include feasible turbine and generator modernization in their overall hydroelectric power expansion plans.

--Develop systems to make sure that future technological improvements are recognized and considered for implementation in existing systems.

FEDERAL HYDROELECTRIC POWER PRODUCTION (note a)

Agency	Number of plants	Number of power units	Total installed capacity (kW) (note b)	Total average annual power production (mWh)	Equivalent energy in barrels of oil consumed (note c)
Bureau	50	180	7,877,906	d/ 34,530,900	57,551,500
Corps	73	315	16,715,705	e/ 75,888,801	126,481,335
TVA	29	109	3,297,930	f/ 13,455,530	22,425,883
Total	152	604	27,891,541	123,875,231	206,458,718

a/Does not include 49,000 kW of installed-hydroelectric power (as of 1965) from plants operated by three other Federal agencies (International Boundary and Water Commission, Bureau of Indian Affairs, and the National Park Service).

b/Bureau as of July 1, 1975, Corps as of August 31, 1975, and TVA as of August 26, 1975.

c/The approximate amount of oil it would take to produce an equivalent amount of electricity by an oil-fired steam plant, based on a conversion ratio of 600 kWh a barrel of oil consumed.

d/Average of the totals of production at each plant over its history of operation to July 1, 1975.

e/Average of the totals of production at each plant from fiscal years 1971 to 1975 (only available data).

f/Average of the totals of production at each plant since 1946 or date of initial operation (if later) to April 25, 1976.