Table 5 Summary of annual costs for peaking plant operation using two turbine-generator units

Items	Reaction Turbines	Impulse Turbines
Annual Fixed Charges	$563,450	$631,950
Credit for Increased Energy Output at 4 mills/kw-hr	-12,000	0
Motoring - 25% of time, consisting of		
Spinning Reserve - 13% of time		
Energy Losses	18,200	8,840
Water Losses	18,500	0
Synchronous Condenser - 12% of time		
Energy Losses	16,800	8,160
Water Losses	3,120	0
Maintenance	7,200	16,500
Total Evaluated Annual Cost	$615,270	$665,450
Saving in Total Evaluated Annual Peaking Plant Operation Cost, Favoring the Reaction Turbine Installation	$ 50,180	

reaction turbines. From Table 2 the energy generated by the impulse turbine-generators is 9 million kw-hr more than that generated by the reaction turbine-generators, therefore, Table 4 shows the value of this energy differential, or $36,000, as a credit to the impulse turbines. The other values in Table 4 have been discussed in preceding paragraphs. The total evaluated annual cost of the reaction turbine-generator arrangement has the lower cost by an amount of $11,580.

Table 5 summarizes the annual cost for the peaking method of operation, based on the use of two turbine-generator units. As the energy generated by the reaction turbine-generator units is higher by 3 million kw-hr, the reaction turbines are credited with $12,000, which is the evaluated cost of this electrical energy. The remaining cost items have been covered previously. Taking all the cost items into account, the total evaluated annual cost of the reaction turbine-generator installation is less by an amount of $50,180. The other peaking condition considered will also show that the reaction turbine annual cost advantage is even greater than the peaking operation considered by Table 5.

Conclusions

This analysis of the two types of turbines for the Mammoth Pool Project shows definitely that the annual cost of ownership and operation of the reaction turbines is less than the comparable cost of the impulse turbines. Another definite advantage in using the reaction turbines is their lower initial project cost. It is very probable on the other hand that, under different operating conditions requiring energy generation at low power outputs, multijet impulse turbines could have a definite annual cost advantage.

On the basis of lower evaluated over-all annual costs and lower first costs the reaction type hydraulic turbines were selected for the Mammoth Pool Project.

DISCUSSION

G. D. Johnson[1]

Since the writer is employed by the company that manufactured the two Francis-type turbines installed in the Mammoth Pool powerhouse, it is obvious that we agree with the author's selection in this case. In our proposal letter to the author's company, we oversimplified the problem as follows: ". . . . We believe that Francis-type turbines are more desirable for this installation. They are more economical due to lower costs for turbines and generators and savings in powerhouse space requirements. Turbine efficiencies are higher on a net head basis, while on a gross head basis there is the further advantage of utilizing the entire head differential to the tailwater surface, whereas Impulse units would sacrifice 8 feet of head when the tailwater is at its normal elevation. During times of high tailwater, normal operation of the Francis turbines is not complicated by the necessity for depressing the water in the discharge pit." Although the author's analysis would differ from ours in a number of details, his conclusions are the same.

The static head of approximately 1100 feet would be suitable for either Francis-type or multijet vertical-shaft impulse turbines, depending upon local water and operating conditions. A 6-jet impulse turbine was selected about ten years ago[2] for the Bridge River Plant of the British Columbia Electric Company Limited with a static head of approximately 1200 feet, primarily because of the silt content of the water which has a particularly destructive effect on Francis turbine runner seals. It was felt that maintenance of the impulse runners, nozzle seat rings, and needle tips would be much more convenient and less expensive. Some twenty years ago,[3] a Francis turbine was selected for the Nantahala Plant of the Nantahala Power and Light Company in North Carolina with a static head of approximately 1000 feet. Maintenance has been reasonable as stainless steel is quite durable in clean water, even at the high velocities due to the relatively high head.

At the time when the order for these turbines was awarded, ours was a relatively small company specializing in hydraulic turbines, pumps, valves and related equipment and, because of our convictions as quoted above, we had not built any 4 or 6-jet vertical impulse units. For the past year, we have been operating as the Hydraulic Division of one of our former large competitors in this field. Now, our combined backlog of experience includes a number of successful installations of all types of impulse turbines, as well as Francis, for the "controversial" head range above and below 1000 feet. As in the past, we will continue to recommend the type of equipment that appears to be most suitable and economical for each particular installation.

The writer wishes to commend the author for his presentation of this very interesting paper. We need more good papers from engineers who purchase and operate hydraulic machines to supplement those written by engineers who design and manufacture the equipment. This résumé of the various economic considerations and operating conditions that must be studied by a power company in order to decide upon the type of equipment for a particular project should assist those responsible for future installations (i.e., both users and manufacturers) to specify and/or to offer the most suitable machines for each installation.

Author's Closure

After the preparation of the original analysis it has been possible to check the assumption that the motoring losses of the turbine-generator units would be 2000 kw. Tests indicate that the electrical motoring losses for one unit on spinning reserve operation are 2300 kw and about 865 kw when the unit is operated as a synchronous condenser.

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[2] W. F. Boyle and I. M. White, "62,000-Hp Vertical Six-Nozzle Impulse Turbines for the Bridge River Hydrodevelopment," TRANS. ASME, vol. 73, 1951, pp. 289–296.

[3] J. P. Growdon, R. V. Terry, and H. H. Gnuse, Jr., "Nantahala Turbine." TRANS. ASME, vol. 68, 1946, pp. 687–700.

On the basis of actual test data there are additional annual savings applicable to Tables 4 and 5. The energy losses of the reaction turbines for spinning reserve operation for 10 per cent of the time become 2300 × 0.004 × 2 × 0.1 × 8760 = $16,118, say, $16,200. For operating the units as synchronous condensers for 9 per cent of the time the energy losses become 865 × 0.004 × 2 × 0.09 × 8760 = $5456, say, $5500. The annual energy losses for motoring the units 19 per cent of the time amount to $16,200 + $5500 = $21,700, which is $4900 less than the original value shown in Table 4. On this basis the saving in the total evaluated annual stream-flow plant operation cost, favoring the reaction turbine installation, becomes $16,400, instead of the originally given value of $11,500.

In a similar manner new values for Table 5 energy losses are computed as $28,400 for operating the reaction turbines 13 per cent of the time as spinning reserve and 12 per cent of the time as synchronous condensers. The saving in total evaluated annual peaking plant operation cost, favoring the reaction turbine installation, becomes $56,780, instead of the originally given value of $50,180.