A Review Of Recent Experience with Twin Turbines

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1 INTRODUCTION

Turbines with more than one Francis runner on a shaft were very common in the early days of hydro-electric development. Stations built in Europe and the USA in the early 1900s often had four runners on a shaft in a "camel back" arrangement driving one horizontal generator. Multiple turbines were used to keep the runner size down to that which could be accommodated by the manufacturing facilities and to increase the speed of the generator.

With the advent of Kaplan turbines these units were rapidly superseded. That progression influenced the selection of vertical Francis turbines where the head is too great for a Kaplan turbine. In many cases this practice has led to vertical Francis turbines being used for low outputs even though horizontal units are simpler and more economical.

Modern twin turbines have one turbine overhung from each end of the shaft. They are able to operate with one or both turbines in service. This flexibility gives high efficiency at part loads.[1]

Our experience shows that twin turbines have significant advantages over the conventional options of two horizontal Francis turbines and generators or a single vertical unit.

Since 1980 Leyland Consultants have been responsible for eight installations with twin turbines. These are summarised below.

Name of Station	Year	Head	Output
Duffers	1980	12 m	0.6 MW
Hinemaiaia C	1981	33 m	2.5 MW
Patearoa	1984	31 m	2.2 MW
Flaxy	1984	30 m	2.1 MW
Wairau	1983	41 m	7.2 MW
Wyangala	1992	50 m	16 MW
Glenmaggie	1994	30 m	3.6 MW
Ord	1996	43 m	35 MW

All these schemes have been private developments so there was a desire to purchase the lowest cost generating plant that could do the job. Most of the schemes required the ability to operate over a wide range of flows with good efficiency. During the feasibility studies the twin turbine option was compared to two conventional turbine generator units and also to a single Francis turbine unit. Twin turbines were selected in each case because, overall, they were about 25% cheaper and had much better part load efficiency.

At Hinemaiaia C and Wyangala, where flood rises are in excess of 10 m, the compact arrangement of the twin unit allowed us to use circular power houses which proved to be lower cost and easier to build compared with a conventional rectangular powerhouse. The success of the Wyangala installation led to the arrangement being adopted by others at Copeton and Burrendong irrigation dams in Australia.

[1] It should be noted that the double discharge Francis turbines manufactured by Neyrpic and others share some of the advantages of twin turbines.

The photograph of Branch (Figure 1) and the drawings of Hinemaiaia C (Figure 2) power stations illustrate the main features of a twin turbine arrangement.

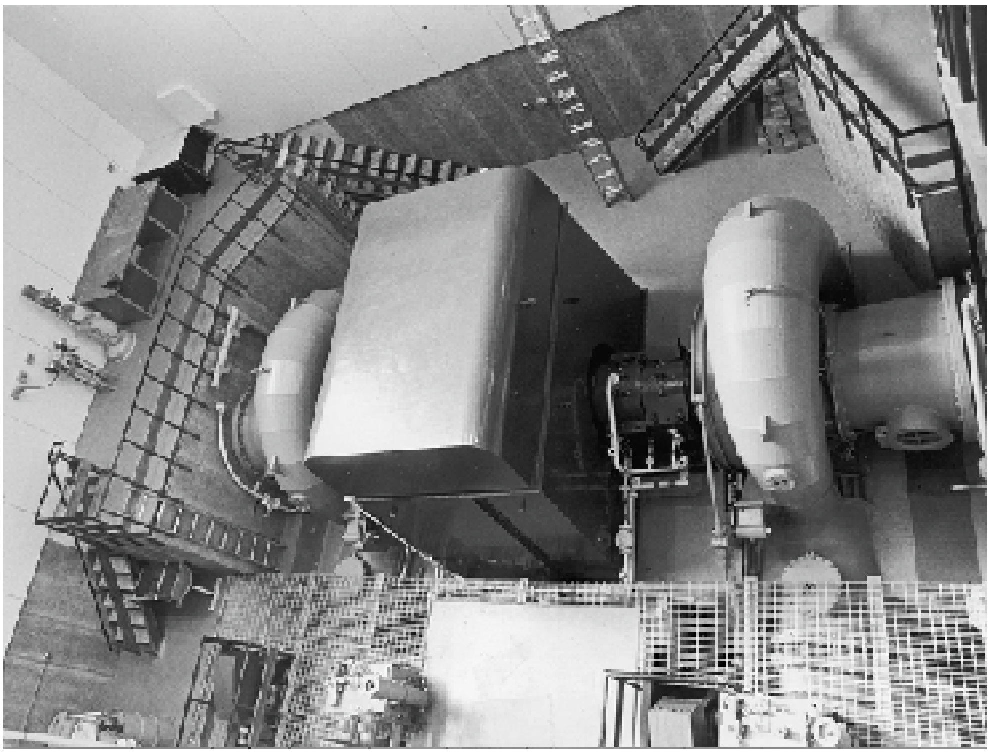

Figure 1 Wairau Powerhouse 7.2 MW at 41 m

At Duffers, Patearoa and Flaxy additional savings were made by selecting turbines without guide vanes. These generating units operate at 50 or 100% load at peak efficiency.

2 DESIGN FEATURES OF TWIN TURBINE UNITS

Twin turbines present a number of challenges to the designer which need to be considered carefully.

2.1 Tailwater Level

If the unit needs to operate with only one turbine in service, then either the lowest part of the turbine runner must be above the tailwater level when the other turbine is at full discharge or arrangements must be made to blow down or seal off the runner which is not needed. (It is not necessary to provide for the turbine runners to be clear of water during floods because it can be assumed that if river flows are high, both turbines will be operating.)

2.2 Cooling

During single turbine operation, cooling water must be supplied to be labyrinth of the turbine rotating in air to prevent the runner overheating and seizing. We do this by cross connecting the two sets of labyrinths so that leakage water from the turbine in service cools the labyrinths of the turbine running in air without any need for special pumping, filtering and monitoring equipment.

At all the stations, cooling water for the generator and bearings has been taken from the turbine cover.[2]

2.3 Generator Rotor Removal

With a turbine at each end of the generator, the rotor and shaft cannot be removed axially. The easiest–but not necessarily the least expensive–way is to have a short stub shaft between the generator coupling and the runner so that the complete generator and stator can be lifted out from between the two spiral casings. A consequence of this is that the power station crane has to be capable of lifting the generator and stator in one piece.

A realistic option is to provide for maintenance of the rotor and stator windings by providing for removal of the rotor poles from the spider without removing it from the stator. With all but small generators this will leave sufficient space for rewinding the stator. Provided that adequate provision is made for access so that the stator plus stripped rotor can be removed by mobile crane in an emergency, this is a sensible approach.

Another option–which we have considered but not used–is to have the generator shafts flange connected to the rotor hub so the shafts can be removed and then the stator and rotor together jacked up until there is sufficient clearance to remove the rotor.

2.4 Governing

If the turbine is required to govern on an isolated system, there are two options available. One is to have a single servomotor operating a cross shaft which in turn operates both sets of guide vanes. If the unit needs to operate on one runner only then the other is isolated by means of the inlet valve but the guide vanes continue to move. This option may not be satisfactory with water lubricated guide vane bearings.

A better option is to use a governor with two distributing valves to control each set of guide vanes. It is easy to adapt a governor designed to control the needles and jet deflectors of a Pelton turbine to operate with a twin Francis turbine in this manner. A major advantage of this solution is that it is possible to program the governor so that operation in the mid range surging area of a Francis turbine is avoided by arranging that one turbine moves quickly through the surging area while the other one reduces flow to compensate. As the load increases further the second one moves rapidly through the surging area while the first one backs off as needed.

If there is no requirement for the unit to govern on an isolated system then the guide vanes can be controlled either by an electro–mechanical actuator or by a simple hydraulic cylinder and a pumping unit. It is normal to have two control valves: one opens and closes the guide vanes at a fixed slow rate for normal operation and the other closes the guide vanes rapidly in an emergency. A simple hydraulic accumulator sized for one and a half servomotor volumes is adequate for emergency closing. Guide vane position transmitters are needed so that the control system can ensure that both sets of guide vanes are at the same position when both are in service.

2.5 Erection

Erection and alignment also need to be considered carefully. The conventional method of installing the turbine and aligning the generator to it will not work with a twin unit. The generator must be installed first and the turbines aligned to the generator shaft. This requires that provision be made for fine adjustment of the spiral casing during alignment and for extreme care while concreting it in.

3 EXAMPLES OF TWIN TURBINE SCHEMES

3.1 Patearoa, NZ

This station operates at 31 m head with an output of 2200 kW. The turbines have no guide vanes and drive a 500 rpm induction generator. As a result the plant is extremely simple: it has only one moving part–the generator rotor, shaft and runners. The station arrangement is shown in Figure 3.

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[2] Leyland, B W., “Cooling Water Systems for Hydropower Schemes”*, Int Journal on Hydropower and Dams* May 1994

The turbines are controlled by the inlet valve and the machine is started by slowly opening one inlet valve to a preset position. The unit accelerates and when synchronous speed is reached the circuit breaker is closed by a speed switch. No attempt is made to adjust the turbine speed prior to closing the breaker by moving the inlet valve, as experience has shown this is not necessary. When the circuit breaker closes, the inlet valve continues to open and, if both turbines have been called for, the second inlet valve opens also.

If only one turbine is required one inlet valve is closed. There is no provision for draining the spiral casings for single turbine operation because operating experience confirmed that it was not necessary. During commissioning it was found that the turbine was slightly below the expected output. The output was increased by grinding a small amount of material from the inner ends of the stay vanes to increase the inlet area and the flow through the turbine.

This station and Flaxy, which has identical generating equipment, have been in operation since 1982 during which time nothing but minor maintenance has been required.

3.2 Wyangala Scheme, Australia

This scheme is based on an existing irrigation dam. The station uses irrigation water previously passed through irrigation valves; hence the ability to operate over a wide range of flows was paramount. As the station feeds into the national grid, it does not need to govern on an isolated system.

Detailed modelling studies were done to compare the generation that would be obtained from two single and twin Francis turbines and to determine the optimum operating range in terms of flow and head. These studies concluded that a twin Francis turbine with a maximum output of about 13 MW at 45 m head was the optimum solution.

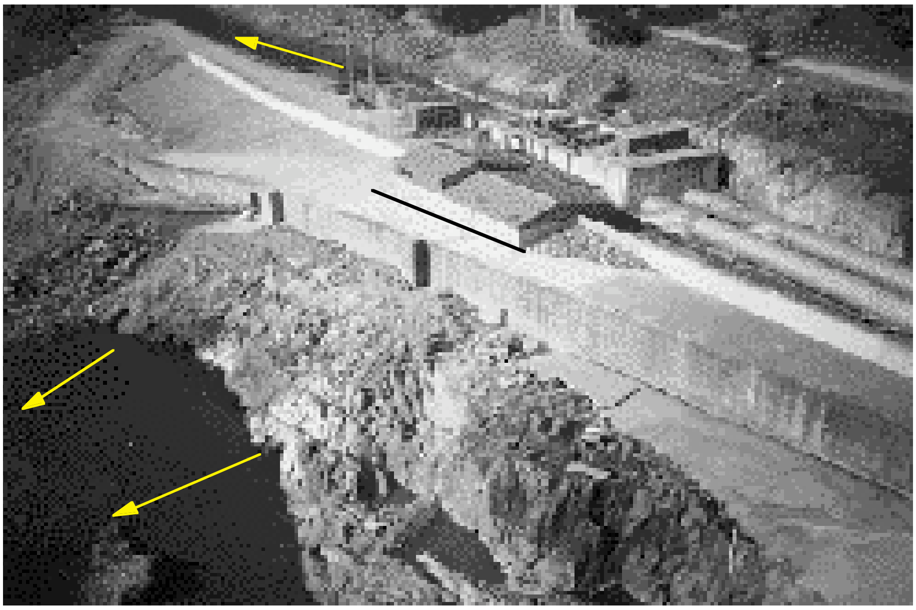
The flood rise at the powerhouse site during a one in 500 year flood was in the vicinity of 15 m and it soon became apparent that a conventional rectangular powerhouse designed to withstand such a flood rise would be very expensive. Based on their previous good experience with Hinemaiaia C Leyland Consultants suggested that a circular powerhouse would be a much more economical solution and this proved to be the case.

In order to minimise the excavation of the penstocks and bifurcation the inlet to the turbine spiral casing was specified to be above the turbine shaft rather than below. This also avoided the need for the excavation of inlet valve pits in hard rock. These features are illustrated in Figure 4.

When tenders were received the efficiencies were better, and the prices lower, than expected. A further round of studies using tenderers' hill curves showed that it would be economic to increase the rating of the unit from 13 to 18 MW. The unit was commissioned in 1992 and has been running reliably–and profitably–ever since.

3.3 Glenmaggie, Australia

Glenmaggie is based on a 30 m high irrigation dam in southern Victoria which supplies an irrigation canal about 10 m above the river bed. As the lake can hold only about 30% of the annual runoff there is a large potential for generating from spill as well as irrigation flow. Spill occurs from August to December and irrigation is required from January to June. During the irrigation season water is released to the irrigation canal and the river.



The challenge to the designers was to provide a scheme which could operate efficiently while discharging spill water to the river and also generate power when discharging flow to the canal and to the river. A number of options were considered and the tender documents were written to allow proposals for (a) a twin turbine arrangement with one of the pair of turbines arranged so that it could discharge to the river or the canal and the other discharging only to the river or (b) a vertical semi-Kaplan arranged with a gate so that the draft tube could discharge either to the river or to the canal or to both.

The arrangement chosen was twin turbines with one turbine larger than the other. A contract was placed with Skoda Export of Czechoslovakia for a 375 rpm generator manufactured by Skoda and a 1600 and a 2800 kW turbine manufactured by CKD Blansko. The larger of the two turbines has a dismantling piece in the draft tube which can be arranged to connect to the river or to the canal. To minimise excavation the turbine inlet was above the turbine centre line and it was angled upwards to simplify to the connection to the pipes leading to the existing irrigation valves. Figure 5 indicates the compact–and complex–arrangement of the station. There is no waste space!

Skoda elected to make the small turbine completely removable so that the generator rotor could be removed axially. Their original design of the spiral casing did not allow for the high loadings that would be placed on the turbine supports but fortunately this was picked up and corrected during the design stage.

The station went into service into 1994 and has been running reliably ever since. Some minor problems were experienced with one of the turbines due to surging. In the end it was solved by a minor change to the air admission.

3.4 Ord, Australia

This scheme is at the Ord irrigation dam in the Kimberley region of Western Australia. The dam was completed in 1970 and included intakes and tunnels for the later addition of a power station.

Between 1970 and 1990 a number of studies into power generation at the dam were carried out: all concluded that it was only marginally economic. The last of these proposals was based on the installation of two 25 MW vertical Kaplan turbines in a conventional powerhouse. This project was intended to supply the electrical load of the Argyle diamond mine about 120 km away and also provide power to the towns of Kununurra and Wyndham which are about 60 and 90 km from the dam. When the final cost estimates were prepared this scheme was found to be uneconomic compared with diesel generation.

Leyland Consultants then worked with a private developer and other consultants to identify ways of reducing the cost of supply to the diamond mine. Finally a scheme with two 18 MW twin turbines in a minimum sized powerhouse with an outdoor crane was decided upon. The studies included a detailed comparison into the alternative of two vertical Francis turbines which showed that the twin turbine option could be built quicker and would cost less. Figures 6 and 7 show details of the plan and sections of the 36 MW installation while Figures 8 and 9 compares dimensions for the original 2x 25 MW Kaplan powerhouse and the 36 MW twin Francis powerhouse.

This plant had to govern on an isolated system–either on its own or in parallel with existing diesel plant. Therefore governing and speed rise following loss of load were important. To increase the inertia, a 35 tonne flywheel was included and a bank of resistors was installed to limit speed rise if the mine load was lost but Kununurra was still on line.

It was also important that the turbines should be able to operate over a wide range of loads without surging or hunting. Operation well below 50% load was required because the local power authority–who had a background in diesel generation–believed that having two machines on line would provide significantly better reliability than a single machine. This low load operation would only occur after the diamond mine's 20 MW load was lost in about 10 years time. The station would then be providing only the local load of 5 - 10 MW. The requirement for two machines on line would require the turbines to operate at 15-25% load for long periods.

Because the excavation for a conventional powerhouse had been carried out when the dam was built, the turbine centreline would be well below tailwater level. This in turn meant that operation with a single turbine during low load periods–which requires that the draft tube be drained–could not be done. However, to be safe, provision was made for isolating one turbine with draft tube stop logs, and draining the spiral casing so that single turbine operation could be adopted if the turbines gave cavitation problems at very low loads.

A contract for the turbines was placed with Kvaerner Energy in Norway and for the generators with ACEC in Belgium. The generators were equipped with self lubricating thrust bearings in order to eliminate the problems experienced in other stations with circulating pumps, separate cooling systems and the need for emergency pumps during run down.

The turbines were on line within 18 months of ordering. During commissioning there were significant problems with surging of the turbines. These were finally solved when the turbine manufacturer implemented our proposal of stepping the turbine through the surging area. Initial efforts to solve the problem were directed at modifying the air admission system. These reduced the problem but did not solve it. The turbines were found to operate smoothly at low loads.

The station has now been in operation for more than a year. Most of the time it is the sole supplier of power to the diamond mine and Kununurra.

4 CONCLUSION

Now that hydro schemes are being built by private developers rather than government organisations or development banks, pressure is increasing for designs which are low in cost, flexible and reliable. Where Francis turbines are indicated, and the flow is less than 40 cumecs, the adoption of twin Francis turbines can show large savings.

Biographical Details of the Author

Bryan Leyland is an Electrical and Mechanical Engineer with wide experience in power generation and power systems.

He has a detailed knowledge of the mechanical and electrical aspects hydro power plant and a comprehensive understanding of the civil and mechanical engineering problems associated with designing, building and rebuilding powerhouses, penstocks, intake structures, canals, dams, screen cleaners, gates and spillways. His expertise includes generators, transformers and power lines, switchyards and cables at voltages up to 330kV.

He has worked in the UK, Mauritius, West Africa, Cyprus, Malaysia, Philippines, Papua New Guinea, Samoa, Australia and NZ.