RADIAL INFLOW TURBOEXPANDER REDESIGN
Steamboat Geothermal Power Plants I/IA -- Reno, Nevada

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ABSTRACT

Steamboat Envirosystems, LLC (SELC) was awarded a grant in accordance with the DOE Enhanced Geothermal Systems Project Development Solicitation DE-PS07-00ID13913. Atlas-Copco Rotoflow (ACR), a radial expansion turbine manufacturer, was responsible for the manufacturing of the turbine and the creation of the new computer program. SB Geo, Inc. (SBG), the facility operator, monitored and assisted ACR's activities as well as provided installation and startup assistance. The primary scope of the project is the redesign of an axial flow turbine to a radial inflow turboexpander to provide increased efficiency and reliability at an existing facility. In addition to the increased efficiency and reliability, the redesign includes an improved reduction gear design, an improved shaft seal design, an upgraded control system and a greater flexibility of application.

This paper shall discuss the activities resulting from this grant and the improvements achieved by the redesign of the axial flow turbine.

INTRODUCTION

Steamboat I/IA geothermal power plant, owned by SELC, experienced a catastrophic failure of an operating axial flow turbine designed by Ormat, Inc. Although the failure was unfortunate, it provided the perfect opportunity to design, install and field-test a new, fully compatible turbine. The radial inflow turboexpander redesign addresses five components: increased efficiency, improved reduction gear design, improved shaft seal design, upgraded control system and greater flexibility.

Increased Efficiency

The new turboexpander has been designed with an adiabatic efficiency point of 88 percent. The design operative conditions are identical to the normal operating conditions of the existing turbine. The Ormat turbine efficiency typically operates in the mid-70 percent efficiency range. With this increase in turbine efficiency, the generator will produce a higher yearly power output that will allow the facility to approach its economic potential.

Reduction Gear

The epicyclic reduction gear is a main component in the operation of this new turbine. The epicyclic reduction gear has a high-speed sun gear and three planetary gears, which are fixed in the planetary wheel holder. The planetary gears are tied into two hollow ring gears, which rotate and provide the low speed output to the generator. Because of its design, the high-speed shaft does not require bearings as it basically floats within the planetary gears, which significantly increases the gearbox's overall efficiency by as much as 3 percent over conventional double helical gearbox assemblies.

The planetary gears are equally spaced around the sunwheel and they share the load uniformly, which results in low noise levels from the gearbox. The high and low speed shafts are in-line and not offset like the current reduction gear. This is important because many of the units at Steamboat I/IA, as well as other axial turbines, are directly coupled to the generator and thus modifying existing units can be done without major changes.

This gearbox was installed with vibration sensors, bearing temperature detectors and speed pickups. All these devices are tied into the control system to provide alarms and shutdowns if a problem occurs. A lack of sufficient monitoring and protection was the major reason the previous turbine catastrophically failed.

<u>Improved Shaft Seal Design</u>

The turbine wheel is directly mounted onto the high-speed shaft of the reduction gear. Instead of using a cartridge type, dry face seal, this turbine incorporates a labyrinth and brush seal combination. The labyrinth seal is designed for process gas to leak by the seal and mix with the oil being applied to the seal. This oil/gas mixture is then sent to a degassing system to separate the two components. A dual set of gas compressors recover the process gas and return it to the process, discharging into the exhaust line of the turbine.

<u>Improved Control System</u>

The turbine control system was significantly upgraded during the redesign process. An Allen Bradley SLC 504 Programmable Logic Controller is the heart of the control system. The SLC 504 interfaces with two Human Machine Interface (HMI) terminals located in the power plant's main control room and at the turbine control panel in the local motor control center (MCC). The control system is used to monitor all protective devices and all analog indications on the turbine generator including turbine bearing temperatures, turbine vibrations, oil temperatures and all parameters associated with the Iso-pentane process.

One significant change for the new control system was actual feedback from devices reporting their status. The previous control system had no feedback from vital equipment such as the feed pump, condenser fans, and brine outlet valve. The new control system requires positive feedback that components are running and in their correct position prior to allowing the next step in the start sequence to commence. In addition, a new turbine bypass valve was installed. The previous open/close bypass valve was converted into a pressure control valve with a positioner controlled by an input from the HMI. The operator inputs a desired turbine inlet pressure and the bypass valve adjusts as necessary to maintain that set point. Constant turbine inlet conditions are important during a turbine startup and subsequent synchronization of the generator. This new bypass valve has provided a sound engineering method of turbine startup that was not previously available.

The turbine speed is actually controlled by a Woodward 505 Governor. The governor will bring the turbine from 0 to 3480 RPM in a few seconds and then maintain turbine speed at that point until the operator acknowledges that conditions are satisfactory for further turbine operation. The governor will then increase turbine speed to 13050 RPM in less than 90 seconds and the auto synchronization circuit will place the generator in service.

Once the generator is online and positive feedback of the generator output breaker is received, the remaining condenser fans are started in sequence by the control system. The remaining brine valves are also opened after generator breaker feedback is received. The Woodward governor is programmed to load the generator at a rate of 100 KW per minute. The previous control system placed full flow into the turbine immediately after the unit was placed in service. A controlled loading of a generator is important to allow for proper heating of the generator thus minimizing the stresses on the machine.

Flexible Design

The new equipment is designed to replace any of the turbines that currently exist at Steamboat I/IA as well as other facilities that operate with Ormat axial turbines. The Steamboat facility has three different Ormat turbine designs, all of which will be compatible with the new design. This is an important factor since many facilities that operate Ormat turbines contain different models of the turbine. The new design can be engineered for any existing binary plant motive fluid and its associated thermodynamic requirements. In addition, the turboexpander can handle almost any amount of liquid condensing in the turboexpander itself. This reduces the amount of superheat or eliminates its need altogether. For a given source of temperature, the radial-inflow turboexpander produces the maximum power from the heat source.

OBJECTIVE

The object of the proposal was the conversion of an axial flow turbine to a radial-inflow turboexpander used in geothermal applications. With the redesign, the following concerns were addressed: greater efficiency and flexibility of application, improved reduction gear design, improved shaft seal design and an upgraded control system.

RESULTS

The turbine skid and auxiliary equipment was received on December 5, 2000 and installation began immediately. All work was completed on December 27, 2000 and the unit was started for initial testing on December 28, 2000. During testing we found a generator sensing current transformer that was not of the same ratio as the other two phases. The incorrect ratio provided an inaccurate reading to the electrical protective system and thus the unit was inadvertently shutting down on generator overcurrent. The unit remained online at reduced generation until the correct current transformer was received and installed on January 5, 2001.

The output of the Rotoflow turbine was much higher than the Ormat unit reaching outputs as high as 1.43 MW during peak operation. The new turbo-expander was designed with an adiabatic efficiency point of 88 percent versus an efficiency in the mid 70's for the Ormat turbine. During its final test run at the Rotoflow facility the unit efficiency was 88.1 percent. The average monthly power output after January 5, 2001 was 1.287 MW. In comparison, the parallel Ormat unit averaged 1.075 MW during the same period. The year to date average through June 30, 2001 is 1.16 MW for the Rotoflow unit and .88 MW for the Ormat unit for an increase of 24.1 percent.

The current degassing system requires heating the oil/gas mixture to 240°F in order to sufficiently degas the oil. The high temperature forced a change in the oil used from a Mobil grade 18M to a Mobil synthetic blend SHC 626. During operation at higher ambient temperatures, and thus higher turbine discharge pressures, the seal oil supply was not sufficient to accurately control the amount of Iso-pentane passing into the degas system. Rotoflow engineers determined that a larger oil port was required on the seal plate to supply enough oil to sufficiently seal the system at higher ambient temperatures. The unit was shutdown to modify the seal plate and the unit was returned to service. Since this modification, the system has operated as expected.

The biggest obstacle with the degas system has been with the gas compressors that are used to return the Iso-pentane from the degas system back to the condenser. Once the Iso-pentane leaves the degas tank and is delivered to the compressor suction, most of the 240°F Iso-pentane condenses before it can be compressed due to fact that Iso-pentane condenses at 82°F at atmospheric pressure. The condensed Iso-pentane is leaking into the compressor crankcase and diluting the oil causing frequent shutdowns of the compressors for oil changes. We made several enhancements to the compressors in an attempt to keep the piping warm. High-grade heat trace and insulation were added to the compressor inlet piping. Check valves were added to the compressor discharge and a downward elevation was installed on the discharge piping to allow any liquid buildup to pool at a low point drain. Finally, a high temperature re-circulating line from the turbine inlet was piped into the compressor discharge to keep the lines warm. We are still experiencing significant problems with the compressors and further solutions are being evaluated. It is possible that we may remove the current degasification system and replace it with an oil purifier. This new system would eliminate the need for the gas compressors currently used, as all components are self-contained within the purifier.

CONCLUSIONS

After reviewing the operation of the new turbine and its associated control system we feel that all the goals of this project were met. We are very pleased with the efficiency and output of the turbine generator as it has met and exceeded our expectations. The control system is exceptional and we have experienced no problems with its implementation. As mentioned earlier, we are still working with GE Rotoflow to solve the oil degasification problem and hope to have a solution in operation very shortly.