Index testing is especially valuable for turbines that use a mechanical linkage and a cam to set the blade angle for various gate positions. A key element in the process is a computerized data acquisition system.

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Maximum hydraulic efficiency for a hydroelectric generator at a given hydrostatic head is determined primarily by the relationship between the wicket gate opening and turbine blade angle. Until recently, Kaplan hydraulic turbines used governors with a mechanical linkage to sense the position of the wicket gate. This linkage rotates a cam that controls a valve used to change the angle of the turbine blade.

For every wicket gate position there is an optimum turbine blade angle. The wicket gate opening and blade angle determine the amount of water that enters the turbine, but efficiency is also a function of hydrostatic head, or the difference between the headwater and tailwater levels. A particular two-dimensional cam can only be used over a certain range of hydrostatic heads. When the operator determines that the head is out of the cam's range, the cam is manually changed.

A set of cams cannot achieve maximum efficiency under all operating conditions, especially since only the position of the wicket gate is monitored. This can be demonstrated by index testing, which is the measuring of a turbine generator's efficiency over its operating range. Through index testing, a variety of hydrostatic heads and power output conditions can be accurately measured. One turbine at a time is tested. From the data, accurate cams can be fabricated to optimize the efficiency of turbines at the hydroelectric plant.

Periodic testing can also detect changes in the characteristics of the turbines. The blade control linkages and blade trunnion bushing can become worn, and welding done to repair cavitation damage to the blades may alter their profile. As these changes occur, the original set of cams becomes less efficient.

Index testing was performed at two hydroelectric plants on the Columbia River in central Washington, one at the Wanapum Dam and the other at the Priest Rapids Dam. Each of these facilities has 10 turbine generators. The combined annual production for the two plants is more than 9.9E9 kilowatt hours.

DATA ACQUISITION

When enough information had been obtained on these two plants, a computerized data acquisition system was specified for further index testing. Five analog and two 14-bit digital inputs were required. A rate of at least 50 measurements per second with 5½-digit resolution was considered necessary for accurate real-time analysis. The system had to be flexible enough to be reconfigured for other applications. The Basic programming language was requested.

The Hewlett-Packard 3054 data acquisition and control system was selected. It includes a controller, hard disk drive, direct memory access, scanner, digital voltmeter, plotter, and printer. It came equipped with the appropriate input and output cards and cost under $30,000.

The transducers described in Table 1 were positioned as shown in Figure 1, and all of their outputs were fed into the data acquisition system. The watt transducer and volt-amperes-reactive transducer were used to monitor the generator's output power and hence its efficiency.

The running time of the test program was 8 minutes broken into 24 periods of 20 seconds each. During the 20 seconds, seven transducers were read 100 times each. The computer display was updated every 20 seconds and showed the data for the previous 100 readings of each transducer. Included in this display were the minimum, maximum, average, and the average converted into engineering units.

TEST RESULTS

Figure 2 shows the test results in terms of relative efficiency versus megawatts generated for Unit Number 8 at Wanapum Dam. The six curves labeled Off Cam were created at six different blade angles for various power output ranges determined by the wicket gate position. Blade angle was measured relative to a horizontal line and is shown as a percentage. A 20-degree angle is equal to 0 percent and a 37-degree angle is equal to 100 percent. Readings were taken at a fixed blade angle; gate positions were changed approximately 3.5 percent for each data point. Each constant blade curve has a distinct peak representing the point at which the gate position allows the generator to produce power at maximum efficiency.

The curve labeled On Old Cam in Figure 2 was generated using 14 gate positions during which the existing mechanical linkage and cam in the governor determined the blade angle. Note that in all cases a blade angle can be found that produces greater efficiency than the cam has been able to achieve. This is especially true for higher power levels, at which a 2–3 percent improvement in efficiency could be realized in the operation of the plant.