FLUKE®

More snow with power quality

Application Note

Testing Functions
Case Study

Tools: Fluke 41B Power Quality/ Harmonics Analyzer

Measurements: Voltage, THD, Current TDD, KVA

Team: Colorado Ski Resort, Starboard Electrical Contractors, Var+Technologies, PQ specialists, Denver Water Board

Note: The Fluke 41B Power Quality Harmonics Analyzer is no longer available. In it's place, Fluke recommends the 434 Power Quality Analyzer.

Scenario

A ski resort near Silverthorn, CO., depends on its snowmaking capacity to augment nature's snowfall, especially during drought years. Pressurized water and compressed air are forced through special spray nozzles to atomize the water in freezing temperatures and create snow.

Background

Air is readily available; however, water availability depends on rainfall. To solve this problem, the resort arranged to divert water from the nearby Snake River, in cooperation with the Colorado Conservation Board and the Denver Water Board. To ensure the river maintained minimum flow levels, the resort would pump water out of the Roberts Tunnel below, via the 900-foot deep Montezuma Shaft, and into the Snake River, above.

In 1996 the resort installed a pumping system in the tunnel comprised of a 350 horsepower SCR (silicone controlled rectifier) VFD (variable frequency drive) operating at 480 volts ac. Because the pump and motor were 900 feet down the shaft, the 480-volt power from the VFD was transformed to 4160 volts at ground level and wired down the shaft to the motor. The shaft pumps could deliver 7.8-cfs (about 3,500-gpm) to the river when both ran full capacity. That allowed the resort to divert about 9.4-cfs (about 4,200-gpm) for snowmaking.

The power source for the pumping system was a 1000 KVA transformer fed by a 25,000 volt, 3 phase #2 overhead power line five miles from the resort going on past the pumping system to the community of Montezuma. This pumping system worked well for several years with only the 350 horsepower pump.

Resort pumping station, including transformer, power filter, VFDs and pumps.

Evolution

As the resort expanded its snowmaking system, its water demands increased. The project installed an additional 750 horsepower VFD in 2002 with a new 12-inch pipe from the tunnel, up the shaft to the Snake River. However, the system was never run to capacity because the power line and 1000 KVA transformer could not support the total 1100 horsepower of VFD load.

If both drives were run at capacity, they would drop off-line because of their under-voltage protection. When the system was on-line, local residences complained of flickering lights and the noisy transformer and VFDs.

Meanwhile, new management assumed ownership of the resort.

Problems

During the 2002-2003 ski season, the new management was disappointed with the snowmaking coverage. The new lift manager worked together with local engineering and electrical contractors and (re)discovered that the problem was not a lack of water but a lack of power to pump the water. They contacted Var+Technologies to see if harmonic power filters could solve the lack of power at the pumping station. Var+ had already supplied six filters that had cured several power issues on the mountain (harmonic related problems with failed battery chargers, night lighting transformers, drive field supplies, and chair lift speed instability).

Investigation

Using a Fluke 41B Power Quality Analyzer, the team measured power at the pumping station in February 2003. The team could only run the 750 hp pump at approximately 50 % load because of the power line and transformer capacity.
The team then calculated horsepower and power (Table 1) and compared that to calculations from the actual measurements (Table 2).

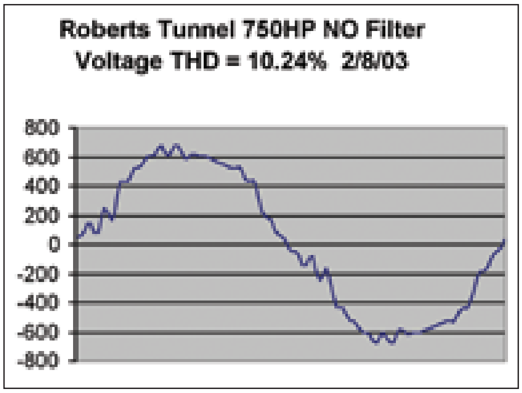


Figure 1. Voltage waveform of the 750 hp VFD.

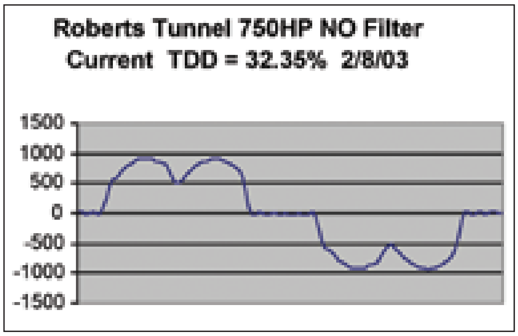


Figure 2. Current waveform of the same VFD.

Note: These waveforms are the result of using a single-phase instrument.

Calculated size of transformer

(Watts/HP)/1000=		KW
350	746	261
750	746	560
1100	746	**821**

Table 1. Calculated horsepower and power.

Note: These assumptions do not take motor efficiency into account.

Actual measurements	KW	KVAR	KVA	Volts RMS	Amps RMS	Amps @ 300 Hz
750 @ 50 %	479	245	535	474	650	186
350 running at 120 % KW	311	94	337	478	406	99
750 running at 120 % KW	*671*	*203*	*728*			*214*
Calculated total load	982	297	1065		1056	313

Table 2. Calculated data from actual measurements

Pumped water flowing into the Snake River.

Findings

The 350 horsepower pump was running 120 % of the expected load. If the 750 horsepower pump were assumed to run at 120 % also, the KVA required for both pumps would be 1065 with 313 amps of 5th harmonic current. The 5th harmonic is the whole number multiple of the fundamental frequency.

Harmonic = whole number x fundamental frequency

5th Harmonic = 5 x 60 cycles per second = 300 cps = 300 Hz

With these numbers and 10.24 % THD (Total Harmonic Distortion) voltage distortion plus 30.78 % TDD (Total Demand Distortion) current distortion, it was no wonder the power line and transformer couldn't handle the load. The Institute of Electrical and Electronic Engineers (IEEE) 519-1992 Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems lists 5 % THD and 8 % TDD as guideline maximums.

Solution

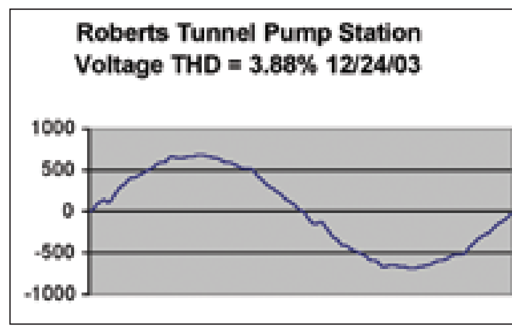
The team thought a Var+ harmonic filter—900 kVAR at 600 volt (594 kVAR at 480 volt) in 9 steps—should be able to manage the reactive power (KVAR) and the 5th harmonic current as well as improve system efficiency, allowing the pumps to run at maximum capacity. (See sidebar on reactive power.) The filter should also reduce the voltage and current distortions to the IEEE guidelines, by filtering out the 300 Hz current with a reactor(inductor)/capacitor network.

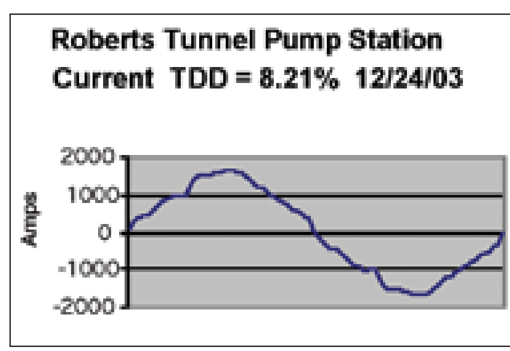
The resort purchased and installed the harmonic filter and activated it in October 2003. Several of the pump manufacture service personnel were on site and they were skeptical about pump drives operating with a power filter and the capacity of the 1000 KVA transformer. The utility also had several technicians there to measure the load, power factor, and distortion on their transformer. Including resort snowmaking personnel and management, there were approximately 15 people anticipating a "fire and light show."

A snowmaker tech started the 350 hp pump and slowly dialed up the capacity. The harmonic filter banged in several 66 KVAR steps to hold the power factor at unity. When the 350 hp pump was at full capacity, the 750 hp pump was started and slowly increased in speed and capacity. With both pumps at full capacity, the harmonic filter had seven of the nine steps energized and the system was pumping approximately 4500 gallons/minute.

The snowmakers walked over to the pumping system outlet pipe and were amazed at the amount of water discharging into the Snake River. The team experimented with different combinations of pump settings and start/stop sequences to check the operation of the drives and harmonic filter. After a half hour, the crowd dissipated because there was nothing to see except water pouring into the river.

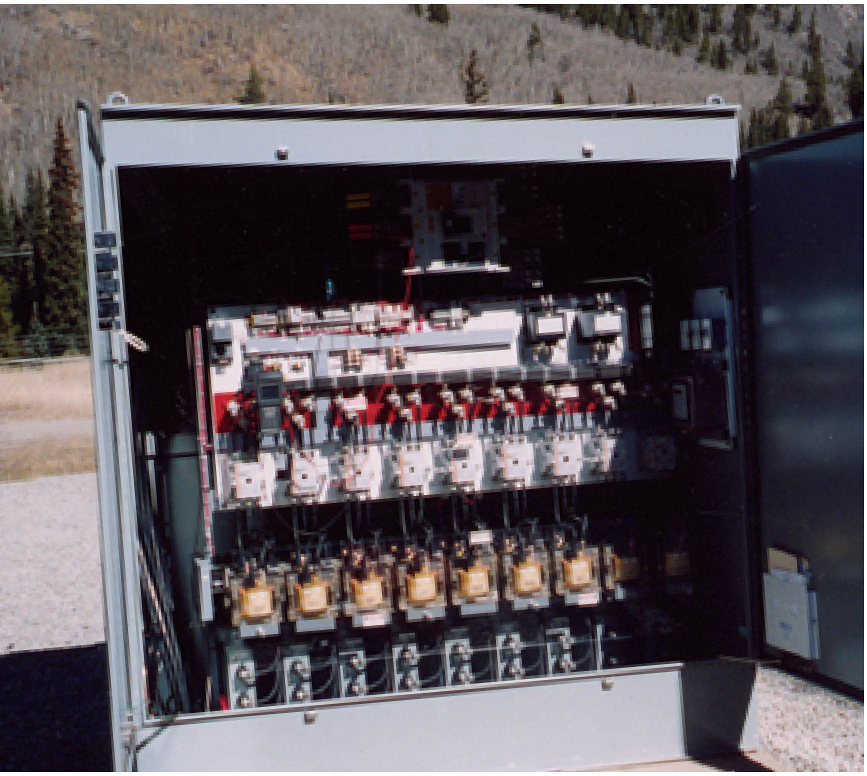
To verify the harmonic filter's operation, the team took one last set of measurements in December 2003 with the Fluke 41B. These measurements were taken at the point of common connection (PCC) of the drives and harmonic filter.





From 12/24/03				Volts	Amps	Amps @
Actual measurements	KW	KVAR	KVA	RMS	RMS	300 Hz
Both pumps running	939	199	964	492	1131	59

Table 3. Fluke 41B Measurements from PCC 12/24/03.


Taking measurements at the power filter.

- Roberts Tunnel Pump Station information from Bill LaClair, Resort Snowmaking Manager, **lleclair@vailresorts.com**
- Events and Fluke 41B documented by Vaughn DeCrausaz of Starboard Electric, **starbrd@vail.net**
- Technical data by William C. McConnell III, Var+Technologies, **wcm@vartechnologies.com**
- Power distribution information by Frederick K. Ottman, Power Quality Specialist, Service Investigation, Xcel Energy of Colorado, fred. **ottman@xcelenergy.com**
- Denver Water information from **www.denverwater.org/aboutdw/history** and **www.agecon.purdue.edu/staff/lovejoy/game/about**

The KVA had been reduced from a calculated value of 1065 to 964, the voltage increased from 474 to 492, and the 5th harmonic (300 HZ) current reduced from a calculated value of 313 to 59-amps. The harmonic filter injected 424 KVAR of reactive power.

The pumping system has been running for the last three snowmaking seasons without problems.

Lessons learned

- Having the proper test equipment to measure voltage, current harmonics and power factor is paramount to identifying the problem and specifying a solution.
- Reactive power (VARS) should be added to the "power systems" to achieve a unity power factor.
- Do not believe everything you hear about a project without proper documentation. Examples:
  - 1100 horsepower of motor load can't operate on a 1000 KVA transformer.
  - Two large motor drives can't be connected on one large transformer.
  - Electronic drives can't operate with harmonic power filters.

References and credits

- "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Systems", IEEE Std. 519-1992 page 78 Table 10.3 "Current Distortion Limits for General Distribution System", page 85 Table 11.1 "Voltage Distortion Limits", IEEE, New York, NY April 12, 1993

Lake Dillon, a reservoir of 252,678 acre-feet when full at a 9,071-foot elevation, is the point of water collection. This water is conveyed east from Lake Dillon under the continental divide through the Harold D. Roberts Tunnel 23.3 miles to the North Fork of the South Platte River and then on to Denver.

Originally the tunnel was first named the Blue River Tunnel, later the Montezuma Tunnel, then officially named the Harold D. Roberts Tunnel for a Denver Water Board attorney who was instrumental in the buying of the water rights and gaining congressional approval for the project. The dam and tunnel construction began in 1942. After a hiatus during World War II, work resumed again on June 24, 1946. The tunnel's west portal, under Lake Dillon, is at an elevation of 8,844 feet, 174 feet higher than the east portal. The gradient averages seven feet per mile. With an inside diameter of 10 feet, 3 inches, the tunnel can carry 1,000 cubic feet per second (680 million per day) if the lake elevation is 9,017 feet. The first water flowed through the tunnel July 17, 1964.

“In any modern-day power grid, the power delivered can do useful work only when current and voltage are perfectly in phase with each other, so that reactive power is neither added nor subtracted. But rotating equipment like motors and generators, in particular, tends to cause current to lag behind voltage, as energy transfers to the magnetic fields of their coils. Left unchecked, this lagging can cause voltage sags on a network to plunge and ultimately bring down an entire system–the way one did on August 14, 2003, when a huge chunk of the U.S.-Canadian grid collapsed.”*

Reactive power is required to counteract lagging currents and sagging voltages, and if it isn’t supplied quickly and efficiently enough, equipment suffers and networks crash. Indeed, reactive-power-supply problems are among the chief culprits in an overall power-anomaly/disturbance problem that costs the United States between US $119 billion and $188 billion a year in lost economic activity. That’s according to a 2001 report by the Electric Power Research Institute, in Palo Alto, Calif. Such losses equal between 1.2 % and 1.9 % a year of the country’s gross domestic product.

To provide a sense of the potential market, note that the Tennessee Valley Authority (TVA), with a generating capacity of about 30 gigawatts, has 259 capacitor banks with a total rating of 9.4 gigavoltamperes-reactive(GVAR). Scaling to the whole United States, which has more than 700 GW of generators, there might be as much as 250 GVAR of transmission capacitors...”

*Adrenaline for the Grid” by William Sweet. IEEE Spectrum, January 2006, page 44

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