# Solving a Power System Capacity Problem

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Concerns over the load-carrying capabilities of a transformer and an overhead transmission line are dismissed by careful measurements and harmonic filter/capacitor installation.



In 1996, a ski resort near Silverthorne, Colo. installed a pumping system to lift water up to a river, whose water flows into a lake at the base village of the resort and is then used on the mountain for snowmaking. At that time, the pumping system consisted of a 350-hp, 480VAC, 3-phase, SCR, variable-frequency drive (VFD), which was located at the base village. Because the pump and motor were positioned 900 feet below the river and VFD, the resort used 4,160V as the distribution voltage from the VFD to the motor and pump. The power source for the pumping system was ¡ª and still is ¡ª a 1,000kVA transformer fed by a 25kV, 3-phase overhead power line located five miles from the ski resort. This line also runs beyond the pumping system and serves a local community.

This pumping system worked well for several years with only the 350-hp pump, but as the ski resort expanded its snowmaking system, more water was needed. As a result, a 750-hp VFD, pump, motor, and new pipe to the river were installed in 2002. At this point, some real operational problems surfaced.

**Problems and symptoms.** During the 2002-03 ski season, the resort experienced poor snowmaking capability, prompting the lift manager to investigate the problem. He came to believe that the poor snowmaking capability was not due to lack of water, but rather a lack of power to pump the water. He based this conclusion on the fact that the resort could never run the newly expanded pumping system to capacity because the power line and 1,000kVA transformer could not support the total 1,100hp of VFD load. In fact, the resort could not run the 750-hp VFD at capacity by itself, let alone together with the 350-

hp VFD running at full capacity. The drives would drop off-line because of their under-voltage protection.

Another concern was that homeowners and businesses in the area and nearby community complained of flickering lights. Still another issue was the audible noise of the transformer when the system was online. The VFDs themselves also emitted an audible noise.

**Measurements and calculations.** The resort decided it was time to call in a manufacturer of harmonic power filters/capacitors to see if these devices could solve the lack of power at the pumping station. The manufacturer previously had supplied six of these units for the resort's largest chair lifts, and had cured several other power issues on the mountain, including harmonic-related problems with failed battery chargers, night lighting transformers, drive field supplies, and chair lift speed instability.

In February 2003, the resort hired an electrical contractor, at the manufacturer's request, to take power measurements at the pumping station. The contractor's measurement team could only run the 750-hp drive at approximately 50% load because of the prevalent problem with power line and transformer capacity. **Figure 1** (above) shows a plot of the voltage waveform of the 750-hp VFD without any harmonic filter/capacitor support. **Figure 2** (below) shows a plot of the current waveform of the same VFD ¡ª again with no harmonic filter support.

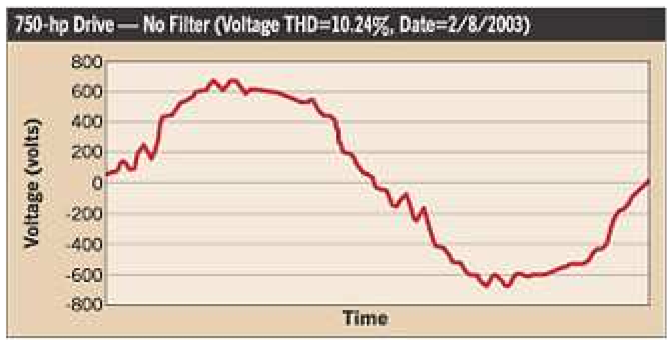


**Fig. 1.** Plot of voltage waveform of the 750-hp VFD before addition of harmonic filter/capacitor. Note the voltage THD of more than 10%.

The harmonic filter/capacitor manufacturer then made calculations of horsepower and power (**Table 1**, below) and compared them to calculations derived from the actual measurements (**Table 2**, below). The manufacturer then evaluated a scenario where both the 350-hp pump and the 750-hp pump were running at 120% of expected load. The manufacturer found that the kVA required for both pumps would be 1,065kVA, with 313A of 5$^{th}$ harmonic current. With these numbers and 10.24% voltage total harmonic distortion (THD) plus 30.78% current total demand distortion

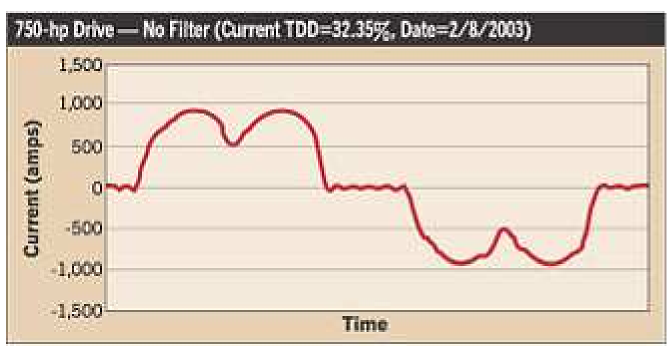


**Fig. 2.** Plot of current waveform of the 750-hp VFD before addition of harmonic filter/capacitor. Note the current TDD of more than 32%.

(TDD), it was no wonder the power line and transformer could not handle the load. (See ¡°Harmonics and Their Effect on Power Factor,¡± .)

IEEE 519-1992, ¡°Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems,¡± lists recommended maximum values as 5% THD and 8% TDD.

| Calculated Size of Transformer | | |
|---|---|---|
| Size of motors (hp) | (Watts/hp)/1,000 | kW |
| 350 | 746 | 261 |
| 750 | 746 | 560 |
| 1,100 | 746 | 821 |

**Table 1.** This table provides a summary of horsepower and power levels lased on actual installed equipment.

| Calculated Data from Actual Measurements | | | | | | |
|---|---|---|---|---|---|---|
| Actual measurements | kW | kVAR | kVA | Volts (rms) | Amps (rms) | Amps @ 300Hz |
| 750hp @ 50% | 479 | 245 | 535 | 474 | 650 | 186 |
| 350hp @ 120%kW | 311 | 94 | 337 | 478 | 406 | 99 |
| 750hp @ 120%kW | 671 | 203 | 728 | — | — | 214 |
| Calculated total load | 982 | 297 | 1,065 | — | 1,056 | 313 |

**Table 2.** This table provides a summary of the actual measurements taken prior to the installation of the harmonic filter/capacitor. Dashes indicate areas where measurements were not taken.

**Solution.** The harmonic filter/capacitor manufacturer concluded that one of its units, a nine-step, 900 kVAR, 600V (594 kVAR at 480V) unit, could be used to supply the reactive power (kVAR) and reduce the 5$^{th}$ harmonic current as well as stiffen the voltage by 5%. This would allow the pumps to run at maximum capacity. The harmonic filter would also reduce the voltage and current distortions to the IEEE guidelines by filtering out the 300-Hz current (5$^{th}$ harmonic) with a reactor (inductor)/capacitor network. The ski resort purchased the harmonic filter in the spring of 2003, installed it during the summer, and put it online in October.

Several of the pump manufacturer's service personnel were on-site at startup because of their skepticism of the pump drives operating with a harmonic filter as well as the capacity of the 1,000kVA transformer. The utility also had several technicians there to measure the load, power factor, and distortion on their transformer. Including the resort's snowmaking personnel and upper management, there were approximately 15 people anticipating the ¡°fire and light show¡± at startup.

A snowmaker started up the 350-hp pump VFD and slowly dialed it up to 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 snowmaker started the 750-hp pump and slowly increased its speed and capacity. With both pumps at full capacity, the harmonic filter had seven of its nine steps energized, and the system was pumping approximately 4,500 gallons per minute. The snowmakers walked over to the pumping system outlet pipe and were amazed at the amount of water discharging into the river.

They experimented with different combinations of pump settings and start/stop sequences to check the operation of the drives and harmonic filter. After about a half an hour, the crowd dissipated because the operation was fairly boring except for the water foaming into the river. The pumping system was test run for one week to verify there would be no problems for the snowmaking season.

| Actual Measurements from PCC (Date = 12/24/2003), Both Pumps Operating | | | | | |
|---|---|---|---|---|---|
| kW | kVAR | kVA | Volts (rms) | Amps (rms) | Amps @ 300Hz |
| 939 | 199 | 964 | 492 | 1,131 | 59 |

**Table 3.** This table provides a summary of the measurements taken after the installation of the harmonic filter/capacitor.

In December 2003, the electrical contractor again took measurements ¡ª this time at the point of common connection (PCC) of the drives and harmonic filter ¡ª to verify the operation of the filter/capacitor (**Table 3**, above). These measurements were derived from plots of voltage and current waveforms (**Figs. 3** and **4**, below) with the harmonic filter online.

Note that the kVA was reduced from a calculated value of 1,065kVA to 964kVA. Also, the voltage increased from 474V to 492V. Finally, the 5th harmonic current was reduced from a calculated value of 313A to 59A. The harmonic filter had injected 424kVAR of reactive power in the system.

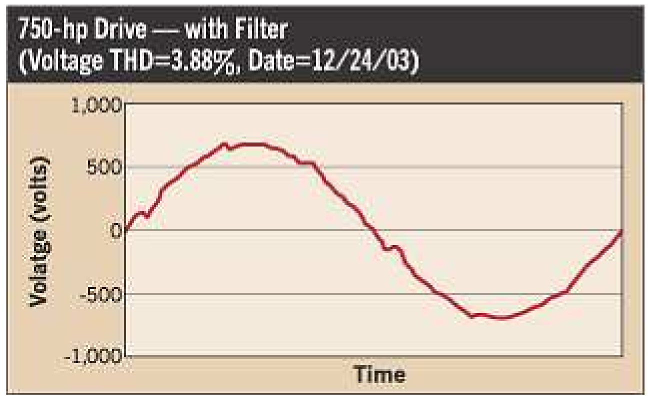


**Fig. 3.** Plot voltage waveform of the 750-hp VFD after addition of harmonic filter/capacitor. Note the new THD at less than 4%.

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

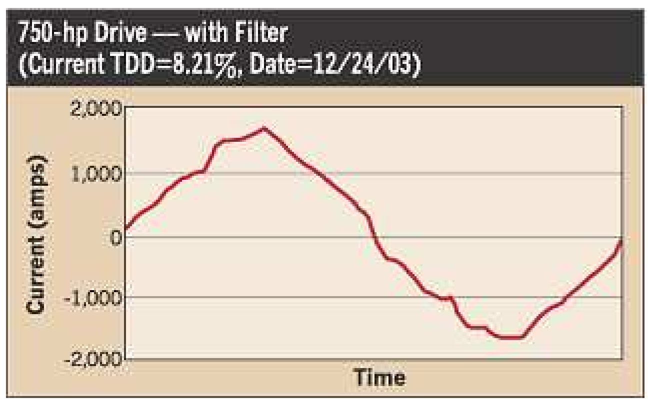


**Fig. 4.** Plot of current waveform of the 750-hp VFD after addition of her harmonic filter/capacitor. Note the new current TDD at just more than 8%.

**Lessons Learned.** The people involved in the ski resort water-pumping problem learned some valuable lessons:

• If necessary, you should add reactive power (VARs) to a power system to achieve, as close as possible, a unity power factor and free up system loading capacity.

• Do not necessarily believe everything you here about a project without proper documentation. Examples: ¡°1,100hp of motor load cannot operate on a 1,000kVA transformer;¡± ¡°Two large motor drives cannot be powered from one large transformer;¡± and ¡°Electronic drives cannot operate with harmonic power filters.¡±

• Having the proper test equipment to measure voltage, current harmonics, and power factor is important to identifying a problem and specifying a solution.

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Sidebar: Harmonics and Their Effect on Power Factor

Many people are surprised when they install new equipment requiring high-frequency currents. What was once 0.88 power factor (PF) before the installation is now a 0.70 PF with the new equipment energized. How can we explain this alarming condition?

We know PF is the ratio between true power consumed (W) and the product of the voltage (E) times current (I), or PF = W ¡Â (E ¡Á I). Solving this equation for true power consumed, we get W = (E ¡Á I) ¡Á PF. For a pure sine wave, PF is often expressed as the cosine of the phase angle theta (¦µ) between the voltage and current, or W = (E ¡Á I) cos¦µ. (**Fig. A**)

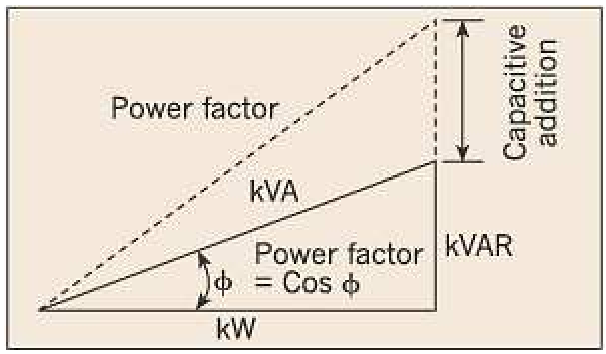


**Fig. A.** The traditional PF triangle consists of the work-producing power (kVAR) component. If we represent the two functions as vectors, then their vector sum is apparent power (kVA).

But the above relationship is not true for nonlinear loads. The only accurate way to find the nonlinear PF is to measure the average instantaneous power, and then divide that by the product of the true rms voltage and true rms current.

Comparing Fig. A (traditional PF vector diagram) with **Fig. B** (nonlinear load PF vector diagram), we notice an additional vector, called ¡°distortion.¡± Also note that Fig. A is two-dimensional, while Fig. B is three-dimensional, as can be noted by the kVA vector coming out of the page.

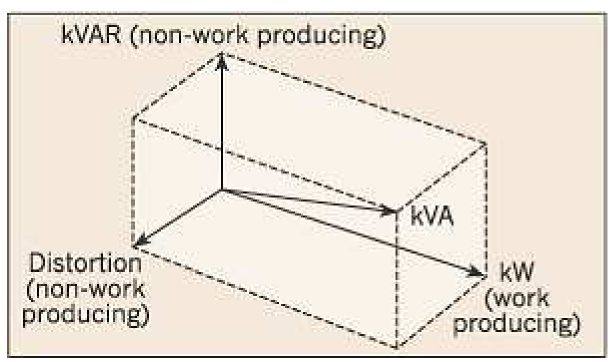


**Fig. B.** The distortion PF diagram reveals that kVAR and distortion are forms of non-work producing energy. The vector addition of these two components, plus the work-producing kW component, results in a longer kVA vector.

Where does this distortion come from? The high-frequency currents required by the nonlinear loads. We call the resulting PF ¡°distortion PF.¡±

To understand the total PF picture, you must understand that both kVAR and distortion are non-work producing. The combination (vector addition) of both with kW, which is work-producing, results in a longer kVA vector (having a greater magnitude). In other words, the greater the distortion and displacement PFs in a system, the larger the system capacity required to power a specific load.