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Challenges When Designing an Effective Harmonic Mitigation System for your Variable Frequency Drive

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ABSTRACT

To address power system harmonics in many water/wastewater Variable Frequency Drive (VFD) applications, transformer phase shifting strategies are often used. To be effective, transformer phase shifting requires the load on multiple rectifiers be shared relatively equally. However, even when the load on multiple rectifiers is perfectly matched, the transformer phase shifting approach can often fall short of expectations.

Most VFD's incorporate a 3-phase, 6-pulse diode bridge rectifier which generates current harmonics in the 5^{th}, 7^{th}, 11^{th}, 13^{th}, etc. When dual bridge rectifiers are used, and the second bridge rectifier is phase shifted by 30° by applying a phase shifting transformer, a 12-pulse scheme is created. A properly designed 12-pulse scheme will only have residual amounts of 5^{th} and 7^{th} harmonics while harmonics will remain in the 11^{th}, 13^{th}, 23^{rd} and 25^{th}. Theoretically phase shifting systems are an effective means of harmonic treatment; however, they can perform rather poorly under real world conditions. Tolerances in the manufacturing of the transformer windings, applied voltage imbalances, pre-existing voltage distortion and light loading levels will all have a detrimental effect on the 12-pulse scheme's ability to cancel harmonic currents, particularly at higher frequencies.

This paper outlines how to effectively solve harmonic distortion using a passive harmonic filter such as the Mirus Lineator™. A passive harmonic filter can significantly reduce current and voltage distortion under real-world conditions with much lower losses.

HARMONIC CHALLENGES CAUSING EQUIPMENT FAILURES WITH A LARGE MINE TUNNEL BORING MACHINE

The Scenario

Figure 1 displays the mine tunnel boring machine's electrical system with two very large 600V/3-phase VFDs that control the speed and torque of two 600 horsepower (HP) AC Motors, one for each side of the machine's drive system. The machine was powered from a trailing 13.8kV feeder cable. The machine designers elected to create a Quasi 12-pulse phase shifting harmonic mitigation system by using two 13.8kV/600V step-down phase shifting isolation transformers, with each feeding one of the machine's large VFDs. On the surface this was a logical harmonic mitigation method to implement since the transformers were already needed to step the machine's 13.8kV feeder voltage down to 600V for the VFDs.

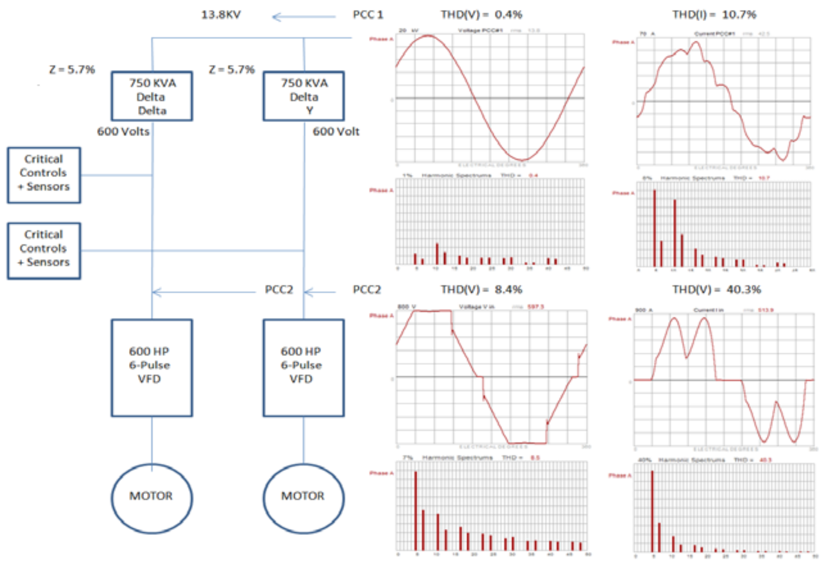

Figure 1: Existing Harmonic Mitigation Single Line Diagram

The Challenge

The problem experienced was that Phase Lose/Phase Imbalance relays on the two 600V buses (located in the machine's critical control panel) were burning out at least once a week. As part of the machine's safety interlocks, these relays were interlocked with the machine's drive control circuits; when one of the protective relays failed the entire machine shut down. These shutdowns were leading to unacceptable production delays.

Soon after the protective relays had burnt out several times, the secondary winding of one of the machines isolation transformers burnt out as well. Once the transformer was replaced, management decided that the root cause of the failures had to be investigated. The Electrical Maintenance Engineer was then asked to use a harmonic meter to scope the transformer's primary and secondary voltage and current waveforms while the machine was running at full load. Findings are shown in Figure 1 and the key measurements are as follows:

- Primary 13.8kV supply THD (V) = 0.4%
- Primary supply THD (I) = 10.7%
- 600V secondary side THD (V) = 8.5% and THD (I) = 40.3%

Although the phase shifting approach (using the two transformers) provided the Utility 13.8kV feeder with harmonic levels that met the IEEE 519 guidelines, the total harmonic distortion with respect to voltage, THD (V), on the 600V secondary was quite high (8.5%) which caused the machine's Phase Loss/Phase Imbalance protection relays to fail. In addition, the high secondary total harmonic distortion with respect to current, THD (I), of 40.3% on the phase shifting transformer secondary had the effect of increasing the losses in the transformers leading to their running hotter and exceeding design temperatures. This was what caused the premature transformer winding failure, and would continue to cause failures in both the transformers and protective relays until it was resolved. The heating also had the unfortunate side effect of increased operating costs, as the additional losses represented lost energy.

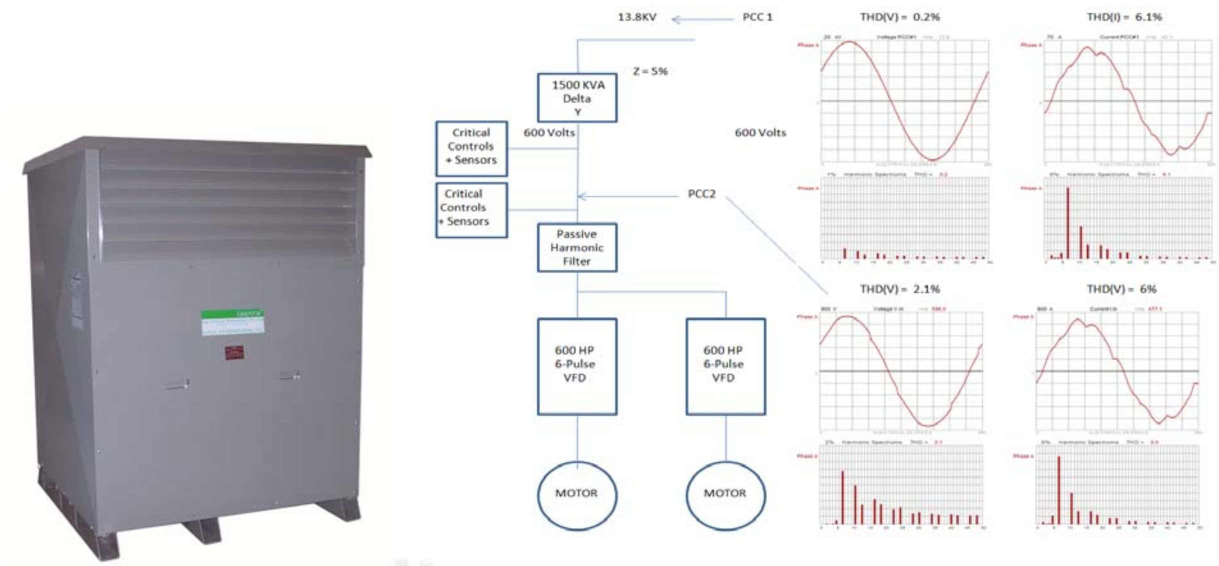

Figure 2: Single Line Diagram of the Solution

The Solution

The solution required several changes to the electrical design of the motor boring skid. First, the two 750 kVA step-down phase shifting isolation transformers were replaced with a single 1500 kVA standard step-down transformer to feed the two 600V VFDs from a common 600V secondary bus. Second, one properly sized 1200 HP Mirus Lineator™ passive harmonic filter was installed on the transformer's secondary feed to the machine's two 600 HP VFDs (see Figure 2). The two changes resulted in an effective, higher performing system. The THD (V) and THD (I) achieved on the primary and secondary side of the step-down transformer were well within the IEEE 519 guidelines.

When sizing passive harmonic filters, it is important to select an appropriately sized filter that is suited to the particular application. An improperly sized harmonic filter can often be just as bad as not having one at all, or even worse. In this particular application, the Lineator™ passive harmonic filter significantly outperformed the existing phase shifting systems by providing lower current distortion, especially under real-world conditions (such as voltage imbalance or pre-existing voltage distortion on the feeder) and much lower losses. The properly sized Lineator™ harmonic filter system resolved the harmonic distortion problem so the tunnel boring machine no longer encountered transformer or protective relay failures (see Figure 2). The 13.8kV Utility feeder had THD (V) of 0.2% and THD (I) of only 6.1%. On the machine's 600V bus, the THD (V) was only 2.1% and the THD (I) was only 6%.

When designing a harmonic mitigation system, it is important to look at the medium voltage (MV) feeder bus and the low voltage (LV) bus, as well as the effects of high levels of THD (V) and THD (I) on transformers, generators and control equipment.

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