INVERSINE Sinewave Filter Resolves ESP Motor Failures

Challenge:

The challenge of maintaining well operation in oil fields today is a daunting one. While some oil wells have enough natural pressure to operate without supplemental lift, over 90% of onshore and offshore oil wells worldwide require some form of artificial lift to reach acceptable production levels. The most common form of artificial lift, Electrical Submersible Pumps (ESPs), have been known to cause serious problems both on their input side due to the high levels of current harmonics generated by their adjustable speed drives (ASDs) and on the motor side due to overvoltages and ringing caused by 6-Step or PWM operation.

The effectiveness of Mirus' Lineator AUHF in resolving input harmonic distortion issues has been well documented. It is the only passive harmonic filter solution that offers an extreme duty (ED) model suitable for the severe environments that oil field equipment is subjected to. It offers the highest reliability and best performance of all harmonic mitigation options available, including other passive harmonic filters, multipulse drive systems, active front-end drives and parallel active filters.

ESPs present an even greater challenge for oil field operators due to premature failures of motors and poorly designed sinewave filters. This can lead to extremely costly repairs and even more costly downtime.

In an oil field in Montana, all ESPs designed for PWM inverter operation are equipped with sinewave filters in an effort to reduce overvoltage transients at the motors resulting from reflected wave phenomenon or harmonic resonance conditions. Unfortunately, on many of these ESPs the sinewave filters have failed, often after less than 6 months operation.

This has either forced shutdown of the well until repairs could be made or the drives have been manually switched to 6-Step operation on those ESPs equipped with dual mode operation. In 6-Step mode, sinewave filters are not used, but this mode tends to operate with higher motor temperatures which also contributes to premature failures. When motors fail, replacement is prohibitively expensive

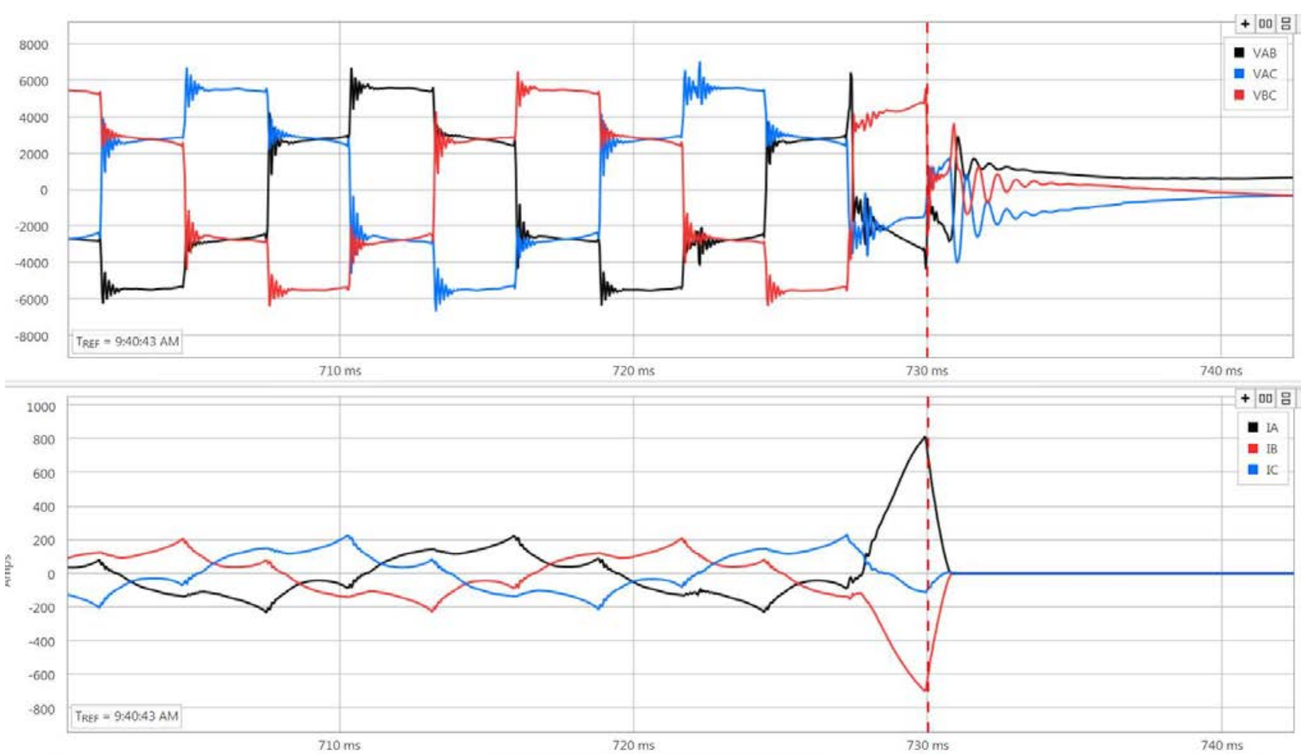

Fig. 1 Voltage and Current Measurements on an ESP Operating in 6-Step Mode at the Moment of Motor Failure

since they require the use of a workover rig to remove the entire assembly.

Fig. 1 shows voltage and current measurements on an ESP installation operating in 6-Step mode at the moment of motor failure. Prior to failure, you can clearly see the overvoltages and ringing in the voltage. When the motor fails, current momentarily increases as it feeds into the fault and the voltage collapses. This is one example of many motor failures that were occurring in the oil field.

In PWM operation, with higher switching speeds and faster rise times, voltage overshoots and ringing can be even more severe. Also, the motor winding appears more like a network of capacitive elements which leads to much higher voltages at the first turn of the motor winding. The resulting dielectric stress can lead to premature motor failure unless sinewave filters are used to smooth out the PWM pulses.

The engineering challenge was to design an effective and reliable PWM sinewave filter that extended the operating life of the PWM ESP and its associated downhole motor. This then would eliminate the need to switch to 6-Step operation and substantially reduce the resultant motor failures that were occurring in that operating mode.

Solution:

Sinewave filters are typically low pass designs which must target the lowest harmonic number with the highest magnitude resulting from pulse width modulation. These harmonics exist near the inverter switching frequency, or carrier frequency, and to achieve a near sinusoidal voltage, the filter's tuned frequency must be well below this frequency. In ESP applications, the IGBT switching frequency is usually in the 2 to 8 kHz range and typically, the larger the size of ASD, the lower the switching frequency.

Design criteria for an improved sinewave filter focused on a target of < 3% voltage harmonic distortion and < 5% current harmonic distortion. And it was important that the design inherently limit system resonance without the need for damping resistors. Computer analysis was done at several tuned frequency points for the filters.

Initial analysis was done for a 200 HP, 480V, 60 Hz ESP system with a tuned frequency of 600 Hz which is typical of conventional filters. Performance of the filter in reduction of switching frequency harmonics was quite poor with 9.1% THDv (Total Harmonic Distortion Voltage). This indicated a resonance condition existed when tuned near 600 Hz. Adding resistors to the filter helped reduce the resonance but not enough to be comfortable with the design.

Better performance was achieved when the filter was tuned near 180 Hz with no apparent system resonance even without resistors. Figs. 2 and 3 show voltage waveforms and spectrums at the inverter output and sinewave filter output respectively indicating an improvement in THDv to < 2%. Similar results were achieved for the 1100 HP, 480V, 60 Hz ESP system. Other important improvements in performance included a very low insertion loss (ie. < 3% drop in voltage at full load) and improvement in PF to near unity at the inverter output.

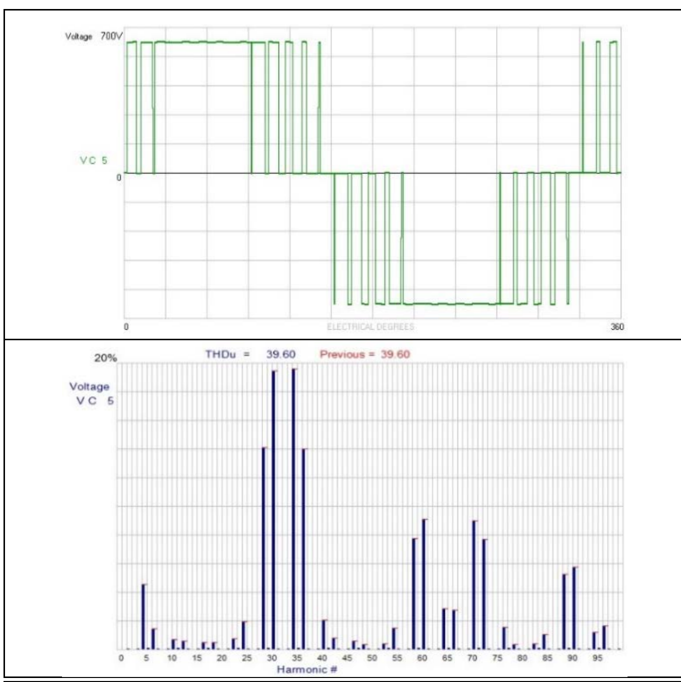

Fig. 2 Inverter Output PWM Voltage Waveform and Spectrum at 2 kHz Switching Frequency

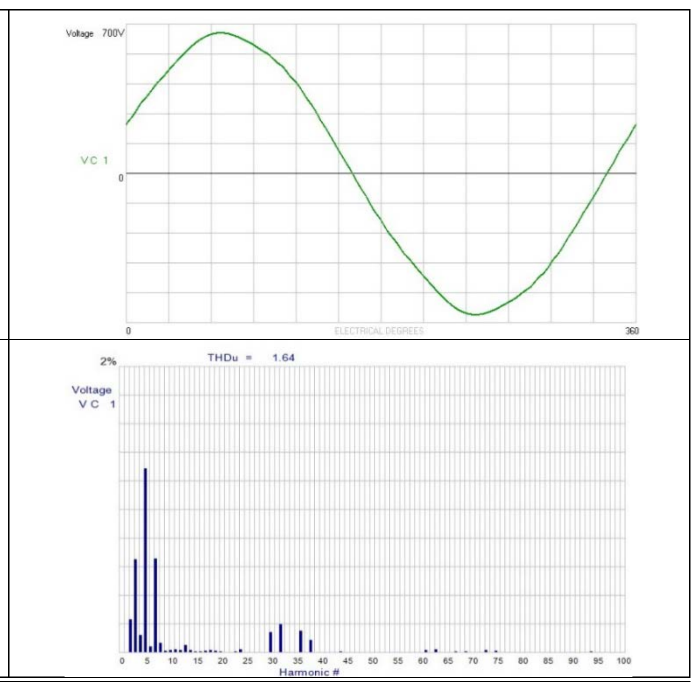

Fig. 3 Output Voltage Waveform and Spectrum of Sinewave Filter Designed with 180 Hz Cutoff Frequency

Result:

An 1100 HP, 480V, 60 Hz Mirus INVERSINE sinewave filter was designed with a tuned frequency of 180 Hz to replace a failed sinewave filter on a well that was having motor concerns after switching to 6-Step operation. After installing the new sinewave filter, the ESP was restarted in PWM mode.

Fig. 4 1100 HP INVERSINE AUSF Sinewave Filter Installation

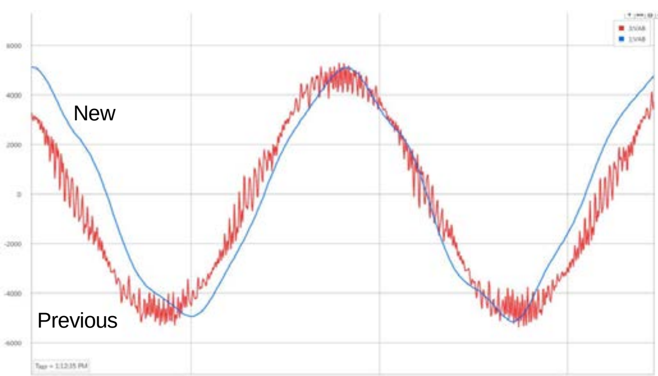

Fig. 5 Comparison of Voltage Waveforms on 1100 HP PWM ESPs Equipped with New and Conventional Sinewave Filters

Fig. 5 shows a side by side comparison of the output voltage waveforms of both a new design sinewave filter and a conventional design sinewave filter on 1100 HP ESPs operating in PWM mode. The higher frequency ripple with the previous filter is clearly evident.

Almost immediately after installing the Mirus sinewave filter, a significant reduction in motor operating temperature was observed. Motor temperature dropped from 249° F to 237° F – a 12° F drop or almost 5% (Fig. 6). Also, the measured voltage drop of < 3% across the filter while running at top speed was as per design. Previous sinewave filters introduced a voltage drop of around 10%. With a lower voltage drop, voltage to the motor was proportionately higher which lowered the motor current and associated losses.

Later measurements highlighted an even more significant drop in motor temperature during startup. In Fig. 7, the top trend shows motor temperature and the bottom trend shows operating speed. The drops to zero on the bottom trend indicate when the ESP was turned off. When it was restarted, the corresponding spike in the top trend indicates the increase in temperature that occurs on startup. Although momentary, this increase in motor temperature puts substantial stress on the motor. These momentary temperature spikes are particularly detrimental to ESPs due to the impact on self-equalizing motor seals. Motor oil in the seal expands and is discharged into the well bore when the motor temperature rises and contracts as it cools, bringing well bore fluid into the seal. While to some degree the well bore fluid contamination in the seal is unavoidable, it is believed that eliminating severe temperature spikes will dramatically improve the life of the motor seal section. After installing the INVERSINE filter and operating in PWM mode, the startup motor temperatures were reduced by nearly 40° F.

Another advantage of the INVERSINE filter is that its capacitors provide nearly full compensation for the inductive reactive power of the motor resulting in a power factor (PF) at the invertor output of near unity. The reduction in load current substantially offloads the inverter reducing its losses and extending life expectancy. In an ESP application, this provides the potential of increasing production as a result of the drop in ASD current associated with the PF improvement. This particular wellsite did not have a large enough pump/motor combination to take advantage of this benefit but when a similar filter was later installed at another well site, an increase of 125 BPD of total fluid produced was reported.

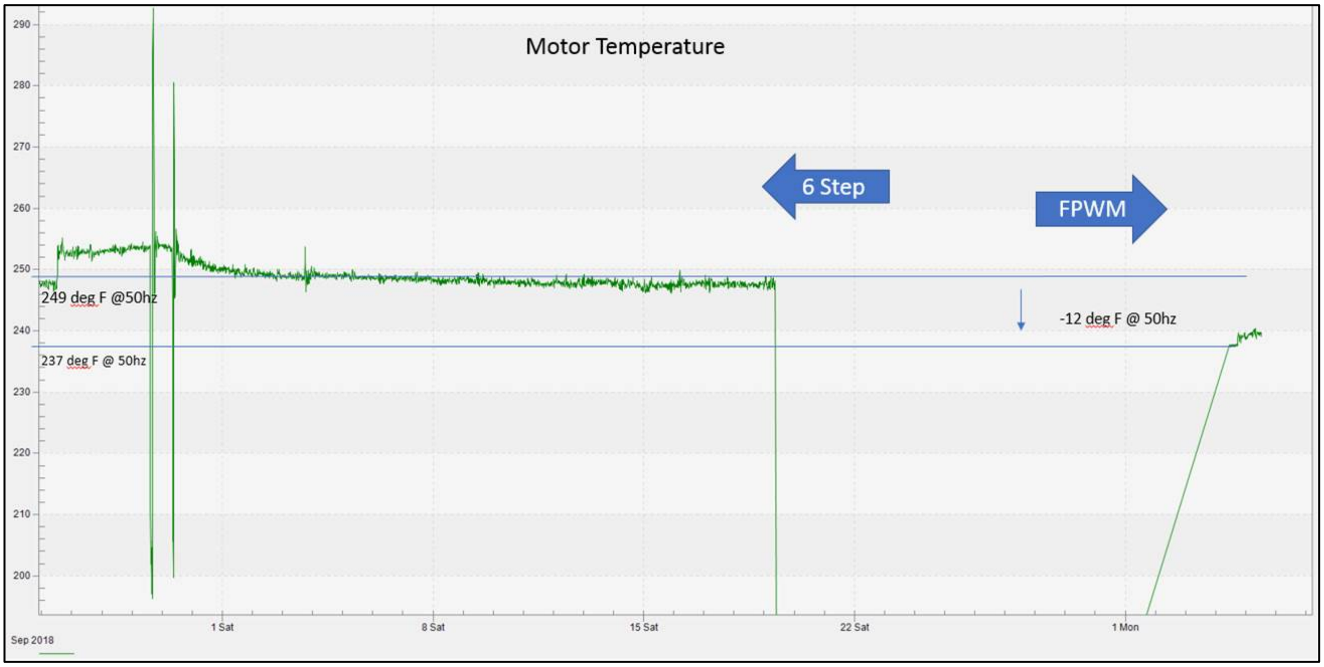

Fig. 6 Drop in Motor Operating Temperature after Switching to PWM with Sinewave Filter

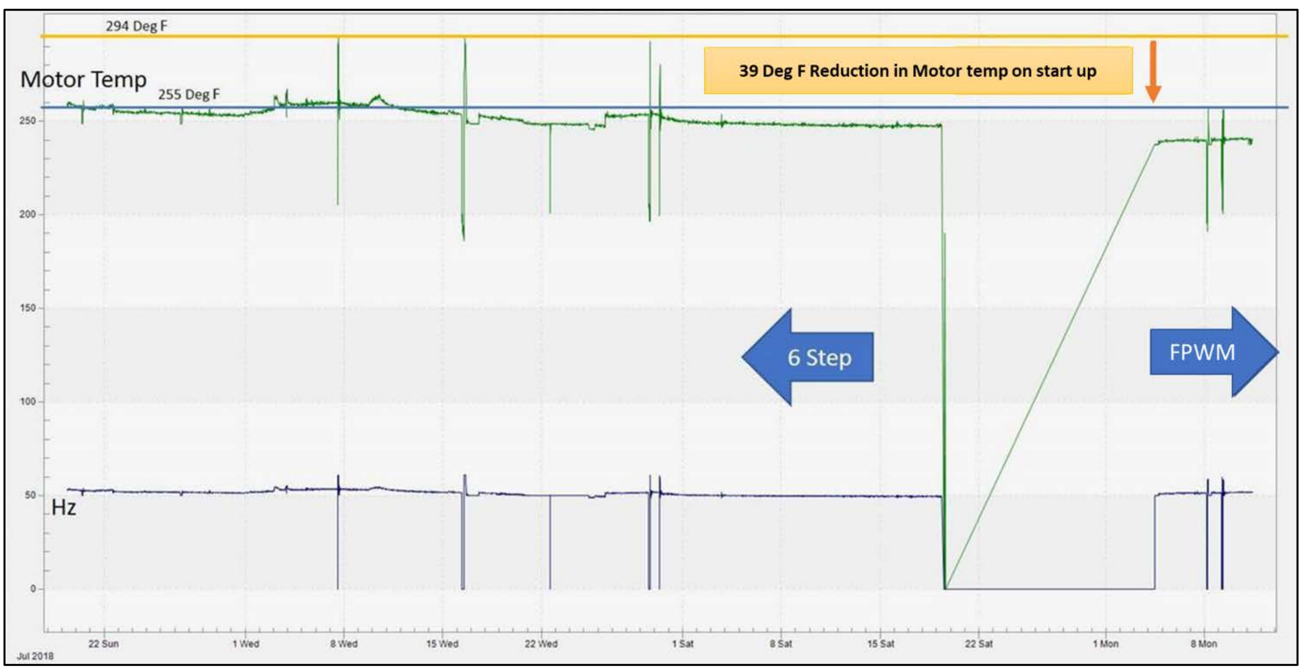

Fig. 7 Drop in Motor Operating Temperature during Start-up after Switching to PWM with Sinewave Filter