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COMPARING ENERGY SAVING TECHNOLOGIES - VFD AND SINUMEC

By Amir Broshi, May 2008

Variable Frequency Drives (VFDs, also known as VSD or AFD) convert the line voltage into a voltage source, controlling the voltage and frequency accordingly. The ratio of voltage vs. the frequency can be controlled to match variable and constant torque/load curves, making it possible to control the speed and efficiency of the motor. While this is the best solution for speed control, other more efficient solutions are available for constant speed applications.

Sinusoidal Motor Controllers are designed for constant speed applications with partial or variable load motors. Power Electronics Systems provides the Sinusoidal Motor Efficiency Controller (SinuMEC), which is a pure sinusoidal voltage controller.

This document compares the differences in performance between the VFD and the SinuMEC.

THE SINUMEC ADVANTAGES

PURE SINE VS. HARMONICS

The SinuMEC provides a pure sine wave, resulting in, no harmonic pollution being introduced to the network. Furthermore, since the SinuMEC has a transformer in series, it can reduce harmonic pollution where such presents. A VFD generates significant current harmonics, typically 30% or more of the fundamental frequency. Harmonics filters can reduce the harmonics content to a certain extent, but the remaining levels are still very high. Moreover, when filters are installed on the NET side, the line between the drive and the motor will still remain polluted.

The problems of harmonics

The harmonics issue is among the most difficult to solve in the electrical field. Some implications of harmonics are:

1. Increased losses throughout the network – conductors, loads, transformers and more.
2. Overheating (typically a VFD increases motor operation temperature by 8 to 10°C).
3. Negative torque in the motor as a result of some harmonics rotating counterclockwise (CCW). The 5th harmonic order is the most dominant in the industry and rotates CCW to the fundamental, thus developing a negative force that breaks the motor.
4. Unexplained breaker tripping as a result of extreme overheating.
5. Controller malfunction and other unexplained phenomena as a result of distorted waveforms.

Possible solutions

The best way to filter harmonics is not to generate them. Harmonics cannot be eliminated, only mitigated. There is no technology that can filter out all the harmonics all the time.

There are different solutions for filtering harmonics, from passive (reactors/inductors with or without capacitors) and active filters (injection of negative current for each distortion) to complete isolation of the source from the network using transformers, such as zigzag transformers. The cost of mitigating harmonics can be higher than the cost of the load that creates them. The maximum possible filtration using passive filters is 50% of the distortion (e.g., removing 15% of 30% distortion) while active filters can filter more than 90% but at up to ten times higher cost.

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INTERNAL LOSSES

Each electrical device has its efficiency, which is the ratio between output and input power. The SinuMEC losses are less than 0.5%, while typical VFD losses are 4% to 8% (note that modern VFDs with PWM have LOWER efficiency but LOWER THD pollution compared to older VFDs).

It can therefore be concluded that for the same voltage output level, with a specific potential saving with SinuMEC, the **VFD will save** 3.5% to 7.5% **less**.

POWER FACTOR

There is a direct link between the network losses and the power factor, which is one of the reasons that utilities charge penalties for low Power Factor.

The Power Factor has two parameters:

DPF – Displacement Power Factor, also known as Distortion Power Factor or Cosine Phi (Cos φ), which is related to the angle between the voltage and the current in the pure sine wave. When harmonics are present, this is the Power Factor of the fundamental harmony (i.e., 50 or 60Hz). The DPF is calculated from the active and total powers of the first harmony as follows:

$$DPF = \frac{P_1}{S_1}$$

(P_1 and S_1 are the active and total powers of the first harmony)

TPF – True Power Factor (or Total Power Factor), also known as PF – Power Factor, is the parameter that incorporates all the harmonics. TPF is calculated from the active and total RMS powers as follows:

$$TPF = \frac{\sqrt{\sum_{h=1}^{\infty} P_h^2}}{\sqrt{\sum_{h=1}^{\infty} S_h^2}}$$

(P_h and S_h are the Active and Total power of harmonic order h)

These two parameters are linked to each other based on the Total Harmonic Distortion (THD), according to the following formula:

$$TPF = \frac{DPF}{\sqrt{1 + THD_i^2}}$$

(if there is voltage distortion, the above is an approximation only):

The conclusion of the above formulas is that even when a VFD does not affect the DPF generated by the motor, the increase of harmonics reduces the Power Factor. The outcome is increased demand to PF Capacitors, which themselves can increase the harmonic level, increased network losses and reduced network utilization.

The SinuMEC improves both the TPF and the DPF. When reducing voltage level, a VFD may improve the DPF. The TPF may improve or deteriorate, depending on the motor operation and the harmonic pollution level.

MOTOR LIFE EXPECTANCY

The parameters that affect motor life expectancy are divided into three major categories:

- Mechanical stress
- Voltage stress
- Operating temperature

Motor controllers do not affect the mechanical stress, but do affect the voltage stress and operating temperature.

Reduced voltage level reduces the voltage stress on the motor and increases its lifetime. However, while VFDs reduce the RMS voltage, they use PWM modulation as shown in Figure 1. Although the RMS voltage is reduced, the voltage stress remains high, approaching the zero crossing area, where pure sine

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wave has zero stress. To this end, voltage reduction via the SinuMEC reduces the voltage stress while a VFD increases it. Moreover, a VFD also generates non-linear voltage, which creates additional stress as a result of reflective waves, partial discharges (PD) and corona power.

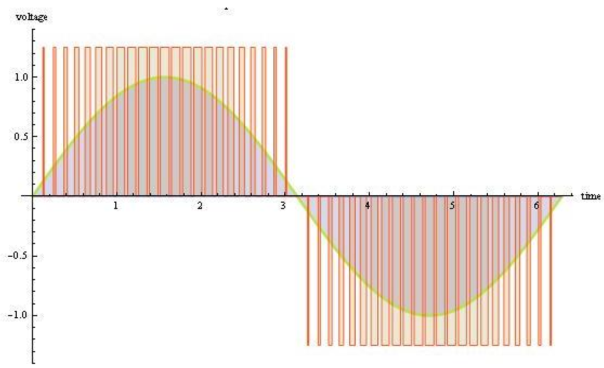

Figure 1: VFD PWM Modulation

In addition, the harmonics created by the VFD increase the motor temperature by 8 to 10°C. According to the Arrhenius law, every 10 degrees Celsius reduces insulation effectiveness by 50%. Therefore, for the same motor lifetime it is necessary to de-rate the motor. In existing installations, however, this means that VFDs shorten the motor lifetime.

The significance of the above is that while the SinuMEC **increases** motor life expectancy, the VFD **decreases** it.

CURRENT TRANSFORMATION

The SinuMEC is based on voltage transformation in a ratio of 4:3. Even if there is no change in power consumption the line current will be reduced by 25%, reducing the conduction losses by 43% ($P=I^2R$).

When voltage is reduced using power switching, this advantage is eliminated

PRICE

The price of a stand-alone SinuMEC is less than that of a stand-alone VFD. In addition, due to the harmonic pollution, VFDs may require additional filters, which further increase the price difference in favor of the SinuMEC. Different filtration solutions, such as chokes, reactors, isolation transformers, reflective wave or RLC filters, provide different levels of filtration. The price differences between the available solutions can reach 100% or more.

ADVANTAGES OF VFD OVER SinuMEC

STEP-LESS VS. STEP OPERATION

VFDs provide step-less operation, which means they can provide a very accurate voltage level. The SinuMEC uses stepped operation, which means there is less control over the aimed voltage level.

Figure 2 shows the motor efficiency vs. load. The red line (lower line) represents normal operation, while the green line (upper line) represents operation with the SinuMEC in Save mode. In addition to the significant saving, the efficiency changes are very small and it is not recommended to introduce more voltage changes to the motor.

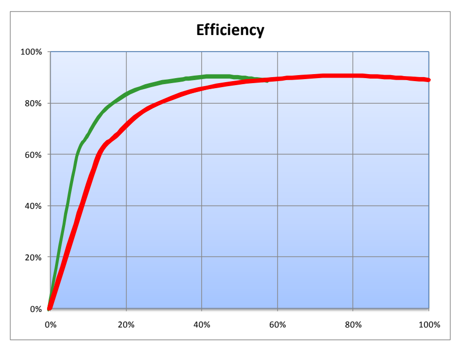

Figure 2: Motor Efficiency vs. Load

As a result, VFDs can provide more accurate voltage, which can increase the motor efficiency by up to 1.5%. This difference between the SinuMEC and the VFD is reversed when taking the internal losses into consideration.

Important Note: Part of the wasted energy consumed by VFDs is not in the fundamental harmony. Since this is the case, it is very important to use a power meter and current transformers that measure at least 25 harmonies (which means that the current transformer band width, as indicated on the transformer, should be at least 3kHz).

WITH SO MANY DISADVANTAGES, WHY THERE ARE VFDS?

VFDs were designed to control the motor speed, not the voltage level. For variable speed applications with inductive motors, there is no other solution and all the disadvantages described above, including losses, harmonics and motor life expectancy, should be considered.

For fixed speed applications, with fixed or variable loads, the best solution is pure sine wave voltage control using the SinuMEC - Sinusoidal Motor Efficiency Controller.

SUMMARY

The following table summarizes the differences between SinuMEC and VFD operation in fixed speed applications:

	SinuMEC	**VFD**
Harmonics	Pure sine operation, can filter some network harmonics delivered to the motor	Generates significant harmonics to the motor and to the network
Internal losses	0.5%	4%-8%
Power factor	Improves DPF and TPF	Improves DPF, may worsen TPF
Motor life expectancy	Increases	Reduces
Current Transformation	Line current is **less** than motor current	Line current is **the same** as motor current
Price	Typically 40% less than VFD only (without optional filters)	Required optional filters may increase price by 100%
Stepped or Step-less	Operation in steps	Step-less Operation