Variable Frequency Drives
Interference with Milking Machines

EMI and RFI

Kyle Knoff
GEA Farm Technologies, Inc.

50th Midwest Rural Energy Council
La Crosse, WI
March 1st
Here are some examples of switching power units: Variable Frequency Drive’s (VFD), Fluorescent Ballast’s, Power Supplies and Welder’s.

These are all potential sources of interference on the power lines and can generate both types of interference, Electro magnetic interference (EMI) and Radio frequency interference (RFI).

I will focus on VFDs for this discussion since they are usually the largest form of interference and cost the most to mitigate.
First let's have a look at the reason VFDs cause interference.
In figure 1 you can see the basic layout of a VFD and the 3 major components.
1) The rectifier.
2) The DC filter.
3) The three phase inverter.

![Basic drive layout](image-url)
The job of the rectifier is to take the AC incoming wave and rectify the full sine wave into half waves to create a DC voltage. This wave form has many ripples and results in current harmonics on the incoming power lines.

The DC filter is used to smooth the AC ripples after rectification. This creates a DC source for the logic controls and switching of the output transistors and provides a capacitive source to ride through minor power fluctuations. The filters generate no external noise.

The 3 phase inverter section generates a PWM waveform (switched DC) which drives the motor at a desired speed or torque. This is the section that generates most of the electrical noise (referred to as Harmonics).
Fig. 2
VFD output waveform

Figures 1 and 2 are from Joliet Technologies website
http://www.joliettech.com/what_is_a_variable_frequency_drive-how_vfd_works.htm
Figure 3A shows the voltage ringing that occurs at the switched outputs of the drive. These will increase with higher switching speeds (carrier frequencies).

Figure 3A and 3B are from Fluke corporation

Figure 3C and 3D
Voltage wave forms at motor terminals with different cable lengths

The issue here is that large reflections (current waves) in the cable increase (compounding) as the length of cable increases.
The resulting wave form has 2 effects increasing EMI and RFI. The voltage at the motor is high enough to cause insulation breakdown and premature motor failure.
An interesting thing about these 2 graphs is the RMS reading goes up by 5.1V indicating an AC voltmeter would only show a slight increase.
Fig 4
Input Current waveforms by rectifier type

Most inexpensive and smaller HP drives are of the 6-pulse variety. This makes for current distortion of 30%. Can be easily overcome with basic filtering since the frequencies are constant.

The 12 pulse, 24 pulse are a more expensive drive unit since a transformer and more diodes are added to the front end.

The IGBT is the most expensive but gives the cleanest current. It is, in effect, two drives in a single package; the input is controlled same as the output. It can regenerate or supply power back to the mains.
A line reactor reduces reflections to some extent and can be used from 15’ to 100’ of cable length. Mount as close to the drive as possible.

Note: Only a slight improvement in EMI/RFI is achieved since much of the higher frequencies are passed through.
Include losses in wiring when sizing drive to achieve 100% output power at motor.

A dV/dT filter is an inductive, resistive and capacitive tank circuit matched to block high frequency ringing in the cable. This protects the motor by reducing the voltage spikes to below 1kV. It should be used for > 100’ of cable. Note: This will have an improvement on both EMI and RFI. Again mount as close as possible to the drive output.
A Output Sine wave filter is the best for the motor and significantly reduces EMI and RFI.  
Note: The cost is high, usually more than the cost of the drive. Most usage is in high HP applications where the motor costs are very high or motor replacement is very costly.

Maybe required for extremely long cable runs >1000’ but you have to include losses in wiring when sizing the drive to operate the motor up to 100% load.
EMI

- There are 2 ways EMI coupling can occur on the wiring.
- Capacitive coupling: This occurs when you have 2 wires running in parallel in close proximity. The charge on one wire causes a charge on the other.
- Inductive coupling: This is occurs when a magnetic field induced by one or more wires couples to other wires in that magnetic field.
- Conduction modes: Can be Common Mode (CM) when the noise in both wires are in phase, or Differential Mode (DM) when the noise appears out of phase.
The EMI triangle
The VFD cable is happy the motor is running fine and our signal cable is not so happy until we get adequate separation of 12” or more.

This is always the best way to lay out your conduits with 12” or more between signal wiring (milking meters, Identification and control equipment) and the high voltage 220/460V switched voltage equipment.

When signal wires and high voltage have to cross, crossing at 90° is the best.
Attenuation is possible with drive adjustments, ferrite beads and/or filtering.

Desensitizing can be done by changing from unshielded cables to shielded cable and grounding the shield at one end or install an optical isolator.

Guarding the source can certainly be done at the motor with a properly shielded and connected cable.

Protecting the victim can be done as well with correct shielding. Often impractical on a dairy due to code requiring non-metallic conduit.
Switching/carrier frequency is the easiest thing to change that can result in less Harmonics and sometimes reduce EMI and RFI below acceptable levels.

The top setting is taken from ABB ACS-550 manual.
The bottom is taken from Mitsubishi FR-E700 manual.
This has the effect of reducing the ringing in the output cable since there will be less overlap (compounding) of the noise in the wire.

Note: There will be an audible increase in noise (motor hum) with lower carrier frequencies.
These are easy to install and give you the best performance per $ spent. Wrapping the wire thru as many turns as possible as in Fig 8 (A) give the best results. Note: Always wrap in the same direction and do not overlap wires between phases. If the cable is too large then stack units as shown in Fig 8 (B) make sure you have 1 width separation between units.
FILTERS the “best solution”?

Fig. 9

A 3 Phase EMC filter such as this unit will greatly reduce the harmonics on the incoming power wiring

http://www.corcom.com/pdf/FCD.pdf
Fig. 10

Typical insertion loss in closed 50 Ohm system

Insertion loss = \(10 \log_{10} \frac{|V_i|^2}{|V_o|^2} = 20 \log_{10} \frac{|V_i|}{|V_o|}\)

This unit is 16Amp, 3ph, 480VAC rated.
Fig. 11

LON cable with EMI noise coupled on wires

Line-to-Line reading on Oscilloscope across signal wires on a LON (Echelon) network with noise.

Signal is 1.4V p-p and it uses Differential Manchester encoding (zero crossing detection) for sending data. The data was garbled and messages were lost every time a washing machine was operating.

Fig. 12
Noise free LON signal

This is the same signal with no background noise after installing the filter in figure 9 on the drive input wires at washing machine.
The ringing at the top and bottom are due to long wire lengths and some low level background noise.
Example of filters installed incorrectly.

The shielded (metallic) conduit helps. But at the higher frequencies the conduit itself becomes a radiator. The TCI enclosure is a KLR line reactor. The bottom box is a KRF filter for EMC.
Make sure the incoming wires and outgoing do not run parallel as shown on the left. Any un-filtered wire length is a radiator. Keep the filter near the drive input.
The highlighted conduit clearly touches the incoming line filter and there is about 2’ of conduit exposed. The best path for return current to ground will be on the conduit since it has a lower resistance than the 14AWG ground wire.

There are parallel conduits and the wires coming in and out of the KRF filter are nearly overlapped. The output wiring to the motor in the conduit (blue) on the right is touching the input filter. This example was causing a large amount of RF interference, on the side of the parlor closest to the drive, no cow identification was possible. The ID system is an ISO system operating at 134.2 kHz. The tags were a standard HDX (half duplex) ear tag. The Antenna is a loop (2’ x 4’) mounted at the entrance.
This is what I suggested to correct the layout and reduce the EMI and RFI on the conduits and wiring.

They chose not to change the filtering and instead moved the drive out of the building over the wells pump head. I have not returned to verify the results.
Motor cable selection

Effective motor cable shields

The general rule for cable shield effectiveness is: the better and tighter the cable’s shield, the lower the radiated emission level. The following figure shows an example of an effective construction (for example Ölflex-Servo-FD 780 CP, Lappkabel or MCCMK, NK Cables).

We have selected an “Ölflex VFD slim” cable part numbers 761404 (14awg) thru 760204 (2awg) for our Variable speed milk pumps, E-drive rotary drive system and Vacuum on Demand II. “Belden” has an excellent cable also part numbers 29500 (16awg) thru 29547 (4/0 awg)
Motor cable connection

On the input power cable, strip the sheathing back far enough to route individual wires.

On the motor cable, strip the sheathing back far enough to expose the copper wire shield so that the shield can be twisted into a bundle (pig-tail). Keep the bundle not longer than five times its width to minimize noise radiation. 360° grounding under the clamp is recommended for the motor cable to minimize noise radiation. In this case, remove the sheathing at the cable clamp.

Route both cables through the clamps and tighten the clamps.

Strip and connect the power/motor wires and the power ground wire to the drive terminals. See the table on the right for tightening torques.

- Motor cable shield wires must be twisted together into a bundle (pig-tail) – the bundle length must be less than five times its width – and connected to the terminal marked ↓ (at the bottom right-hand corner of the drive).
- At the motor end, the motor cable shield must be earthed 360 degrees with an EMC cable gland, or the shield wires must be twisted together into a bundle (pig-tail) not longer than five times its width and connected to the PE terminal of the motor.

<table>
<thead>
<tr>
<th>Frame size</th>
<th>Tightening torque</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N·m</td>
</tr>
<tr>
<td>R1, R2</td>
<td>1.4</td>
</tr>
<tr>
<td>R3</td>
<td>2.5</td>
</tr>
<tr>
<td>R4</td>
<td>5.6; PE: 2</td>
</tr>
<tr>
<td>R5</td>
<td>15</td>
</tr>
<tr>
<td>R6</td>
<td>40; PE: 8</td>
</tr>
</tbody>
</table>
Screen Termination Do’s & Don’ts

Good Methods

1. If using a metal box, trap the screen in a slot under the lid. Take care not to trap the screen too tightly or else it could result in cable damage. The cable will require strain relief.

2. Saddle-clamp the screen to a bulkhead immediately inside the “Quiet Zone”.

3. “Pigtail” the screen to a suitable earth point. Ensure the pigtail length is as short as possible.

Poor Methods

4. Screen left unterminated in the quiet zone. This will re-radiate any noise it has picked up.

5. Pigtail termination too long. Ideally the pigtail should be no longer than 5 times its width.

6. Long pigtail coiled up.
Some call it an art but there is definitely science behind it. The drive wires and/or conduit act as antenna and radiate noise over a large spectrum. Animal identification systems come in either 120kHz or 134.2kHz (which is the ISO standard 11785) which has a wavelength of 6975 ft. Some new systems running at much higher frequencies are under development but none are approved ISO systems for animal ID so we won’t address these.
All of the items that help with EMI will also address RFI.

However, RFI can also be coupled to steel (such as buildings) and travel over large distances similar to an AM radio station.

The frequency range 120 - 134.2 kHz can transmit through ground, wood and plastic with very little interruption in signal. Steel in close proximity can become magnetically coupled and distort or weaken the field.

Don’t always assume the source is on farm. We have seen welding down the road and drives wired to remote buildings generate a large amount of RF noise.
Perform and document read range measurements at the antenna with a properly functioning tag. Here are some examples of the different tags available. As you can see the larger the tag the greater the read range. We have had to solve read issues with all variety of tags, but the hardest to solve are farms using the 22mm tags and especially those that normally read in a RF noise free environment at location 5. Type 1 is a neck or leg tag and these perform the best due to a much larger antenna in the tag.

<table>
<thead>
<tr>
<th>Tag Type</th>
<th>*Max. ID Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Management Identification Systems</strong></td>
<td></td>
</tr>
<tr>
<td>1 Responder/Rescouter FDX</td>
<td>100%</td>
</tr>
<tr>
<td>2 Nedap 40 mm FDX</td>
<td>75%</td>
</tr>
<tr>
<td><strong>Lifetime Identification Systems</strong></td>
<td></td>
</tr>
<tr>
<td>3 Allflex HDX or FDX</td>
<td>70%</td>
</tr>
<tr>
<td>4 Nedap 22 mm FDX</td>
<td>45%</td>
</tr>
<tr>
<td>5 Other 22mm FDX/HDX tags</td>
<td>45%</td>
</tr>
</tbody>
</table>

This image depicts the signal ranges of various RFID systems in an interference-free environment. The object to the left is the receiver antenna. Spacing from antenna to tags shows actual signal distances. *Percentages are based on a 48” read range in an interference-free environment.
Locating the RF sources

To locate the source of the RF energy we have specific handheld tools for analyzing noise in the range of 120 – 134kHz shown below and on the following slides. Or a spectrum analyzer can be used.

Note: You must shut off the power to all identification systems on the farm before doing analysis of any RF fields since the ID system will be the largest source of RF energy!!

RFID noise meter - approximately 0.1dBuA/M
0 – 400  Relatively noise free
400 – 600 marginal
600 – 1999 Noisy
This tool shows field strength in dBuA/M in the range of 119-139 kHz.
Shut off all the ID systems (Sort gates and rotary).
Hold the panel in the location of the antenna.
It needs to be flat to the antenna or gate (parallel as shown).

Write down readings with everything ON, Noise reading ________.
(example range < 200-350 OK , 350-700 Some noise and >700 extreme noise)

Then shut off 1 device at a time leaving the units off as you move to the next unit.

Lights off, Noise reading ________.

Drive off Vacuum on Demand, Noise reading ________.

Drive off MCR (rotary drive panel), Noise reading ________.

Drives ________?

Variable speed fans ________?

Note: Make sure you shutdown the devices at the incoming power panel!

The front end of the drive is a noise emitter even when sitting idle at Zero speed.

Test readings: lights first then lights+VOD second then lights+VOD+MCR and so on till all known noise sources are located. Then power up in same order.

Continue until the noise level drops below 350 hopefully or as low as possible. Leave all units off and power up one unit at a time On then Off. Drives On then Off etc...

Lights ON only, Noise reading ________
Vacuum Pump ON only, Noise reading ________
MCR ON only (rotary drives), Noise reading ________
Other ________________drives ON only, noise reading ________
Practical Example:

We had a 15 HP well pump drive located in the basement at a large rotary milking parlor.

Every time the well pump was called to run the ID system would only identify 75% of the cows.

We were able to trace this back to the source by shutting down different pieces of equipment and energizing each 1 at a time.
The picture above shows the antennas at the dairy. One located under the white plate and one under the black plate for receiving ISO eartag identification. The read range would often vary from 6” to 1’. The RFID noise meter was used to identify the noise source.
We were able to follow the wiring under the ground to the well head approximately 800’ away. The conductors were all 10awg (3 individual wires + a ground wire) buried in a PVC conduit. The noise level was at > 1200 on the RFID noise meter all the way to the well head. A filter and lowering of the switching frequency was tried.
After no noticeable improvement they decided to move the noise source to the well head. This reduced the noise below 600 from the previous readings and allowed them to properly ID every cow.
Summary

New installations:
Install drives that include a 5% Harmonic filter on the front end.
Select a good VFD cable and ground and shield at both ends. Keep the motor cable as short as possible.
Run conduits such that all high voltage is at 12” minimum in parallel runs from low voltage/signal wiring.

Field issues:
Lower the carrier (switching) frequency.
Install Ferrite beads on the motor and input wire connections.
Install line filters incoming and drive output if necessary for long cable runs.
Move the drive to reduce long runs creating an antenna.