REGEN AVOIDANCE IN OIL & GAS APPLICATIONS

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North American Electric

INTRODUCTION

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Rick Cornutt has 42 years of experience in complex factory automation systems and has been a part of NAE's team for over 7 years. During his time at NAE, he has overseen the launch, development and growth of the Motor Controls division while also launching and running the newest sector of the company, NAE Automation.

Rick has worked in a variety of vertical markets including automotive, tire and rubber, water wastewater, oil and gas, irrigation, pulp and paper, and appliance and air freight. He is also responsible for the development of several software standards in use today, including his "event driven" logic design that is a standard specification at companies like Bridgestone/Firestone.

Rick earned a BS in Electrical Engineering from Auburn University in Auburn, Alabama in 1979.

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INTRODUCTION

The purpose of this paper is to provide a working explanation of Regen Avoidance in AC variable frequency drives, sometimes referred to as VFDs or VSDs. To do this, we need to understand the basic characteristics of an AC induction motor. So let's start there:

This will be a simple explanation, but it should help explain the characteristics of AC induction motors. Specifically we will discuss motoring and generation. We will skip over the effects of impedance.

First, some variables:

N = shaft rpm
Nsync = motor synchronous rpm
Nslip = slip rpm
T = motor torque (we'll use in-lb)
HP = HP
k = constant
T = 63000 x HP/N or HP = T x N / 63000

For a four (4) pole AC induction motor, the motor synchronous speed, or Nsync, is 1800 rpm. Using the calculation below the synchronous speed of a 4-pole AC induction motor is:

Nsync = (60 cycles/sec) x (60 sec/min) x (4 poles/2 pole in a North/South pair)
= 1800 rpm

In reality, a A 4 pole AC induction motor typically will have a name plate speed rating of around 1750 rpm. So why doesn't an AC induction motor run at its synchronous speed?

A rotating magnetic field in the stator is the first part of the explanation. To produce torque and thus rotate, the rotor must be carrying some current. In induction motors, this current comes from the rotor conductors. The revolving magnetic field produced in the stator cuts across the conductive bars of the rotor and induces an EMF, or electromotive force.

The rotor windings in an induction motor are either closed through an external resistance or directly shorted. Therefore, the EMF induced in the rotor causes current to flow in a direction opposite to that of the revolving magnetic field in the stator, and leads to a twisting motion or torque in the rotor.

As a consequence, the rotor speed will not reach the synchronous speed of the RMF (rotating magnetic field) in the stator. If the speeds matched, there would be no EMF induced in the rotor, no current would be flowing, and therefore no torque would be generated. The difference between the stator (synchronous speed) and rotor speeds is called the slip.

The rotation of the magnetic field in an induction motor has the advantage that no electrical connections need to be made to the rotor. An induction motor derives its name because currents are induced in the rotor. Faraday's Law states that an electrical current is created when a conductor passes through magnetic field lines of force. So if the stator's magnetic field rotates within the motor housing at 1800 rpm –it's synchronous speed—and the rotor is also rotating at 1800 rpm, the rotor conductors will not pass through any magnetic field lines but rather be moving in sync with them. The rotor must be rotating slower than the stator's rotating magnetic field for the motor to produce mechanical power, or torque. Likewise, if the rotor moves faster than the stator magnetic field rotation, the motor becomes a generator of AC power—more on this later. The faster the speed difference, the higher the induced rotor current, the higher it's magnetic field, and the higher the torque the motor produces. In truth, an induction's motor torque is proportional to slip rpm, Nslip, or the speed difference between synchronous (the stator's rotating magnetic field) and actual speeds.

Nslip = Nsync - N

T = k x Nslip = k x (Nsync - N)

Example: An induction motor rated 2 hp @ 1750 rpm (Nslip = 50 rpm).

T = 63000 x 2 / 1750 = 72 in-lb.

If the motor is actually running at 1775 rpm (Nslip = 25 rpm). With Nslip cut in half, torque is cut in half to 36 in-lb. HP = 36 x 1775 / 63000 = 1.01 HP

An AC induction motor's torque and horsepower both vary almost linearly with the slip rpm for speed. Below the motor's synchronous rpm it is "motoring" (acts like a motor) and above the motor's synchronous speed it is "generating" (acts like a generator). An AC induction motor only runs at nameplate speed for exactly nameplate conditions.

Regeneration:

VFDs (variable frequency drives) are used to vary AC motor speeds by intentionally changing the frequency supplied to the motor. A VFD will "soft start" the motor while a normal "across the line" (or ATL) starter will generate 3-5 times normal running torques started at 60 Hz. The VFD will start at 0 Hz and slowly (varied by a ramp setting in the VFD) ramp the motor to 60 Hz. (The impedance of the motor and resistance of the wires feeding the motor are all that prevent starting torques more like 36 times normal running torque.)

Using a VFD, AC motors are now variable speed motors. This causes some unique issues when motors encounter an "overhauling" load. Overhauling loads push a motor above the speed set by the VFD, and in this instance, the motor's rotor is moving faster than the rotating magnetic field induced by the current and voltage from the VFD. The motor is now returning power back to its power supply—the VFD. This can happen by simply setting the ramp down time so short that the motor and load inertia overcomes the VFDs ability to slow down the load.

Typically, VFDs cannot return this excess power to the power line (as a basic motor starter does). To understand this we need to understand the basic design of today's VFD:

VFD OPERATION

Understanding the basic principles behind VFD operation requires an understanding of the three basic sections of the VFD: the rectifier, dc bus, and inverter. The voltage on an alternating current (ac) power supply rises and falls in the pattern of a sine wave (see Figure 1). When the voltage is positive, current flows in one direction; when the voltage is negative, the current flows in the opposite direction. This type of power system enables large amounts of energy to be efficiently transmitted over great distances.

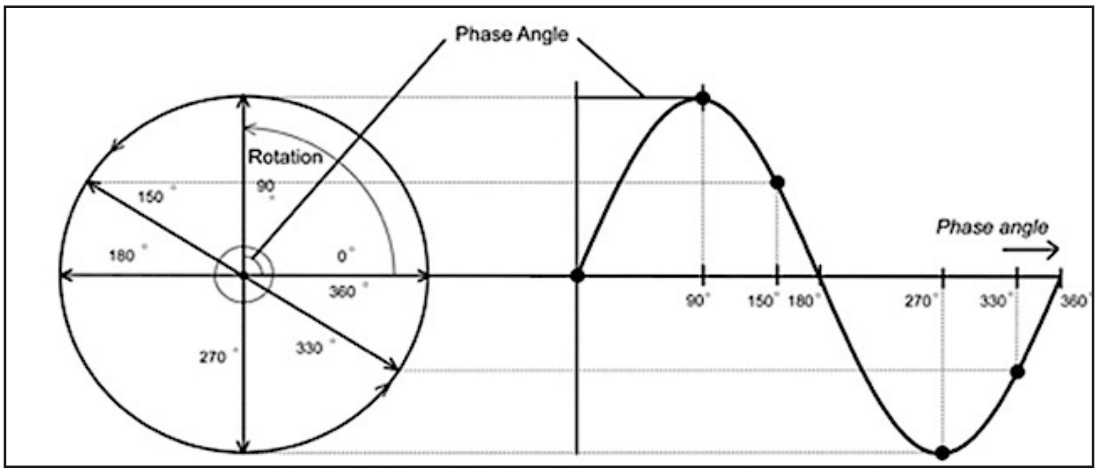

Figure 1: AC sine wave

The rectifier in a VFD is used to convert incoming ac power into direct current (dc) power. One rectifier will allow power to pass through only when the voltage is positive. A second rectifier will allow power to pass through only when the voltage is negative. Two rectifiers are required for each phase of power.

Since most large power supplies are three phase, there will be a minimum of 6 rectifiers used (see Figure 2). Appropriately, the term “6 pulse” is used to describe a drive with 6 rectifiers. A VFD may have multiple rectifier sections, with 6 rectifiers per section, enabling a VFD to be “12 pulse,” “18 pulse,” or “24 pulse.”

Rectifiers may utilize diodes, silicon controlled rectifiers (SCR), or transistors to rectify power. Diodes are the simplest device and allow power to flow any time voltage is of the proper polarity. Silicon controlled rectifiers include a gate circuit that enables a microprocessor to control when the power may begin to flow, making this type of rectifier useful for solid-state starters as well. Transistors include a gate circuit that enables a microprocessor to open or close at any time, making the transistor the most useful device of the three. A VFD using transistors in the rectifier section is said to have an “active front end.”

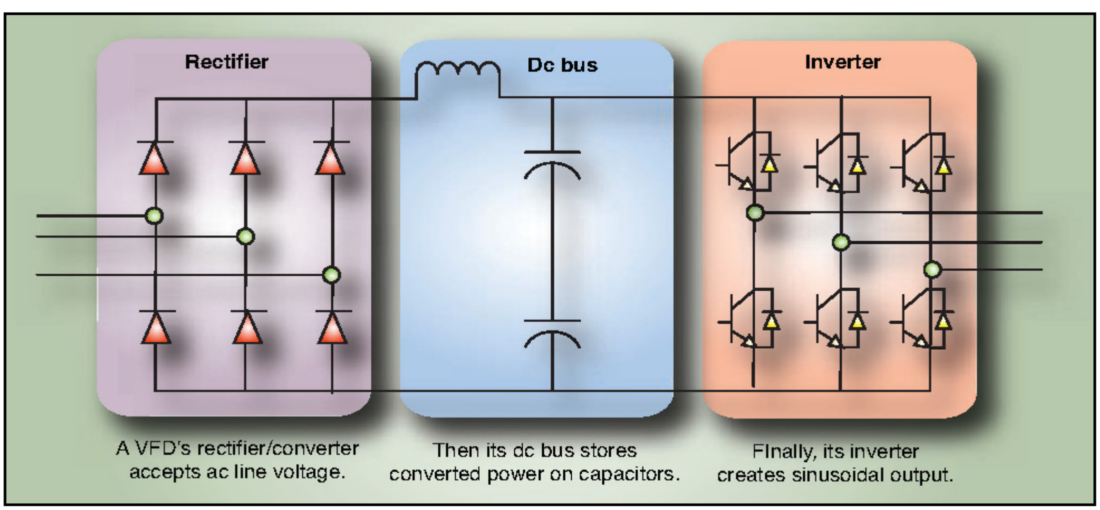

Figure 2: VFD basics: Existing Technology 1

After the power flows through the rectifiers it is stored on a dc bus. The dc bus contains capacitors to accept power from the rectifier, store it, and later deliver that power through the inverter section. The dc bus may also contain inductors, dc links, chokes, or similar items that add inductance, thereby smoothing the incoming power supply to the dc bus.

The final section of the VFD is referred to as an "inverter." The inverter contains transistors that deliver power to the motor. The "Insulated Gate Bipolar Transistor" (IGBT) is a common choice in modern VFDs. The IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor. The IGBT uses a method named "pulse width modulation" (PWM) to simulate a current sine wave at the desired frequency to the motor.

Motor speed in a 3 phase induction motor is dependent upon frequency. Varying the frequency output of the VFD controls motor speed:

> Speed (rpm) = frequency (hertz) x 120 / no. of poles
>
> Example:
>
> 2-pole motor at different frequencies
> 3600 rpm = 60 hertz x 120 / 2 = 3600 rpm
> 3000 rpm = 50 hertz x 120 / 2 = 3000 rpm
> 2400 rpm = 40 hertz x 120 / 2 = 2400 rpm

The front-end of a drive contains a diode bridge that takes AC power and charges a capacitor bank in the dc bus described above (see figure 2 above). With diodes that is a one way trip. The capacitor bank is connected to the motor via the inverter section of the VFD. The inverter and it's IGBTs is bi-directional. If the motor becomes a generator, the resulting current flowing through the inverter section begins to charge and potentially overcharge the capacitor bank. Most drives have the ability to shut down to protect the VFD from this overvoltage. Some drives switch on a resistor to dump the excess energy. In this case, the VFD is not really regenerative, although the motor does not know any better. For an application with a high duty cycle, resistors are costly.

MITGATION OF REGENERATIVE ENERGY

One method to mitigate or "avoid" regenerative applications is to outrun the condition. This is accomplished by detecting an expected rise in the dc bus voltage and increasing the speed of the motor in order to force the motor's rotating magnetic field to catch-up and outrun the rotor's speed. The rotor speed is then slower than the stator's rotating magnetic field and the motor no longer generates power (becomes a motor again).

To accomplish regen avoidance, the drive needs to be capable of using a simple PID algorithm with dc bus voltage as the process variable. To illustrate this we will look at a specific application on the following page—Beam Pumps in the Oil and Gas Industry.

APPLICATION – BEAM PUMP

Beam Pumps are a type of oil pump that mechanically lifts liquid (being water, crude oil, etc.) out of the well if there is not enough bottom hole pressure for the liquid to flow all the way to the surface. This method is commonly called “artificial lift”.

The Pump Jack converts the rotary motion of a motor to a vertical reciprocating piston motion which drives the rod string. A sucker-rod pump is attached to the opposite end of the rod string and is submerged in the well. the rod string. A sucker-rod pump is attached to the opposite end of the rod string and is submerged in the well.

APPLICATION CHARACTERISTICS

- Conversion of rotary motion to up/down reciprocal movement (VFD runs in a constant set speed)
- Regenerative energy generated 2 times per stroke(Up/Down) of the horse head and counter weight
- Stroke per min (SPM) is regulated through the speed of the VFD

ISSUES

- Due to heat dissipation the DB resistors can be a potential fire hazard, DB resistors cannot be used with Pump Jacks without special consideration.
- High duty cycle of the regenerative energy (approx. 50%)
- Regenerative energy causes overvoltage trip faults in the VFD

REGEN AVOIDANCE

Definition

Mechanical over speed of the motor can cause a dangerous rise in the dc bus voltage and a VFD overvoltage trip fault.   To mitigate (or “avoid”) the regenerative energy from an overhauling motor load, the VFD increases speed to cause the motor to transition from generating energy to consuming energy.

Functionality

When the DC link voltage rises due to an overhauling load, the VFD uses a regen avoidance turn-on level to speed the motor and resume consumption of energy. Depending on the type of the pump jack, the motor can over speed up to the over speed trip level. (Over speed trip level at 150% based on set max. freq.)

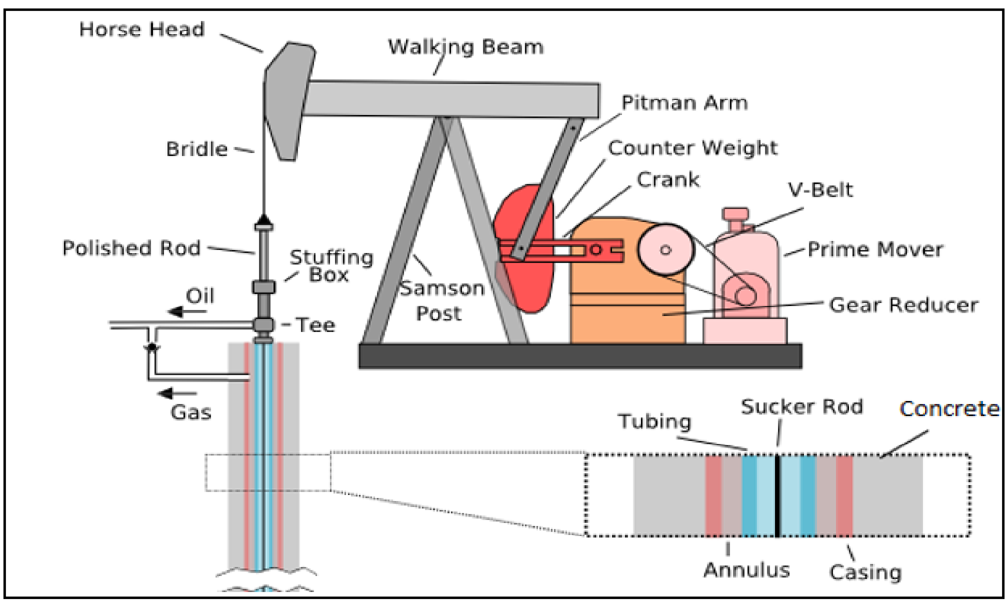

Figure 3: Pump Jack System2

PARAMETERS

Regen Avoidance Enable:
Enables or disables the regen avoidance function

Regen Avoidance Selection:
Selects between V/F or sensorless regen avoidance.

Regen Avoidance Level:
The max level the DC Bus voltage will be allowed to reach before faulting (given in VDC)

Compensation Frequency:
The maximum allowed increase in frequency to compensate for regen (given in Hz)

Regen Avoidance P-gain:
The P factor in the regen avoidance formula (given in %)

Regen Avoidance I-gain:
The I factor in the regen avoidance formula (given in msec)

DC Bus Turn on Level:
The level of the DC Bus voltage when the regen avoidance kicks in (given in VDC)

CONCLUSION

Regen Avoidance can be used effectively in Oil Field (or any rotary/cyclical) applications where an anticipated overhauling load exists and a VFD is desired or needed for the application.

PHOTO SOURCES

1. Figure 2
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2. Figure 3
Wikipedia Encyclopedia

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