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SYNCHRONOUS TRANSFER

STARTING MEDIUM VOLTAGE MOTORS MORE RELIABLY AND EFFICIENTLY WITH VFDS

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This article outlines the importance of understanding the operation of Closed Transition Synchronous Transfer, and it's significance in improving reliability and power quality for medium voltage VFD applications.

Electric motors play a critical role in nearly every modern industrial application. Engineers naturally focus on the specifics of the mechanical work that is to be performed. Objective specifications are often driven by the torque profile of the load, the precision required by the application, and the allowable energy consumption. Industrial motors may be run across-the-line (switched on-off) when speed and torque control is not required. Variable Frequency Drives provide a much greater level of speed and torque control when required, and generally minimize mechanical and electrical stresses on a motor system.

Variable Frequency Drives provide speed and torque control for electric motors and generally minimize mechanical and electrical stresses on a motor system.

MOTOR BACKGROUND

An induction motor is comprised of two sets of conductor coils. The stator coils (fixed "motor windings"), are perhaps the most intuitive, because they are the connections with which we interact. The rotor coils (rotating) are less intuitive. The rotor is a cylinder comprised of conductive bars, resembling a "squirrel cage" or hamster wheel, that rotates inside the stator (with no external electrical connection).

To understand the physics behind an induction motor, consider the following two statements:

1. When electric current travels around a circular coil, a perpendicular magnetic field is induced.
2. When a magnetic flux passes through a conductive coil, a current is induced in the coil.

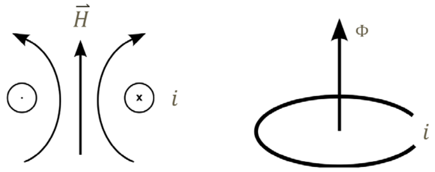

Figure 1: Current induces magnetism. Magnetism induces current.

When rated voltage is initially applied to the stator coil, the initial impedance of the coil is low, which results in a large current (Current = Voltage/Impedance). This relatively high stator current induces a proportionally strong magnetic field. The magnetic field passes through the air gap to the rotor coils, inducing current to circulate in the rotor coils.

Just as circulating stator current induced a magnetic field, the newly induced current in the rotor coils induces it's own opposing field. The interaction of these magnetic forces results in a torque applied to the rotor shaft. As the rotor speed increases, so does the Back EMF Voltage. The increasing Back EMF counters the applied voltage, reducing the effective voltage seen by the stator coil. Reducing the effective stator voltage in turn reduces the stator current, which reduces the magnetic field induced by the stator current, which reduces the induced current in the rotor, resulting in a reduction of the rotor field. As the motor reaches rated speed, stator and rotor currents decrease until they reach steady state operating conditions.

During this process, until the motor reaches rated speed, typical MV motor starting currents may be 5 to 7 times greater than steady state rated full load current.

Starting current creates significant mechanical and thermal stresses on the motor windings and rotor coils. For this reason, many large motors are designed and specified for a limited number of starts per hour. Restricting the number of starts allows the rotor to return to an acceptable temperature before continuing steady-state operation. It is important to note that motor RTDs (Resistance Temperature Detectors) monitor the stator coil temperature. There is typically no direct means to measure the rotor coil temperatures.

Reduced Voltage solutions provide a traditional means of reducing starting currents, but may still result in motor heating and insufficient torque generation.

Across-the-line starting current also creates a significant stress on the power supply. On a 5,000 HP motor, starting current may represent 30 MVA of load on the power system. Depending on the capacity and impedance of the utility supply transformer, this starting load may result in a significant supply voltage drop, impacting other users on the power system, and potentially triggering the utility to impose financial penalties.

REDUCING STARTING CURRENT

Reduced Voltage Starters (RVS) and Reduced Voltage Soft Starters (RVSS) provide a traditional means of reducing harmful motor starting currents. These devices switch large resistor arrays or autotransformers in series with the motor, or utilize semiconductor switching devices, to reduce the available voltage during start. Once the motor is started, the reduced voltage device is isolated, and full line voltage is switched to the motor.

Ohm's law dictates that current is proportional to voltage. Utilizing an RVS device to reduce starting voltage by 50% will result in a corresponding current reduction of approximately 50%. While this represents a significant reduction compared to 600% across the line starting current, 300% starting current will still have a negative impact on motor heating and starting duty, and still places a significant starting load on the power distribution system.

Another consideration of Reduced Voltage solutions is the impact on available starting torque. As starting voltage is reduced, the available starting torque is reduced proportionally to the square of the reduction in voltage. For example, reducing voltage to 50% results in a reduction of starting torque to $(50\%)^2 = 25\%$ of rated starting torque. When implementing a reduced voltage starting solution, it is critical to evaluate the required load torque. If the reduced pull-up torque is insufficient to accelerate the load, the motor will stall. Mechanical systems may be employed to disengage the load during starting, but not without adding additional cost and complexity.

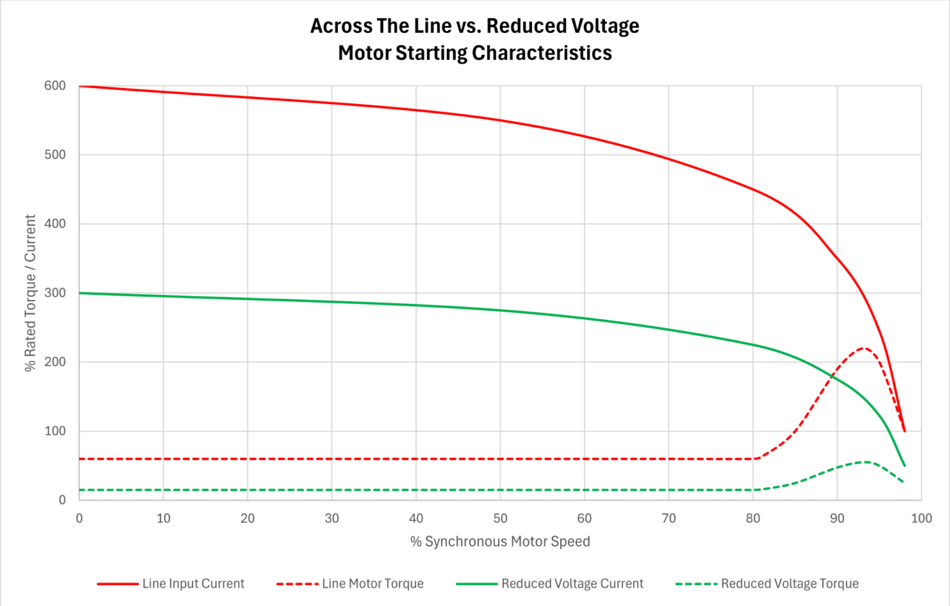

Figure 2: Across the Line vs. Reduce Voltage Motor Starting Characteristics

Variable Frequency Drives (VFDs) provide an ideal solution to manage motor starting. Unlike a reduced voltage starter, which can only control the applied voltage, VFDs can adjust both the applied voltage and the applied frequency for optimal motor performance. By maintaining the optimal ratio of voltage to frequency (V/Hz), a VFD is able to start a motor at 100% rated current, while producing 100% rated torque throughout the speed range.

This operational efficiency improvement allows a VFD controlled motor to produce greater starting torque than the same motor could produce started on the line, while eliminating the motor thermal stress, mechanical stress, and system voltage drops associated with line started motors and RVS solutions. In many applications, a VFD is the only acceptable means to start a large medium voltage motor on the existing utility supply.

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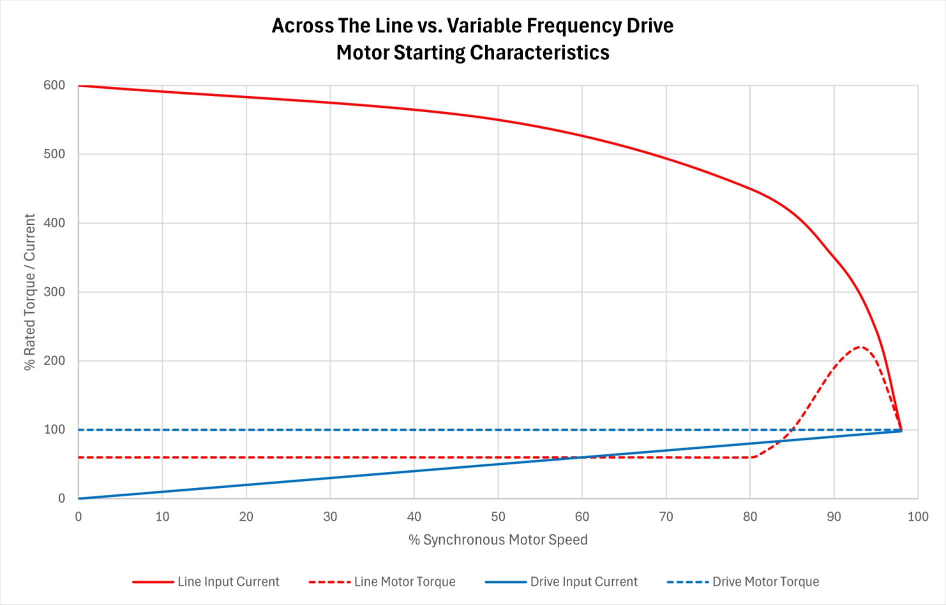

Figure 3: Across the Line vs. VFD Motor Starting Characteristics

The only potential disadvantage of using a VFD for medium voltage motor starting is cost. In applications that do not require speed or torque control, utilizing multiple VFDs to operate multiple MV motors can be cost prohibitive. For these applications, Synchronous Transfer provides a means to use a single VFD to efficiently start multiple motors, smoothly transferring each motor to utility line power once steady-state operation is reached.

SYNCHRONOUS TRANSFER

In a medium voltage closed transition synchronous transfer, a Variable Frequency Drive is used to start and accelerate a motor as shown by the blue lines in Figure 3. Once full 60Hz rated motor speed is achieved, the drive synchronizes the voltage and frequency of its output precisely with the voltage and frequency of the utility supplied line power. When the waveforms match, a contactor is closed to connect the utility supply to the VFD output. Since the voltage and phase have been synchronized, essentially no current flows between the line and the VFD, while both provide current to the motor. After a brief [closed transition] period of synchronous operation with both sources connected, the VFD output is switched off, and a second contactor opens to isolate the VFD from the circuit, leaving the motor connected solely to utility power. Once isolated from the first motor, the VFD is available to operate other motors, while the first motor continues to operate on utility line power.

Synchronous transfer uses contactors to transition a motor from VFD power to utility power, freeing the VFD to operate other motors.

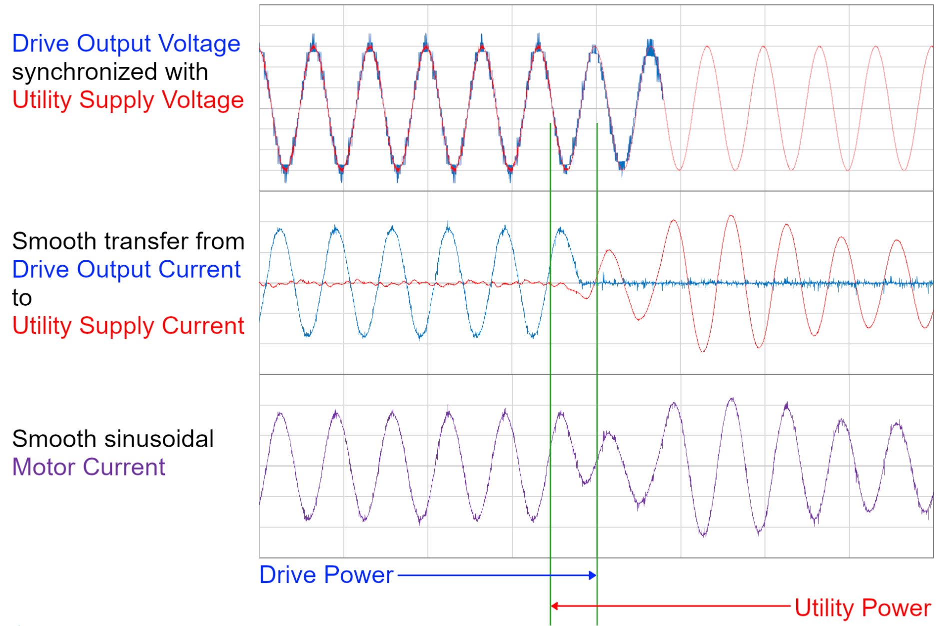

Figure 4

This is referred to as a 'closed' transition because the drive synchronizes the magnitude and phase of the utility supply to it's own output so precisely that both are connected simultaneously during the "make-before-break" transition (the period in which "Drive Power" and "Utility Power" overlap in Figure 4). It is important to distinguish a 'closed' transition transfer from an 'open' transition or 'bypass' sequence. In an 'open' "break-before-make" transition, the drive accelerates the motor to speed, but then simply disconnects, allowing the motor to spin uncontrolled until the utility line contactor closes, completing the 'open' transition to the line. Because magnitude and phase are not synchronized and controlled, closing the bypass contactor during an 'open' transition will create a significant mechanical torque transient as the utility supply attempts to pull the motor into sync, as well as corresponding current transients that may result in upstream overcurrent trips or unacceptable supply voltage drop.

Figures 5A to 5G illustrate the typical operation sequence for a three-motor synchronous transfer motor starting application.

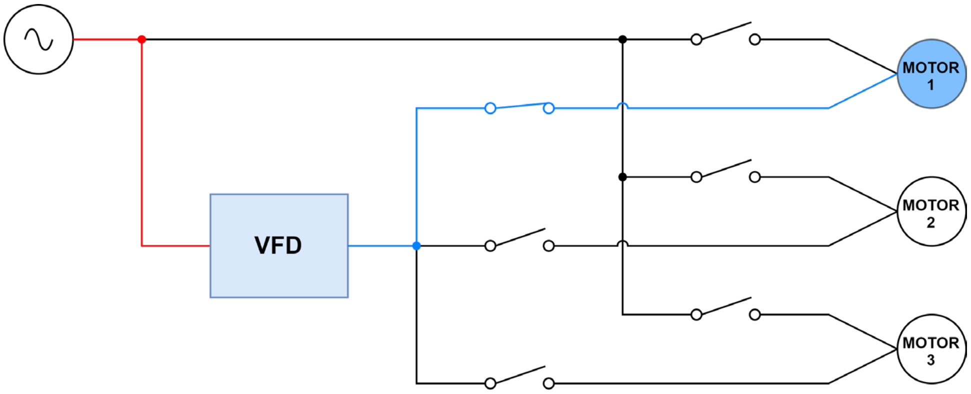

Figure 5A – VFD output connected to Motor 1. VFD starts and accelerates Motor 1.

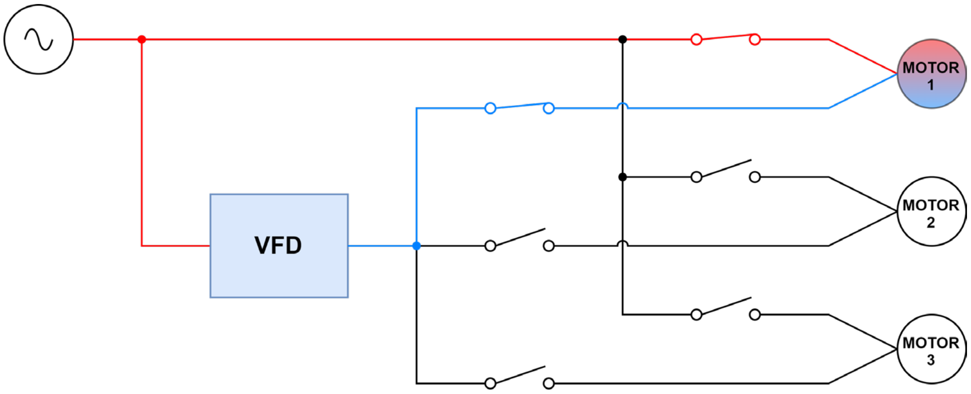

Figure 5B – VFD synchronizes output to line power. Motor 1 is connected to VFD and utility simultaneously.

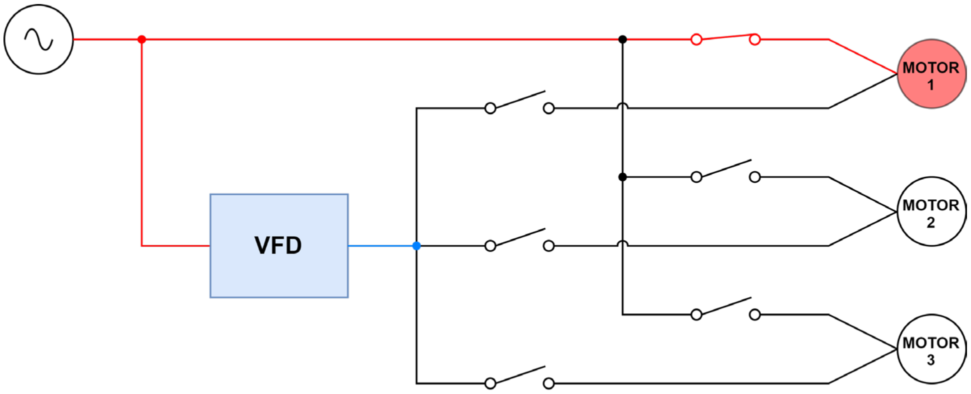

Figure 5C – Output contactor opens, Motor 1 transferred to utility line power

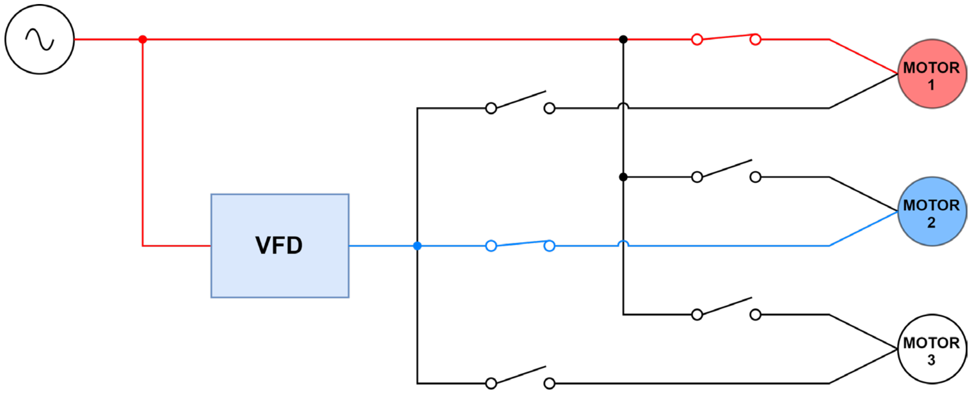

Figure 5D – Output contactor connects VFD to Motor 2. VFD starts and accelerates Motor 2.

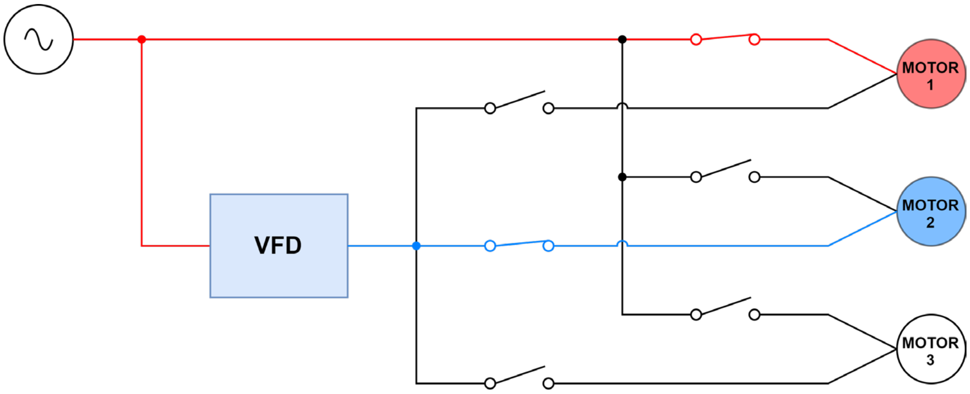

Figure 5E - VFD synchronizes output to line power. Motor 2 is connected to VFD and utility simultaneously.

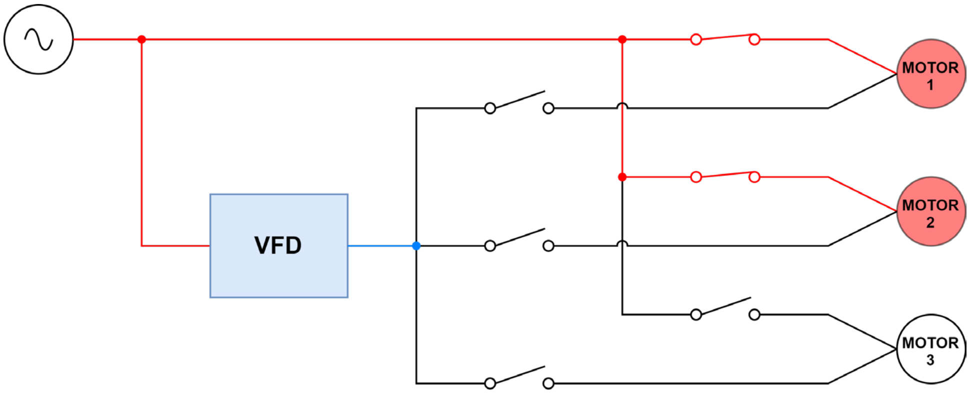

Figure 5F - Output contactor opens, Motor 2 transferred to utility line power

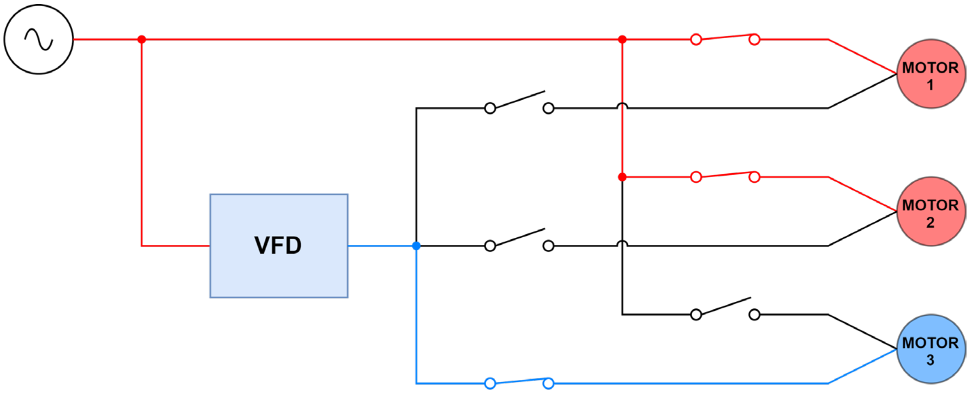

Figure 5G - Output contactor connects VFD to Motor 3. VFD starts and accelerates Motor 3.

Closed transition synchronous transfer provides a cost effective means to smoothly start multiple medium voltage motors with a single drive

Closed transition synchronous transfer provides a cost effective means to smoothly start multiple medium voltage motors with a single drive. Unlike traditional starting methods, the drive maintains full speed and torque control of the connected motor. For example, in Figure 5G, the application load may require Motor 3 to be synchronized to the line, or it may require the VFD to maintain speed control. The control can be designed to operate as required by the load.

Closed transition synchronous transfer combines the benefits of starting a motor with a drive with the benefits of operating a motor on the utility line.

As the load is reduced, each of the sequences shown in Figure 5 may be reversed. Each motor may be smoothly synchronized back from utility to VFD control, decelerated, and isolated – effectively moving backwards through Figures 5G-F-E-D-C-B and back to 5A.

Using this sequence, a drive equipped with closed transition synchronous transfer capability may be used to start multiple motors, while eliminating the motor thermal stress, motor mechanical stress, and system voltage drop problems associated with other starting methods. By transferring the motor to the line once accelerated, steady state operating efficiency is improved by eliminating the thermal losses associated with operating a drive at full load. Closed transition synchronous transfer combines the benefits of starting a motor with a drive with the benefits of operating a motor on the utility line.

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