Phase Converter

Introduction

A wide variety of commercial and industrial electrical equipment requires three-phase power. Electric utilities do not install three-phase power as a matter of course because it costs significantly more than single-phase installation. As an alternative to utility installed three-phase, rotary phase converters, static phase converters and phase converting variable frequency drives (VFD) have been used for decades to generate three-phase power from a single-phase source.

A phase converter is a device that converts electric power provided as single phase to multiple phase or vice-versa. The majority of phase converters are used to produce three phase electric power from a single-phase source, thus allowing the operation of three-phase equipment at a site that only has single-phase electrical service. Phase converters are used where three-phase service is not available from the utility, or is too costly to install due to a remote location. A utility will generally charge a higher fee for a three-phase service because of the extra equipment for transformers and metering and the extra transmission wire.

Rotary and Static Phase Converters

Phase converters provide 3-phase power from a 1-phase source, and have been used for decades. The simplest type of old technology phase converter is generically called a **static phase converter**. This device typically consists of one or more capacitors and a relay to switch between the two capacitors once the motor has come up to speed. These units are comparatively inexpensive. They make use of the idea that a 3-phase motor can be started using a capacitor in series with the third terminal of the motor. It is almost guaranteed that a static phase converter will do a poor job of balancing the voltages on the motor. Unless motors operated on static converters run only for short periods or deliver significantly less than half of their rated output, they will be damaged from overheating.

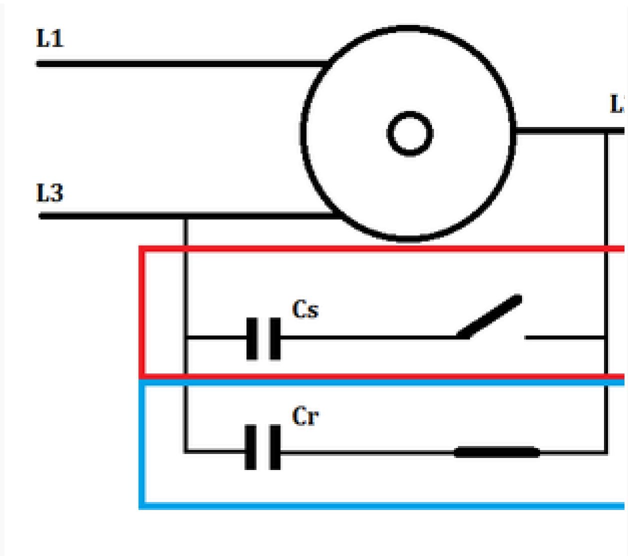

Figure 1. Static Converter Scheme: L1 and L3 are the single phase legs going to your motor application and L2 is

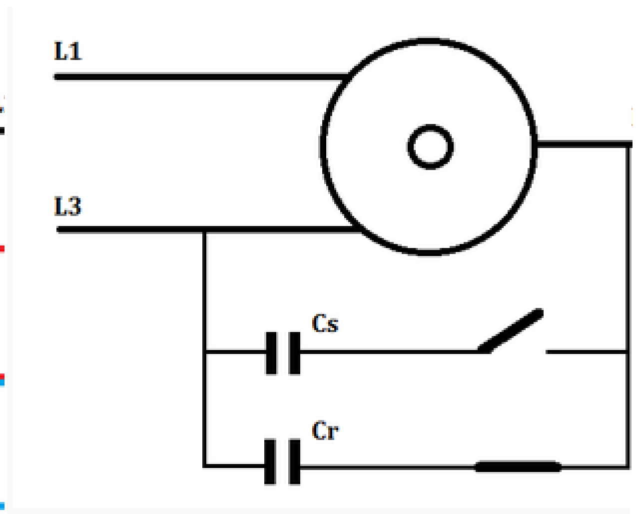

Figure 2. Rotary Converter Scheme: L1, L2 and L3 are the three phases of the internal motor. Cs is the start capacitor which is switched out after the internal motor starts. Cr is

produced when motor starts turning. Cs is the start capacitor which is switched out after the internal motor starts. Cr is the fixed run capacitor.	the fixed run capacitor.

How Does a Static Converter Work?

The Static Converter is made up of two small components: A voltage sensitive relay and a standard capacitor (Cs) connected to your motor application. The capacitor delays waveforms (or shifts the phase) during the start-up of your motor application. The relay disconnects this start capacitor after the motor has started. From this point, the motor will continue turning on the single phase supply. The performance of such a motor is fairly poor and can be compared to a car motor running on only a few cylinders. Motors operated on a static converter will produce about 50-60% of their name plate power. When you add another low cost run capacitor to the simple design, rated power goes up to around 70% of the motors name plate power. To help with understanding, the Start Capacitor (Cs) is used only to start the motor and then it is switched out completely. The Run Capacitor (Cr) is always in the circuit and is carefully sized to balance the voltages at one load rating (generally around 50% full load). Since Cr is fixed the voltage balancing at either end (0% and 100%) is quite poor.

The second type of old-technology phase converter is generically called a **rotary phase converter**. This device consists of a 3-phase motor (usually without external shafts) and a bank of capacitors wired together to act as a single large capacitor. Two of the leads to the motor are connected to the 1-phase power source and the third lead to the motor is connected in series with the capacitor bank to either one of the 1-phase inputs. The output leads from the phase converter are connected across the three motor terminals. Typically the motor used in the phase converter is larger than the loads it is supplying. For example, a rotary converter designed for a 5 kW load might use a 7 kW motor frame. The electrical interaction between the capacitor bank and the free-running phase converter motor generates a voltage on the third motor terminal which approximates the voltage needed for a balanced 3-phase system. However, it usually isn't a very good approximation. For example, measurements on a 5 kW rotary converter in an actual machine shop installation resulted in line-to-line voltages of 252 V, 244.2 V and 280.5 V, which is about a 12% imbalance in the voltages.

Voltage Imbalance In Percent	Derate Motor to These Percentages of the Motor's Rating
1%	98%
2%	95%
3%	88%
4%	82%
5%	75%

How Does A Rotary Converter Work?

If you add an idle running motor to a static converter, you have a rotary converter. The added motor will compensate for some of the static converter weaknesses and help extend the range of motor sizes and loads. The internal motor is inactive at average load, but works hard when loads don't match the value of the chosen run capacitor (Cr). Rotary converters are clearly somewhat better than static converters. They can run several motors of different sizes. Large motors will produce up to 90% of their nameplate power, small motors (motor being much smaller than the converters idling motor or pilot motor) a bit more. If the manufacturers oversize these motors, the output symmetry, start capability and capacity will all be increased. This is why manufacturers ask you so many questions about your applications. When in doubt, they will offer a converter with a larger pilot motor or suggest a larger converter altogether.

Variable Frequency Drives

Variable frequency drives (VFDs) are designed primarily to control the speed of AC motors, but can be adapted to function as phase converters. They also have some problems with power quality. While a phase converter will supply a 3-phase output at the same frequency as the input voltage from the power line, a VFD has the ability to create voltages that vary in frequency. A VFD has an input rectifier (either 4 or 6 semiconductor diodes) which charge up a DC link capacitor. Three pairs of semiconductor switches are also connected to the DC link capacitor. Each switch pair is connected in series and has connections to the two capacitor terminals. The center connection of each switch pair is connected to one of the output terminals. If the top switch is on, the output terminal will be connected to the top or positive terminal of the link capacitor. If the bottom switch is on, then the output terminal will be connected to the bottom or negative terminal of the DC link capacitor. Each of the three output terminals is connected to one of the leads of a 3-phase induction motor.

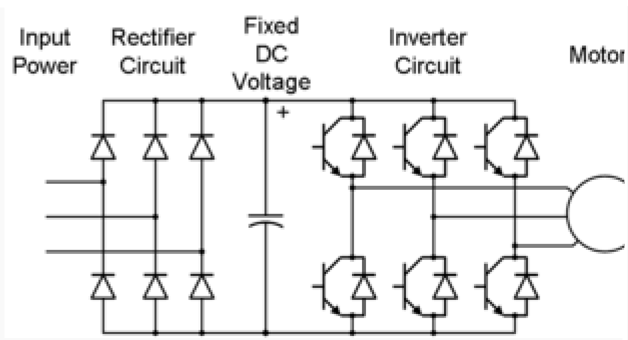

Figure 1. Electrical scheme of the VFD

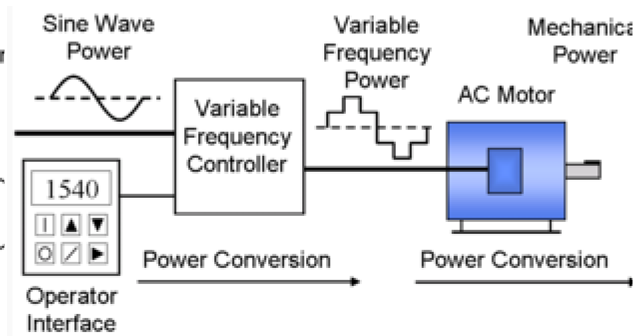

Figure 2. Simplified block-diagram of the VFD

A VFD cannot produce a sinusoidal output voltage. It can only connect the output terminals to either the positive or negative terminal of the link capacitor. For example, the voltage on the top terminal of the capacitor is +170 V and the voltage on the bottom terminal of the capacitor is at -170 V. If during some short time interval the top switch is on half the time and the bottom switch is on half the time, the average voltage at that output terminal would be zero. If the top switch were on all the time, the average voltage would be +170V, and if the bottom switch were on all the time then the average voltage would be -170 V. Thus, the switches can produce average voltages over a short interval that can have any value between +170 V and -170 V.

The inductance of a motor powered by a VFD responds to the area beneath the curve of a plot of the voltage as a function of time. So, even though the voltage isn't sinusoidal, if the on/off times of the switches are chosen correctly then the current in the leads to the motor can be sinusoidal as long as the average value of the voltage is sinusoidal. Since the torque generated by the motor is proportional to the currents and not the voltages, then to a first approximation the motor behaves as if it had sinusoidal voltages applied to it.

Problems can arise with VFDs if they are used to power loads other than motors, if there are multiple loads on the VFD, if the motor needs to provide braking action, if the distance between the motor and the VFD is appreciable, or if the current drawn by the VFD is large compared to the rating of the utility step-down transformer.

VFDs were not originally designed to function as phase converters, in fact most VFDs are powered from a 3-phase source. When used in this manner, six input diodes rectify the 3-phase input signal and are used to charge up the DC link capacitor. If a 1-phase source is used instead, then 2 of the input diodes go unused and all of the current into the unit has to be carried by the remaining 4 diodes. Also, the ripple current in the DC link capacitor will be significantly larger, so the power handling capability of all these components has to be increased if the unit is to be powered from a 1-phase source. This type of input rectifier typically produces large harmonic distortion in the input current. Table below gives typical values of the harmonic distortion expressed as a percentage of the fundamental component of the input current at 60 Hz.

Harmonic	3rd	5th	7th	9th	11th	13th	15th
Percent	73.2%	36.6%	8.1%	5.7%	4.1%	2.9%	0.8%

The harmonic component of the current will be a problem when the current flowing into the VFD is a significant portion of the total current load that the step-down transformer is capable of delivering. If a very large VFD is used or if multiple smaller VFDs are all attached to the same line then there may be problems. The relatively large current drawn by the input circuit of the VFD at the peak of the voltage sine wave can distort the voltage waveform and cause problems for other users on the power system. Input line reactors are often used between the VFD and the power system to help alleviate this problem.

VFDs are designed to drive a single motor load. The manufacturer's recommendations usually are that the wires to the motor be solidly connected to the VFD and that the connections not be broken under normal operating conditions. That is, one would not normally install a contactor between a VFD and a motor because the high voltage and arcing that are a normal part of the contactor opening and closing can have unpredictable effects on the semiconductor switches in the VFD and increase the risk of failure. If multiple loads are connected to a VFD with individual contactors for each separate load, the VFD may not be able to handle the current surges which occur when individual loads are switched on and off. If a VFD were connected to a piece of equipment which contained 3-phase motors as well as other controls, it is very likely that both the VFD and the equipment would be damaged. For example, if there were any capacitors in the equipment connected directly across the VFD outputs, the VFD would have to shut down immediately or be destroyed by the extremely high currents that would flow when the output voltage pulses were applied to the capacitors. The starting sequence of a VFD is carefully controlled to avoid damage. When the start button is pushed, the pulse sequence to the output switches is adjusted so that the average voltage applied across the motor has a low value, with low frequency. As the motor starts to spin, the voltage is allowed to increase and the frequency is increased until the motor reaches full operational speed. A start at full voltage and max frequency would overload the output switches. If a VFD is putting out full voltage at 60 Hz to one motor on its output, and a second motor is suddenly connected by closing a contactor, then the VFD will probably either shut down if it can respond to the overload, or be damaged if it can't. The circuitry in a VFD does not allow power to flow from the motor back to the power system, as is required when the motor acts as a brake. If the application requires this feature, then one or more braking resistors and additional switches must be added to the VFD so that this power is absorbed without destroying either the output switches or the DC link capacitor. Rotary and static phase converters intrinsically have the ability to absorb braking currents because two of the wires to the motor are connected directly to the supply system.

The output voltage from a VFD is not sinusoidal, but rather a series of pulses which have average values that are sine waves. The switches that control these pulses have to make their on/off transitions very rapidly (in about 0.2 microsecond) for the VFD to operate efficiently. The high frequency components of these pulses travel from the VFD to the motor through the connecting wires, which become an electrical transmission line. Transmission line effects are normally not a problem at 60 Hz to the average user because the wavelength of a 60 Hz signal is about 3500 kilometers (assuming the signal travels at 0.8 x the speed of light in the wires). However, at 5 MHz the wavelength drops to about 50 meters and the effects become important. The electrical impedance of the transmission line is unpredictable but typically has values between a few tens of ohms to a few hundred ohms. On the other hand, the impedance of the motor and the VFD is usually just a few ohms. This mismatch between the line impedance and the impedance of the terminations at the motor and the drive causes standing wave patterns to be set up in the line with resultant voltages that can be much larger than the voltage at the drive output. These standing-wave voltages can damage the wiring, the motor and the drive. If the distance between the VFD and the motor is short (less than 3 meters), there shouldn't be any problem. As the distance approaches 15 meters or more, most VFD manufacturers recommend that output line filters be used on each of the output leads. In their simplest form these filters consist of an inductor in series with each output line with a capacitor connected to the second terminal of each inductor. The other terminal of each capacitor is connected to a common point. This filtering does not make the output voltages sinusoidal, and so even with filtering, residual harmonics may have some impact on the wire and motor in installations where the motor and drive are far apart. At distances of 60 meters or more, as would be typical for a deep-well submersible pump, output line filters are a necessity and will add to the cost of the drive installation.

Digital Phase Converters

Digital phase converters are a recent development in phase converter technology that utilizes proprietary software in a powerful microprocessor to control solid state power switching components. This microprocessor, called a digital signal processor (DSP), monitors the phase conversion process, continually adjusting the input and output modules of the converter to maintain perfectly balanced three-phase power under all load conditions.

Like rotary and static phase converters, a digital phase converter generates a third voltage, which is added to L1 and L2 of single-phase service to create three-phase power. There the similarity ends.

A process called double-IGBT conversion generates the third voltage. Double conversion means that AC power from the utility is converted to DC, then back to AC. The power switching devices used in this process are insulated gate bipolar transistors (IGBT).

The input module, or rectifier, consists of IGBTs in series with inductors. Operating at a switching frequency of 10 kHz, the IGBTs are controlled by software in the DSP to draw current from the single-phase line in a sinusoidal fashion, charging capacitors on a constant voltage DC bus. Because the incoming current is sinusoidal, there are no significant harmonics generated back onto the line as there are with the crude rectifiers found in most VFDs. The electronic power factor correction on the input module also corrects the power factor of any inductive loads so that the utility sees a system that operates at near unity power factor. The power factor correction makes digital phase converters very efficient and utility friendly.

The output module, or inverter, consists of IGBTs that draw on the power of the DC bus to create an AC voltage. A voltage created by power switching devices like IGBTs is not sinusoidal. It is a pulse-width-modulated (PWM) waveform very high in harmonic distortion. This PWM voltage is then passed through an inductor/capacitor filter system that produces a sine wave voltage with less than 3% total harmonic distortion (standards for computer grade power allow up to 5% THD). By contrast, VFDs generate a PWM voltage that limits their versatility and makes them unsuitable for many applications. Software in the DSP continually monitors and adjusts this generated voltage to produce a balanced three-phase output at all times. It also provides protective functions by shutting down in case of utility over-voltage and under-voltage or a fault. With the ability to adjust to changing conditions and maintain perfect voltage balance, a digital phase converter can safely and efficiently operate virtually any type of three-phase equipment or any number of multiple loads.

The solid state design results in a relatively small package with no moving parts except for small cooling fans. The converters are very efficient, operating at 95-98% efficiency. When the converter is energized with no load, it consumes very little power.

Digital phase converters are a patented technology developed by Phase Technologies, LLC, who is the only manufacturer of true digital phase converters.

Reference

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Source:

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