Rockwell Automation

Allen-Bradley

Phase Controlled Rectifiers and AC Motor Controllers

The effect on feeder lines by various types of power converters, by Howard G. Murphy.

Line operation of motors

In fixed speed applications, the impact on the feeder lines providing power to electrical motors, has been limited to consideration of the inrush currents. These inrush currents are necessary to permit the motor to achieve ample torque while accelerating the motor and its connected load to a fixed operating speed. For most applications, the impact of the feeder lines was for time periods no greater than a few seconds. For a few applications, the limiting factor was the tripping of the motors overloads where the acceleration period exceeded the thermal overload time period. With the advent of electronic motor control, the effect on the feeder lines was extended to longer periods of time and for most applications, the effect was continuous.

Line pollution: Its cause and impact

Feeder line pollution became a concern, due to its impact on other equipment obtaining its power from the same feeder line. To understand this concern, it is necessary to: clarify the term "line pollution," describe the variations that exist and to determine how those variations are created. Line pollution can be defined as any variation which modifies the volt-second area of the sinusoidal voltage supply. Any change in amplitude from the normal waveform will effect the power measurements and the resulting cost of operating an electric motor. Fast changes in amplitude, (i.e. high dv/dts), can cause insulation breakdowns and shorten the life of equipment sharing that feeder line. High dv/dts occur when the feeder line must supply high currents in small periods of time. Some types of electrical control equipment connect low impedance loads to the feeder lines during their normal operation.

Line Pollution Forms

For electronic controls, line pollution exists in two forms. Notch pollution, is the most common form. This occurs when "chunks" of current are created due to the low impedance load connected to the feeder line. Harmonic pollution also exists. In addition to the fundamental currents provided by the feeder line, harmonic currents will exist in the feeder line and distort the sinusoidal form of the voltage. Harmonic pollution does not create high dv/dt's but can also effect power calculations.

Transfer of Power

In simple terms, the control of electric motors, whether fixed speed or variable speed, is a matter of the transfer of power from one source to another source. In the case of electric motors, the transfer of power is defined by the product of the applied voltage, the resultant current, and the angular relation between them. The effect on the feeders line is a result of the RMS sum of all the current carried by the feeder and the impedance of the feeder. The cost of power carried by that feeder is a result of the amplitude of that current and the angular relationship (displacement angle) between that current and the supply voltage. If the displacement angle is small (.97pf), the cost penalty is small. If the amplitude is small, the cost is small. However, if the amplitude is small and the displacement angle is large (.60pf), the cost penalty could be expensive. If the displacement angle is small and the amplitude is large, the cost would also be expensive. The ideal situation would be one where the displacement angle is small and the amplitude does not exceed the nominal current necessary to allow the motor to develop the torque required to efficiently handle the load.

Method of Voltage Control

Since the primary control of electric motors is to control the application of voltage to the motor, the method of voltage control will determine the impact on the feeder line. In the fixed speed situation, the inrush or locked rotor currents will cause line pollution which reduces the available voltage of the feeder by an amount determined by the impedance of the feeder and by the power factor of the motor. In that case, a large displacement angle and a large amplitude will exist for the time period necessary to bring the motor to its operating speed. If power factor correction capacitors are connected to the feeder line, a large amplitude of current will exist for a short period of time, but the displacement angle will shift from a lagging towards a leading angle. It is likely that voltage ringing will occur and could cause very high amplitudes or spikes which could cause damage or shutdowns to equipment connected to that feeder line.

Electronic Control and Pollution

DC Drives

In the control of DC motors, the use of Phase Controlled Rectifiers, or SCR's provide for the application of variable DC to the motor to eliminate the inrush currents that would exist if full voltage were applied. With full voltage applied to the motor and full torque being provided by the motor, the effect on the feeder line is minimal since the current into the motor is being provided by each feeder line (phase). The distortion occurring, due to the current, is small since the current in each phase tends to follow the amplitude of the phase voltage. As the speed of the DC motor is reduced, the voltage must be reduced proportional. The motor current can only be provided during the period when the SCR's are conducting. This results in "chunks" of current taken from each feeder line. Since the current is forced to flow during a smaller portion of the voltage wave, a further "phase' shift in the current/voltage relationship occurs. This reduces the power factor and creates current of greater amplitude. These current "chunks" distort the feeder lines causing problems with other equipment on those feeder lines. At very low speeds and large torque demands, the distortion can be very severe. The other negative effects are that larger feeder wires are required. Larger input transformers are required, if transformer are used for isolation.

AC Drives- V V I

In the control of variable speed ac motors, a similar situation exists in variable voltage type inverters where SCR's are used to convert the AC feeder lines to variable DC. This method of converting AC to variable dc which is then directed to the motor as a variable frequency provides the constant volts per hertz necessary for constant torque operation. Although, the power factor of the AC motor is not reflected directly back to the feeder line, the motor current required at full load conditions must be obtained from the feeder lines. Like the DC motor, at speeds below base speed, the current from the feeder lines is provided in "chunk" form and is then filtered by the DC bus. Due to the characteristic of the DC bus filter, the power factor will decrease as the speed is decreased and as the load is reduced. The impact on the feeder line is similar to the DC motor case and results in cost penalties both for larger displacement angles and for larger input current amplitudes than the amplitude of the motor current.

In variable voltage type inverters which use rectifiers to convert AC to a constant dc and a "chopper" to change the constant DC to variable DC, the characteristic of the distortion of the feeder line changes from large "chunks" taken from each phase cycle to many small "chunks" taken from the constant DC bus. These small "chunks" are then filtered by the variable DC bus. The high frequency chopper currents will transfer to the feeder lines if the constant dc bus filter action is inadequate. Typically, most products provide a suitable buffer in the form an LC network for the constant DC bus. The displacement angle and the amplitude of the feeder current in this type of converter provide a minimum of distortion to the feeder line.

AC Drives - PWM

In variable frequency type inverters which use rectifiers to convert AC to a constant DC and pulse width modulation to develop the constant volts per hertz required for constant torque operation of an AC motor, the effect on the feeder lines is like the "chopper" method and is the most effective of any of the electronic motor control methods.

The small displacement angle and amplitude of the feeder currents reflect the characteristics of the motor load but with an improved power factor.

Harmonics

All electronic motor control methods will cause harmonics currents in the feeder lines, however, since amplitudes of these harmonics are proportional to the amplitude of the fundamental (60 Hz), it is important that the fundamental be as small as possible so that the effect of the harmonic currents on the feeder lines are also small.

Comparison of Waveforms

Figure 1 shows a comparison of the voltage and current waveforms related to various delay angles.

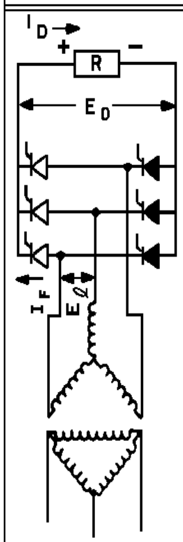
Circuit Diagram	DELAY ANGLE	Output Wave Values					Controlled Rectifier Wave Values						Converter Characteristics	
		Voltage Wave Form	E_D / E_ℓ	DC Volt (XE_ℓ)	F.F.	RIPPLE CURRENT %	Current Wave Form	θ	I_F / I_D	I_F / I_{RMS}	V_{FBM} / E_ℓ	V_{RM} / E_ℓ	E_H	Power Factor
	0°		1.35	1.35	1.002	4.6		120°	.333	.577	0	1.41	99.5	.951
	30°		1.16	1.165	1.015	15.3		120°	.333	.56	.745	1.41	96.5	.84
	60°		.67	.67	1.1	26.8		60° 2 pulses	.333	.52	1.192	1.41	77	.54
	90°		.133	.133	1.6	17.3		30° 2 pulses	.333	.36	1.29	1.41	37.5	.20
	120°	———	0	0	0	0	———	0	0	0	1.41	1.41	0	0

Figure 1. Comparison of Voltage and Current Waveforms

Summary

In summary, the most effective electronic control method of AC motors is the method which provides close to unity power factor, minimizes the amplitudes of the currents carried by the feeder lines and uses hardware which is the most efficient. That method is a rectifier converter section with an LC filter and a pulse width modulated inverter section.