Induction Motors and Rotary Phase Converters

How They Work, Why They Work

by Bob Swinney

Photos by Author

Safety hazard warning! *Potentially lethal voltages are found in rotary phase converters. It is strongly recommended that you consult an electrician for the wiring and construction of these devices. Check your local electrical code for specific connection and electrical safety requirements. Since the examples given cover a range of horsepower, wiring sizes are omitted from the diagrams. Use common sense and wiring tables to size all current-carrying conductors, especially for input wiring and circuit breakers.*

When faced with the problem of obtaining three-phase power, you have maybe three choices. The first one, involving your electric utility, is not very attractive. Having a special three-phase power drop installed by the electric utility is not cost effective for the average small machine shop. The next choice, generating three-phase current in a motor-generator set, is also not very attractive from the equipment cost standpoint. The remaining solution is some type of phase converter, which is generally used in the home shop and in small commercial machining establishments.

Phase converters are more accurately described as phase adapters. The rotary phase converter can be conveniently viewed as a sort of rotary transformer. An induction motor operates as a transformer, and this inherent quality easily leads to adapting it as a "phase converter." Basically, a rotary phase converter is a three-phase motor running on single-phase power with its terminals connected in parallel with a three-phase load. That's it! However, performance can be enhanced with capacitors – a concept that will be dealt with later.

Another form of phase converter is the variable frequency drive (VFD). Variable frequency drives electronically generate three-phase current over a range of frequencies. The induction motors in most metalworking machines are designed to operate from ordinary three-phase, 60-hertz (Hz) – or 60-cycle – power. Although a VFD delivers three-phase *variable frequency current*, the varying frequency forces an induction motor to perform an unnatural act! Induction motors are simply not designed to run at variable speeds. Forcing one to operate from a VFD over a wide speed range can cause heating, de-rated horsepower and a general loss of efficiency. Also, the cost goes up. Variable frequency drives capable of operating induction motors of more than two horsepower are pricey beasts, indeed. This article will not consider the VFD as a choice for phase conversion.

ALTERNATING CURRENT MACHINERY

The squirrel-cage induction motor is the most common alternating current (AC) motor in use today. Induction motor operation is best explained by the revolving field theory. Because an induction motor runs on AC, and AC comes from a rotating generator (called an alternator), it is convenient to visualize the rotating magnetic field of the generator as being reproduced on the stator (stationery part) of a motor. Commercial 60-Hz current changes direction, or alternates, 60 times a second between maximum positive voltage and maximum negative voltage. From the familiar sine wave analogy, voltage above the base line is considered to be positive and voltage below the base line is negative. With 60 seconds in a minute there will be 3,600 alternations, or cycles, per minute. Magnetic poles are formed when current flows in a coil of wire around an iron core. Flux, or magnetic lines of force, exists between opposite magnetic poles. Rotation of the stator flux field causes "motor action," or torque, in the rotating part (rotor) of an induction motor. Opposite magnetic poles occur at each end of a continuous coil

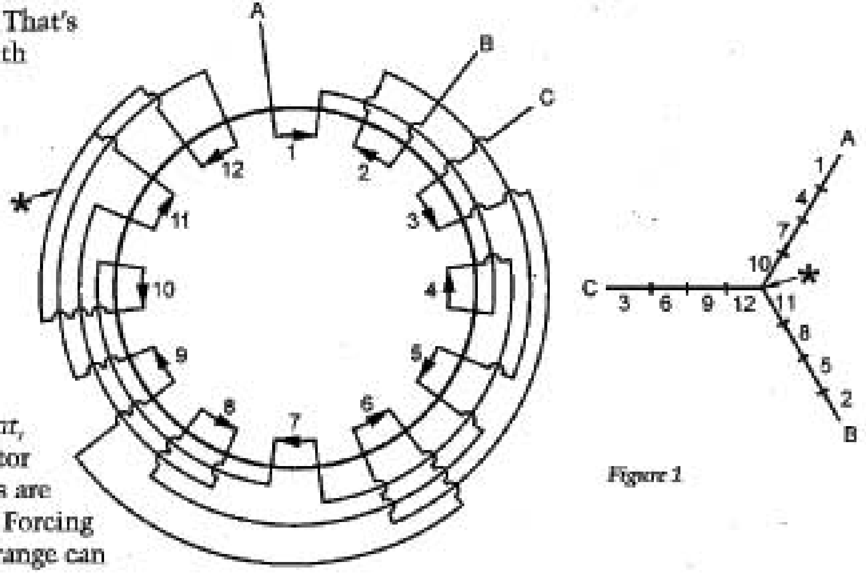


Figure 1

of wire. For descriptive purposes, these poles are designated with "polarities" of North and South. Polarities change, or "swap ends," as the direction of current flow reverses. A polarity change occurs with each cycle. One cycle occurring in one second is known as 1 hertz (Hz). In the US, most commercial alternators (AC generators) run at closely governed speeds such that the frequency of their output is always 60-Hz or 3,600 alternations per minute. The speed of synchronous and induction motors is directly related to the frequency of the supply voltage and inversely to the number of pole pairs on their stators.

Alternating current generators (alternators) and three-phase induction motors have three separate sets of windings. The winding sets, or phases, are insulated from each other, with each set (or phase) wound to form a pair of magnetic poles. Two poles – i.e., one North and one South – are the minimum necessary for generation or motor action. In fact, many steam-driven turbo-alternators used for power generation are two-pole, three-phase, 3,600 rpm machines. This is not necessarily a commentary on design simplicity – the number of poles in an alternator is directly associated with design speed and 3,600 rpm is a favorable speed for direct drive by a steam turbine. With input current alternating 3,600 times per minute and motor action occurring between opposite poles, a two-pole motor will tend to run at the *synchronous* speed of 3,600 rpm, a four-pole motor at 1,800 rpm, a six-pole motor at 1,200 rpm, etc. Essentially, the rotor "locks in" with the rotating magnetic field on the stator and revolves at a speed that is equal to 3,600 divided by the number of pole pairs.

The two basic types of AC motors are the synchronous motor and the induction motor. Synchronous motors have DC (direct current) applied through slip rings to either the stator or rotor in order to establish a steady magnetic field. Torque is produced by interaction between a steady magnetic field on one member and a rotating magnetic field on the other. Synchronous motor speeds are as consistent and unvarying as the frequency stability of the power source. A two-pole synchronous motor will rotate at exactly the same speed as the rotating field of the alternator that supplies power to it. In a 60-Hz system this will be 3,600 rpm. Induction motors are similar to synchronous motors and are also considered to be constant-speed machines. However, induction speed is load-dependent and not as consistent as it is in the synchronous motor. The main difference between synchronous and induction motors is the way the rotors are magnetized. Rotor current in the induction motor occurs via transformer activity, or induction, from the stator.

All poly-phase motors have the same number of winding sets on their stators as there are phases in the power source. Each winding set is connected to one "phase" of the source and each phase set forms one or more magnetic pole pairs around the periphery of the stator. Magnetic lines of flux "flow" from each stator pole to the corresponding opposite pole, cutting across the air gap and rotor. Flux sweeps across, or "cuts," rotor coils, inducing current and forming magnetic poles in the rotor. Torque is produced when rotor magnetic poles react against stator magnetic poles. Transformer action (induction) is responsible for rotor current in induction motors.

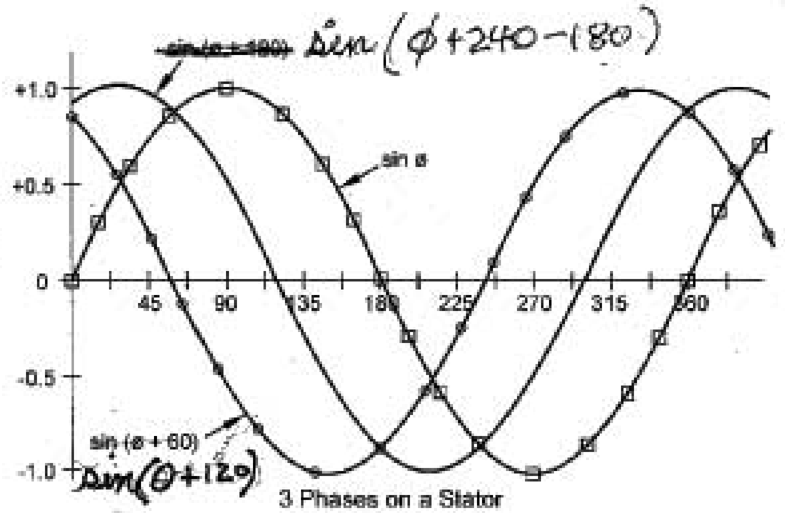


Figure 2

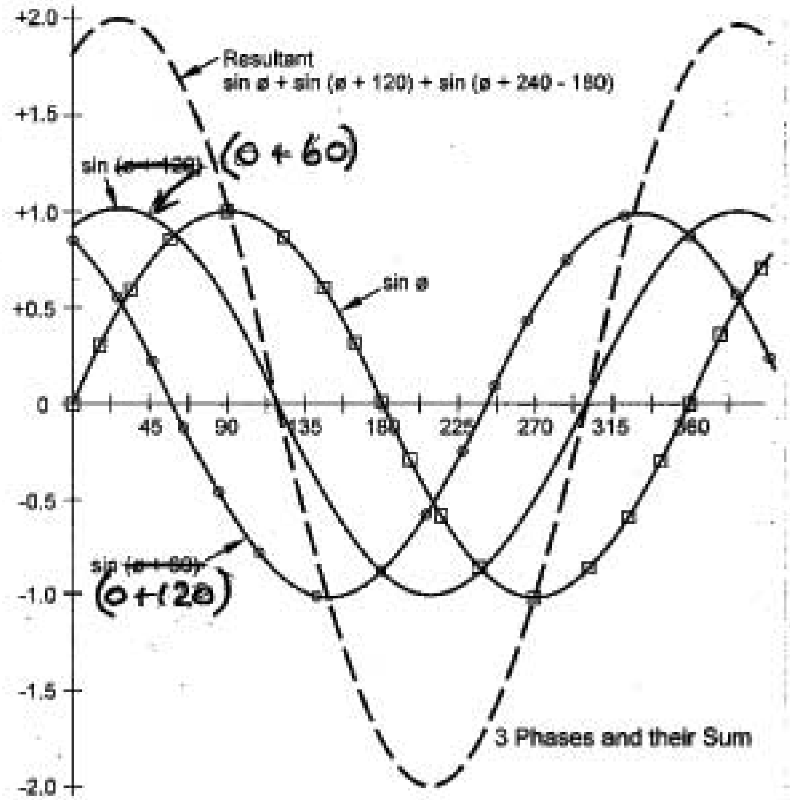


Figure 3

P.L. Alger describes the induction motor (*The Nature of Polyphase Induction Machines*, New York, John Wiley & Sons, Inc., 1951):

> "Principle of Operation: An induction motor is simply an electric transformer whose magnetic circuit is separated by an air gap into two relatively movable portions, one carrying the primary and the other the secondary winding. Alternating current supplied to the primary winding from an electric power system induces an opposing current in the

> secondary winding, when the latter is short-circuited or closed through an external impedance. Relative motion between the primary and secondary structures is produced by the electromagnetic forces corresponding to the power thus transferred across the air gap by induction. The essential feature which distinguishes the induction machine from other types of electric motors is that the secondary currents are created solely by induction, as in a transformer, instead of being supplied by a DC exciter or other external power source, as in synchronous and DC machines.
>
> "Induction motors are classified as squirrel-cage and wound-rotor motors. The secondary windings on the rotors of squirrel-cage motors are assembled from conductor bars short-circuited by end rings or are cast in place from aluminum or another conductive alloy. The secondary windings of wound-rotor motors are wound with discrete conductors with the same number of poles as the primary winding on the stator. The rotor windings are terminated on slip rings on the motor shaft. The windings can be short-circuited by brushes bearing on the slip rings, or they can be connected to resistors or solid-state converters for starting and speed control."

It shall be assumed that all rotors described in this article are squirrel-cage rotors.

The secondary currents in the rotor "created solely by induction" that Alger refers to, form magnetic poles that interact with the rotating stator field. Speed difference between the rotating magnetic field of the stator and the actual mechanical speed of the rotor is known as "slip." Transformer action (induction) occurs between stator and rotor as the rotating magnetic field of the stator sweeps past slower-moving rotor coils. Slip is always present in an induction motor. The rotor will revolve at a lower speed than the revolving field of the stator – a condition necessary to support transformer activity. When an induction motor is unloaded, just enough current is induced in the rotor to maintain torque against bearing resistance and windage. Slip is very slight and the motor runs at nearly synchronous speed. As the load is increased, slip increases causing greater transformer activity and more torque. Torque will continue to increase to match that required by the load until maximum slip is reached. When producing maximum horsepower, a motor will be running near its nameplate speed. Nameplate speed is a percentage of the "pole design speed" or synchronous speed of the motor. For example, a fully loaded four-pole, 1,725 rpm motor runs at about 96% of its 1,800 rpm synchronous speed. It is said to have 4% slip. Rated horsepower is achieved at a point near maximum slip, where the greatest sustainable magnetic interchange between stator and rotor occurs. Slip can increase up to the point of rated horsepower which is usually a small percentage of synchronous speed, beyond which stall will occur. The slip/torque characteristic of an induction motor comes very close to that of a theoretically perfect governor!

SOME INDUCTION MOTOR DIAGRAMS

Shown in Figure 1 is a circle diagram for the very common four-pole, three-phase, 1,725 rpm induction motor. Most three-phase machine tools use induction motors of this type. A three-phase circle diagram shows groups of windings as straight lines with arrowheads indicating the direction of current flow. Circle diagrams for three-phase motors are drawn with each winding group (straight line) facing in the opposite direction. The math describing *one* of the three phases is:

$$Y = \sin x$$

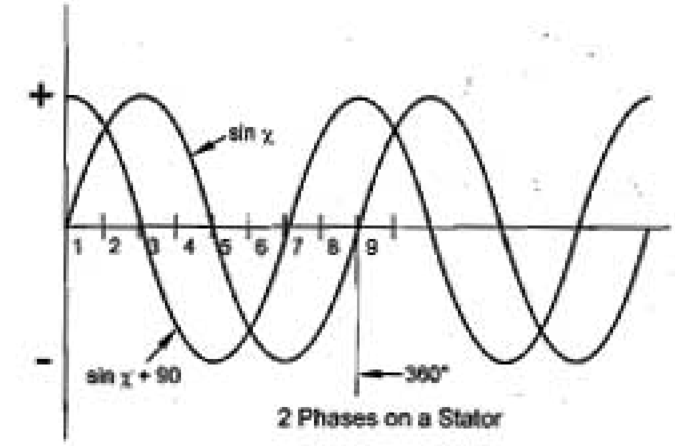
Where x is the instantaneous position of voltage, current or flux of 1 phase on the stator of an induction motor.

The math is "normalized" in these equations. That is to say, in a real system, quantities
would be multiplied by a reference standard –
say, 240 volts, etc.

When two or more phases are present (Figures 2 and 3), they combine in the stator resulting in a magnetizing wave of flux applied across the air gap and rotor. The math for three-phases is:

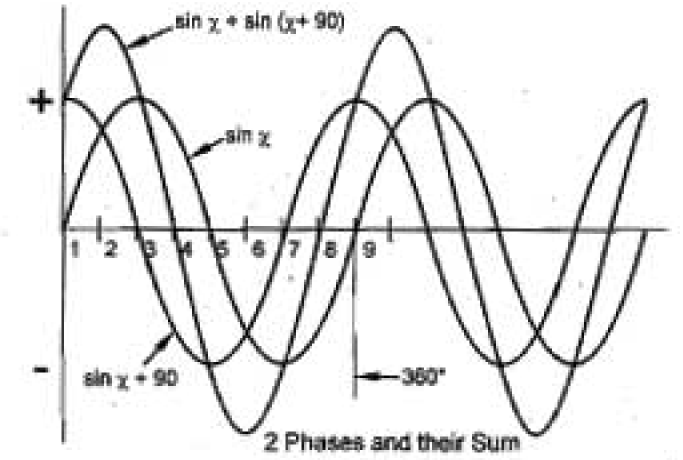
$$R_3 = \sin x + \sin (x + 120) + \sin (x + 240 - 180)$$

Where R is the "resultant" or combination.



2 Phases on a Stator

Figure 4



2 Phases and their Sum

Figure 5

Note the term sin (x + 240 – 180) accounts for a reversal in the winding sense of the middle set of three phases. In a three-phase motor the phases are separated by 60 electrical degrees, whereas the mechanical or winding separation (phase-to-phase spacing) is 120°. The graph of the equation above shows the resultant effectively moves around the stator. The three separate phases "stand still" in time, or oscillate in place, while their sum or resultant appears to move around the stator.

Two-phase power (Figures 4 and 5) is obsolete in most of the world today. However, "two-phase" will be discussed here because it is used in practice to start most single-phase motors. First, consider the circle diagram as drawn for two-phase motors. A two-phase circle diagram shows straight lines in alternating groups of two, pointing in the same direction. Phases are separated by 90° in a two-phase motor.

The resultant or combined waveform from two phases is described mathematically as:

$$R_2 = \sin x + \sin (x + 90)$$

Again, the two phases appear to stand still, or oscillate in place, while their resultant moves around the stator just as in the three-phase case above.

Figure 6 shows the circle diagram of a single-phase, four-pole induction motor. Note the "extra" winding that is displaced 90° from the main winding. This is the auxiliary, or start winding, which is momentarily connected during start time. Start windings are necessary in single-phase motors for reasons that will be shown later. Single-phase motors require special means to start them – poly-phase motors are self-starting.

STARTING

Consider any induction motor at the moment of starting. The rotor of an induction motor has to do two things: 1) receive an induced current through

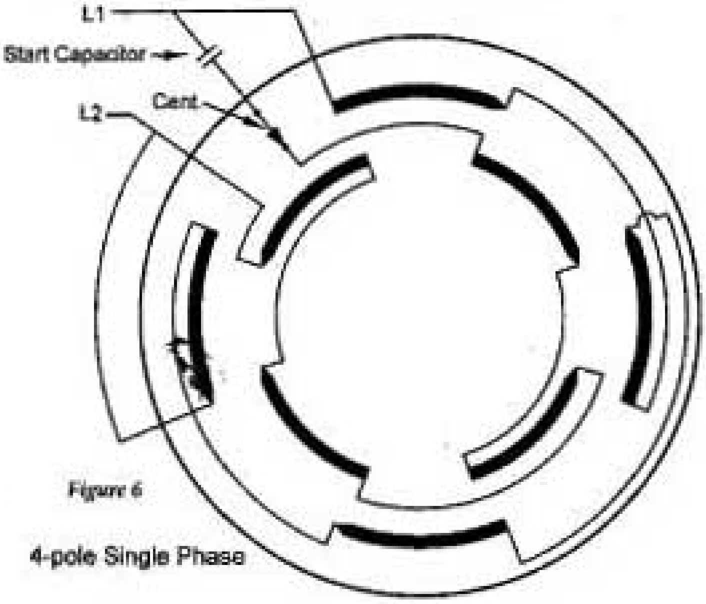
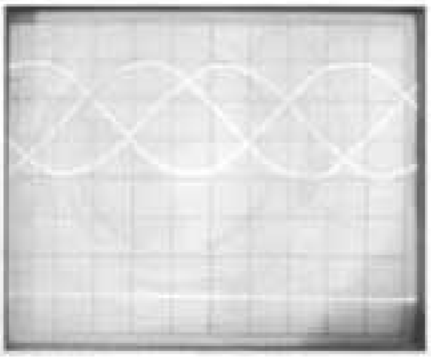


Figure 6

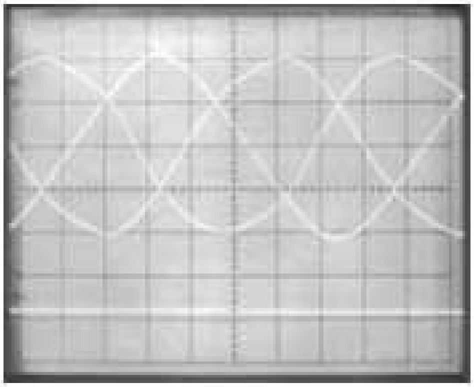
4-pole Single Phase

transformer action, and 2) use this current and resulting magnetism to make torque. Looking at these events individually, they are:

1) The first diagram (Figure 7) looks at a single coil in the rotor. Flux from a pair of poles on the stator is being forced through the rotor. At the instant of starting, flux cuts through the rotor from the N stator pole to the S stator pole. The magnetic field of the stator and flux have just begun to rotate in a clockwise (CW) direction while the rotor is stationary. Although stationary, the rotor can be considered to be moving counterclockwise (CCW) relative to the rotating flux. Generator theory (Fleming's right-hand rule) says that if the rotor moves CCW, current will be generated (induced) to flow in the direction indicated. In the diagram a point means current flows out of the page toward the observer and an arrow means current flows into the page away from the observer. Rotor current results from transformer action (induction) across the air gap. From a transformer perspective, there are very few coils on the rotor compared to many coils, or turns, on the stator, therefore the stator/rotor configuration represents a step-down transformer.



Oscilloscope showing commercial 240 volt, three-phase power.



Oscilloscope showing 240-volt, three-phase power output from the author's 7-1/2 hp rotary phase converter.

2) The next diagram (Figure 8) explains why the rotor moves, and in what direction it will go. This is in accordance with Fleming's left-hand rule for motor action. Stator flux is "flowing" through the rotor from North to South and heavy rotor current (by way of the step-down transformer effect) is circulating in the closed-coil conductors of the rotor. Note the direction of current flow designated by the arrow symbols. Under the conditions shown for flux and current flow, Fleming's rule says a conductor carrying current will be moved in the direction shown. Thus, conductors above the center shaft of the rotor will move to the right and those below the center shaft will move to the left, imparting a CW rotation to the rotor. Note the rotor turns in the same direction as the rotating flux from the stator. This is why we speak of the rotor as being pulled around by the rotating magnetic field of the stator.

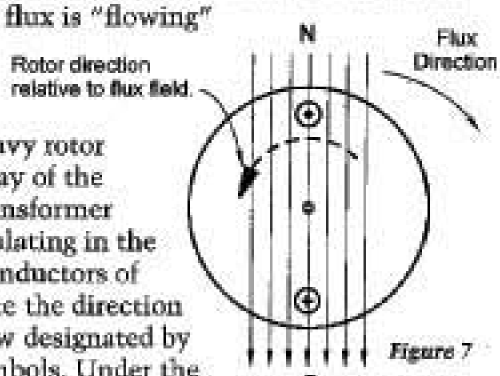


Figure 7

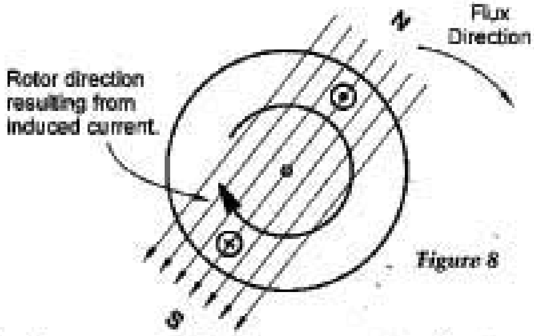


Figure 8

In order for a rotor to develop magnetic poles it must have current flowing in it. This is addressed in 1) above. Flux from a rotating magnetic field cuts across rotor conductors and induces current flow in the conductors. Then, in 2), the induced current is flowing in a conductor suspended in a rotating flux field. Torque is produced as magnetic poles formed on the rotor react against rotating magnetic poles on the stator. The rotor conductors move in a specific direction in accordance with Fleming's left-hand rule. The rotor will continue to follow the rotating magnetic field of the stator, but its speed will always lag behind that of the stator field. The speed difference is slip. Slip is necessary in order for transformer action (induction) to occur as depicted in Figure 7 above. If the rotor and stator were to run at the same speed, no flux would cut the rotor coils. Accordingly, there could be no current induced in the rotor and, hence, no torque.

FOOTNOTE:

Fleming's Rules (also called the right-hand generator rule or the left-hand motor rule): If the thumb and the first and second fingers are extended at right angles to one another, with the thumb representing the direction of the wire motion, the first finger representing the direction of magnetic lines of force (from the north pole to the south pole), and the second finger representing the direction of the current, then the right hand will give the correct relationships for a conductor in the armature of a generator, and the left hand will give the correct relationships for a conductor in the armature (rotor) of a motor. This rule applies to the so-called conventional current flow, which is the opposite of electron flow.

It is a well-known fact that a three-phase motor will continue to run after "losing a phase." In Figure 9, we see a three-phase motor with an open connection in one of the input lines. Effectively, the break deactivates two of the phases, leaving only the single "B - C" phase connected. Now, rather than rotating, the stator field (and flux) pulses only 180° back and forth between poles. Only if the rotor is already turning will it "cut" the pulsating lines of flux and develop torque in accordance with Fleming's Rules. For motor action to occur, either the flux field or the rotor must revolve. In a single-phase motor, rather than rotating, the stator field jumps back-and-forth between opposite poles and merely passes by the stationary rotor coils. There is no relative (transverse) movement as described in 1), 2) and Fleming's Rules above, and no torque is imparted to the rotor. Thus, an induction motor cannot start with single-phase current applied to its stator. The same is true with any induction motor, no matter whether it is designed for single-phase or poly-phase operation.

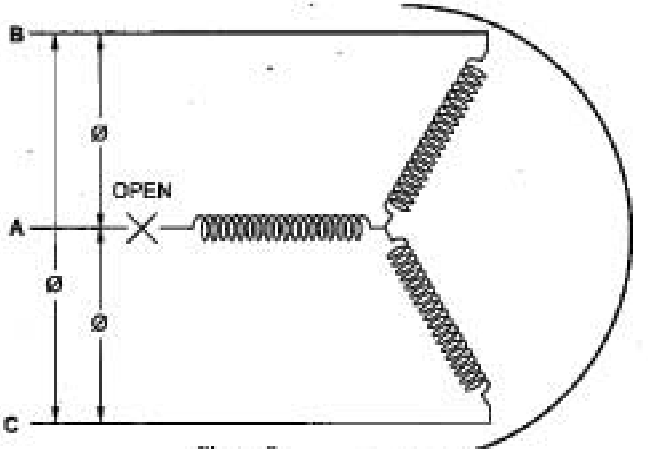


Figure 9

SINGLE PHASE STARTING

Single-phase induction motors have an auxiliary winding for starting purposes. In practice, single-phase motors are temporarily configured as two-phase machines for starting. The auxiliary (or start) winding is spaced 90° away from the main winding much like the windings in a two-phase motor. Together, the start winding and main winding behave the same as if they were in a two-phase machine. The "resultant" rotating flux field cuts across stationary rotor coils to provide starting torque. The motor starts as a two-phase machine. After coming up to speed, the start winding is disconnected and the rotor continues to turn in the pulsing single-phase field as described above. Single-phase motors under 10 horsepower usually have a centrifugal switch that connects and disconnects the start winding.

STATIC PHASE CONVERTERS

As has been shown above, three-phase motors can run on single-phase power if they are started by other means. A static phase converter is merely a device for starting three-phase motors on single-phase power. Basically, a static phase converter momentarily configures a three-phase motor as a two-phase motor for starting purposes. After coming up to speed, the start circuitry drops out and the motor continues to run "single-phase." Static phase converters offer the convenience of automatic operation, disconnecting the start circuit after the load motor reaches operating speed.

Figure 10 shows a static phase converter suitable for starting 240-volt motors up to 7-1/2 horsepower. Actually, the one shown is "heavy duty" and probably good for starting motors up to 10 horsepower. However, I have tested it only on my 7-1/2 horsepower motor. The parts are easily obtainable from motor repair outlets and industrial suppliers such as Grainger. The static phase converter shown can be built for around $50 with all new parts – much less if you use surplus. Use the heavy-duty 50 amp potential relay shown or Grainger's stock number 6X550 rated at 35 amps. A good rule-of-thumb for start capacitance in 240-volt motors is 70 to 100 microfarads per horsepower of load motor.

Bill of Materials 65

Potential Relay, STEVECO No. 90-~~69~~, 50 amp or Grainger type 6X550, 35 amps

120-volt relay, Grainger item No. 3A353, or equivalent 4PST relay (strap pole terminals together)

Electrolytic Motor Start Capacitors, (2) Grainger type 4X662 or equivalent 270 microfarad, 250 ~~330~~-volt AC, motor-start capacitors

Neon lamp assembly, 125-volt, start interval pilot (or substitute small 125-volt incandescent lamp) 500 ohm, 10-watt resistor

Optional (not shown) 120-volt, 7-1/2 watt "night light" and 2,000-ohm, 10-watt resistor in series for idler motor "on" pilot, connected between A and C of the motor.

HOW IT WORKS

It is important that the converter be permanently connected across the single-phase 240-volt supply. Only a trickle of quiescent current will flow, limited by the series combination of a 15K-ohm resistor and potential relay coil of around 10K ohms. When the motor is switched on, there are two current paths – one through the A and C windings and the other through the A and B (third leg) windings. Because of phase differences between the windings, the third leg behaves as a start winding, making the motor "think" it is a two-phase machine. A large starting current will surge through the potential relay contacts and the start capacitors. Voltage between "B" and "C" will rise to eventually cause the 120-volt relay contacts to close. (Note, "eventually" is on the order of 1 second or less!) During the "start time" just described, the 125-volt neon pilot light will be "on." Open the switch immediately if the pilot light stays on for more than *two* seconds – something is wrong!

When the 120-volt relay closes, shorting out the 15K resistor, the potential relay will energize, opening its contacts as the coil potential ("A" to "B" voltage) reaches approximately 170 volts. Start capacitance is removed by the open contacts and the motor continues to run on single-phase power across "A" and "C." When the start circuit opens, the 120-volt relay will fall back to its normally open condition, re-inserting the 15K-ohm resistor. Now, normal voltage between "A" and "B" is enough to hold the potential relay open even with the 15K-ohm resistor in the circuit.

The "running" condition will be: Potential relay energized (contacts open); 120-volt relay de-energized (contacts open) keeping the 15K-ohm resistor in circuit.

The "non-running" or stand-by condition is: Both relays de-energized.

Static phase converters are suitable for starting and running most machines used in the home shop. Inasmuch as the machine motor will be running "single-phase" on two of its three windings, it can be expected to produce about 2/3 of rated horsepower. That is enough power for most cases. I don't want to stand too close to anyone making two horsepower cuts on a three horsepower lathe! Obviously, it might not be wise to run a three-phase CNC machine on a static phase converter with its sagging third leg voltage. But, in general, static converters allow for an easy and economical way to operate three-phase machines on ordinary single-phase power. In the author's opinion, the best use for a static phase converter is for starting and running your own rotary phase converter!

ROTARY PHASE CONVERTERS

Now, we finally come to the topic of this article! Even if you aren't very interested in induction motors by themselves, don't go too lightly over the basic motor theory presented in the beginning of the article. A firm grasp of what is really going on will make you the proud superintendent of your own power plant! Besides, a firm understanding of theory will come in handy for troubleshooting any problems that may arise.

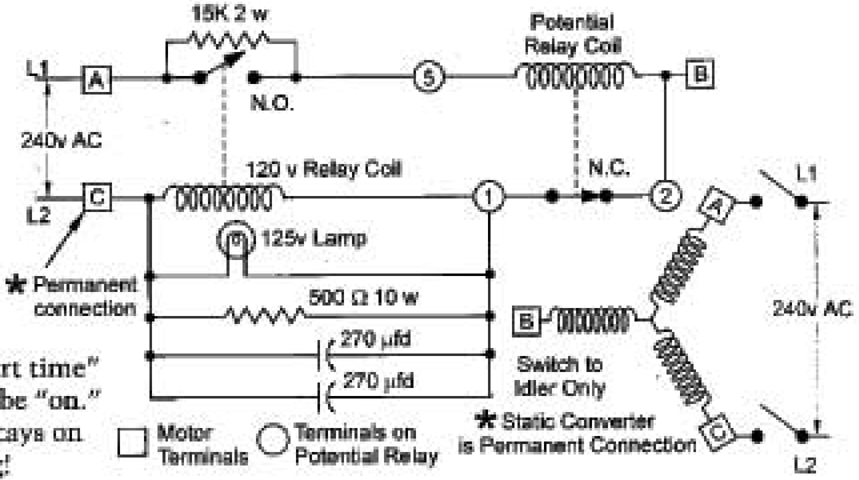


Figure 10

STARTING THE ROTARY PHASE CONVERTER

Any of the rotary phase converters described here can be started with a static phase converter or with a simple push-button control panel (Figure 11). Start-stop panels are easy to find on the surplus market because they are used with many types of machines. Be sure to get one that is rated for the horsepower of your phase converter. Switches shown in the diagram have 240-volt magnetic contactors. The same switching arrangement is also available in manually operated versions.

OPERATION OF THE START/STOP CONTROL PANEL

Pushing the start switch causes both the start and run contactors to close. Line 1 and Line 2 (240 volts) are switched on to terminals A and C of the idler. Simultaneously, the combined start and run capacitance is placed in series with the third leg (B) allowing a heavy start current to flow in that leg. The idler motor will start as a two-phase machine. After coming up to speed, in approximately one second, the start button is released, thus dropping out the start contactor and removing the start capacitors. Only the run capacitors are left in circuit. Normally-closed contacts on the stop switch apply 240 volts to the coil of the run contactor, holding it "on." The idler motor will continue to run "single-phase" until the stop switch is pushed. Pushing the stop switch opens the run contacts, thus removing power from terminals A and C of the idler motor.

IDLER MOTORS

A key point, covered earlier, is that a static phase converter provides a means to start and run three-phase motors on single-phase power. And so it is with an idler-motor phase converter – the idler must be started by external means. Idlers can be started by pulling a rope wound around its shaft or by a pony motor, but such inelegant methods won't be considered here. Please note, in the following diagrams of rotary converters, the "starting method" is indicated only as a block.

IDLER MOTOR ROTARY PHASE CONVERTER, TYPE 1

Three-phase motors (Figure 12) are rotating masses of copper and iron – call them transformers. Current through transformers in parallel is shared or circulated

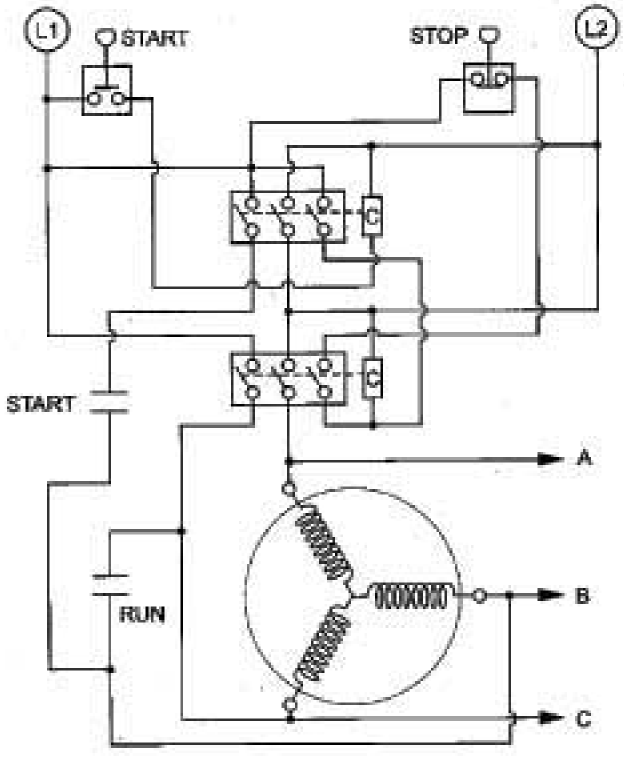


Figure 11

through like elements (windings) of each transformer. Induction motors are transformers, and each motor in a parallel group of motors acts as both a current consumer and a current generator via shared transformer activity. Because the third leg is fed by transformer action and not directly driven by input power, the voltage (and power) developed in that leg will "sag down" below what it would be in a three-phase system. Now, if one motor in the group has no mechanical load and is considerably larger than the others, it will provide a measure of "extra" circulating current to the group. *This is an idler motor.* With no torque demand on the third leg of the idler, its current is free to circulate through the other motors, complementing their transformer action. The ability of the idler to hold up third-leg voltages in the rest of the group is proportional to the size ratio. The original phase converter was a large three-phase motor connected in parallel with load motors (see Figure 12). For good regulation (less third leg "sag"), the idler motor has to be several times larger than the load. Before the development of oil-filled capacitors in the 1930s, most rotary phase converters were large idlers as described here.

BASIC ROTARY PHASE CONVERTER WITH RUN CAPACITANCE, TYPE 2

Probably, the basic capacitor-compensated rotary phase converter (Figure 13) is the type found most often in the home shop. Capacitance added to the third leg "tunes out" inductance and forms a better path for mutual current flow. It can be thought of as a phase shift network – which it is. But remember, phase relationships are determined by the physical location of windings on the stator. Run capacitors are continuous-duty, oil-filled types that must be rated for at least 370 volts for use with 240-volt motors. Oil-filled capacitors are used extensively in the commercial motor trade and are frequently available on the salvage market at considerable savings. As with all rotary phase converters, horsepower of the idler motor should be at least twice that of the load. Note the use of a static phase converter for starting purposes. The only caution is that the static phase converter and run capacitors should be connected to the same side of the input power line. This arrangement gives an extra starting boost by placing the start and run capacitors in parallel (see Figure 13). When sufficient capacitance is connected from one side of a single-phase line to the third leg of a three-phase motor, current will flow in the third leg in much the same fashion as would be obtained if the motor were running on three-phase power. The rule-of-thumb is *30 microfarads of capacitance per horsepower of idler motor*. Actually, a proper amount of capacitance will overcompensate the motor when it is "idling." Then, when the parallel load is switched on, third-leg voltage will drop to near line voltage.

VOLTMETER ADJUSTMENT OF THE BASIC ROTARY PHASE CONVERTER

Start with 30 microfarads per horsepower and use a voltmeter to measure the voltage between the third leg and one side of the line. Adjust capacitance in small increments of, say, 10-12 microfarads until you obtain approximately line voltage plus 8 or 10%. Excessive voltage will cause the idler motor to run hot as well as put extra strain on its insulation. As a final check, measure the third-leg voltage with the load motor turned on. The third-leg voltage now should be about the same as line voltage. Ideally, when loaded, the third-leg voltage will sag down to near line voltage or slightly below. The amount of "sag," or regulation, is a function of the relative size of idler to load motor. Comparatively larger idler motors provide better regulation.

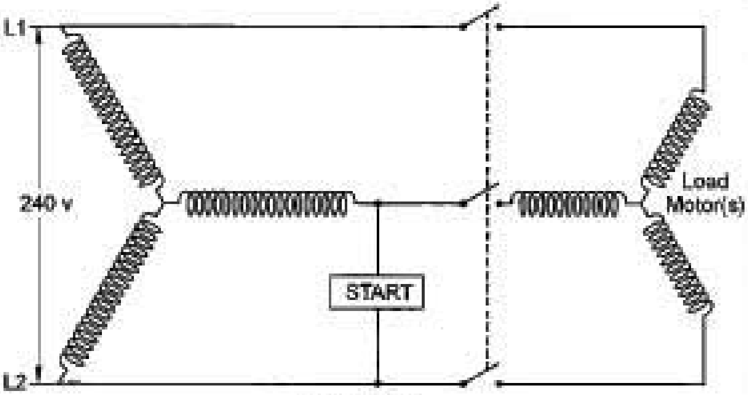


Figure 12

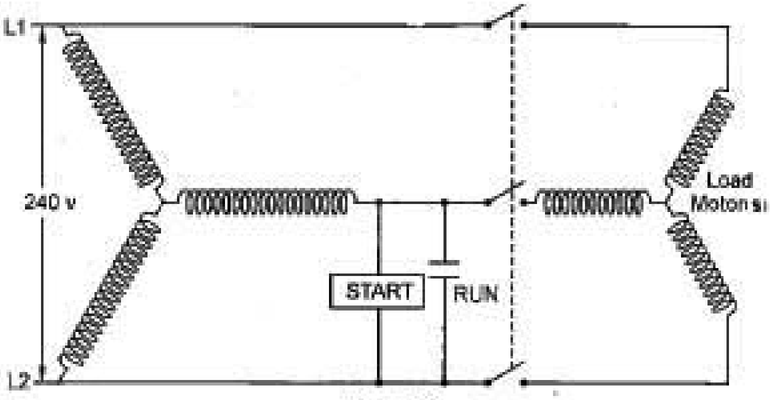


Figure 13

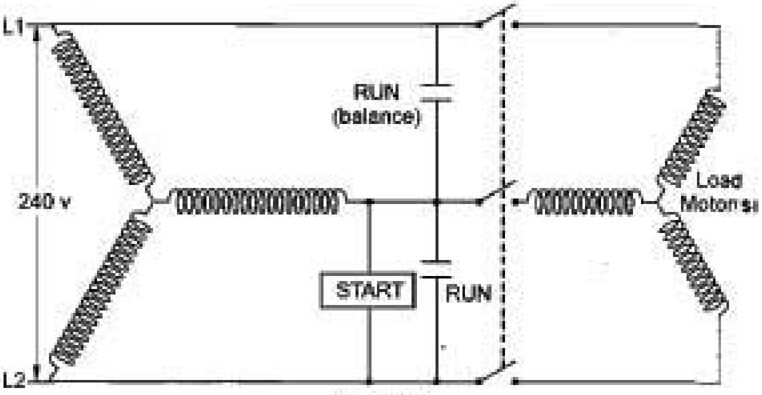


Figure 14

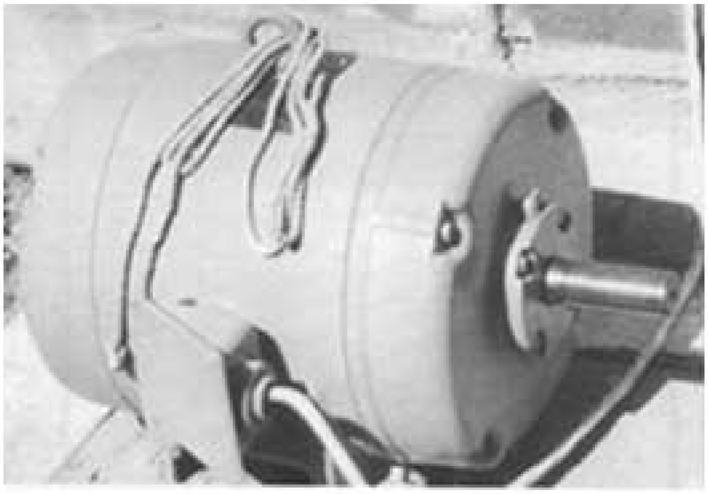
BALANCED VOLTAGE ROTARY PHASE CONVERTER, TYPE 3

Voltage "balancing" of a capacitor-compensated rotary phase converter (Figure 14) offers a way to achieve almost exactly the same voltage on all three phases. Having equal voltage on each phase and thus the same voltage waveform is a good idea when powering CNC or other voltage-sensitive equipment. Careful voltmeter measurements and some extra capacitance can result in a nicely balanced rotary phase converter.

Outdoor housing for the idler motor of the author's rotary phase converter.

VOLTMETER ADJUSTMENT OF THE BALANCED VOLTAGE ROTARY PHASE CONVERTER

More capacitance is required than with the basic rotary phase converter. Start with the usual 30 microfarads per horsepower of idler motor and place about 60% of the capacitance in the B-C leg and 40% in the A-B leg (see Figure 14). Measure the line voltage and the B-C and A-B leg voltages. The two leg voltages will be lower than the line voltage. Add capacitance in small increments of, say 10, microfarads – to each leg – one after the other – and record the leg voltages at each step. Continue adjusting capacitance until the voltage in each leg is 8 to 10% greater than the line voltage. Then, as with the basic converter, when the load motor is switched on, the two leg voltages will sag down to approximately equal the line voltage.



Idler motor shown with the housing removed. The rope is another way to start phase converters on single-phase power!

ADJUSTMENT WITH THE LOAD MOTOR IN CIRCUIT

The balanced rotary phase converter can be precisely adjusted for a specific load as follows. Perform the balancing adjustment in steps, as above, with the normal machine load connected. This time, bring each of the two leg voltages up to equal the line voltage. This method will assure all three "phases" are equal when supplying power to one specific load.

AMPROBE ADJUSTMENT FOR THE FINAL TOUCH (OPTIONAL)

Although only voltage measurements have been specified so far, the final step in adjusting the balanced converter is done with an amprobe, or "clamp-on," type ammeter. The simulation of three phases from a single-phase source involves very complex current flow, indeed. The power factor, or phase relationship of the input current and voltage in a rotary converter, is affected by the methods used to achieve "voltage balance." The input power line to a balanced converter will "see" excessive inductance causing heavier current to flow than if the power factor was "unity." The power factor can be corrected by adding some capacitance to the 240-volt input line, between L1 and L2. Figure 10% of the total capacitance used in the converter and put that amount across the input line. Measure the input current with an amprobe meter clamped on either L1 or L2 and adjust the capacitance in small increments until the line current is *minimum*. The input current should become a minimum when about 12 to 15% of total capacitance is added.

Input power factor correction is not critical to the operation of a small home-type phase converter and can be eliminated altogether with no ill effects.

In closing, consider the complex current flow necessary in order to convert single-phase current into three-phase current. Figure 15 is an equivalent circuit diagram of a paralleled idler and load in which the legs are viewed as both consumers and generators. This has to be true in order to achieve the convoluted currents necessary for phase conversion. Solid lines show aggregate current flow; "bucking" current is shown by dotted lines. Bucking currents, which don't contribute to torque, represent an amount of uncompensated inductance. The effect of that inductance is "reflected" to the input and appears similar to a coil connected across the terminals (Figure 16). It is this "ghost" inductance that upsets the input power factor. Sufficient capacitance added in parallel with the reflected inductance tunes the input power factor to near unity.

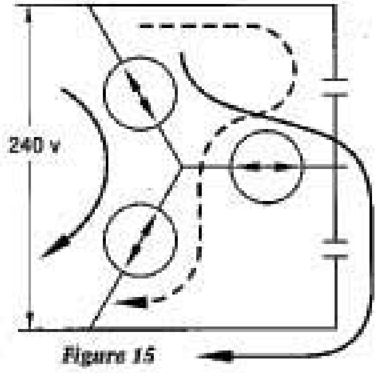


Figure 15

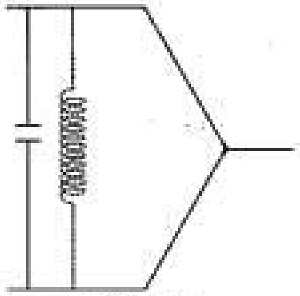


Figure 16