

# Phase Converters

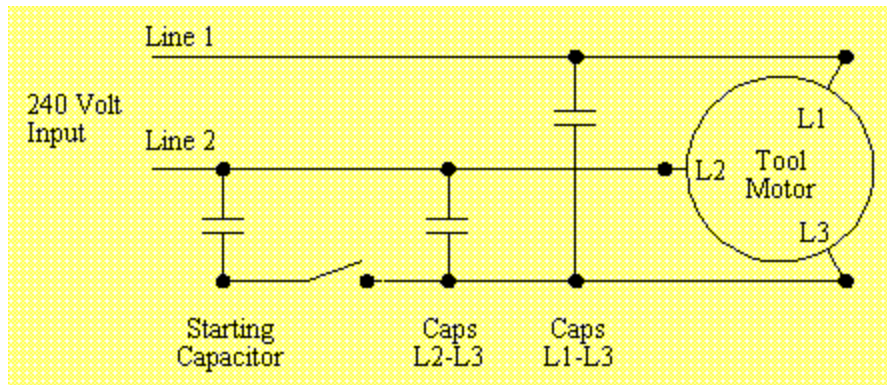
By Rick Christopherson

Sometimes a woodworker will find himself with a 3-phase tool, but his shop only supplies single phase, 240 volt power. 3-phase motors are common for industrial grade tools, as their efficiency is higher than their single phase counterparts. In order to operate a 3-phase motor on single phase power, we need to make an artificial three phase system. This is accomplished by using a phase converter.

The phase converter will artificially generate the third leg of a three phase system from the two poles of a single phase system. This is not a perfect transformation, but it does get the job done. There are two types of phase converters: the *static phase converter*, and the *rotary phase converter*. The rotary phase converter is built using a static phase converter, plus an idler motor.

## Balanced Static Phase Converter

The static phase converter is the basic building block for any phase converter, and so it makes sense to start with that. With the static phase converter, the motor will only receive about 80% of its normal operating power. Additionally, you need a separate static phase converter for each three phase motor. These are the primary drawbacks to the static phase converter. However, the static phase converter is very simple to build. This loss of power is balanced by the lower cost of the static phase converter. The significant cost savings is why static converters are so popular.

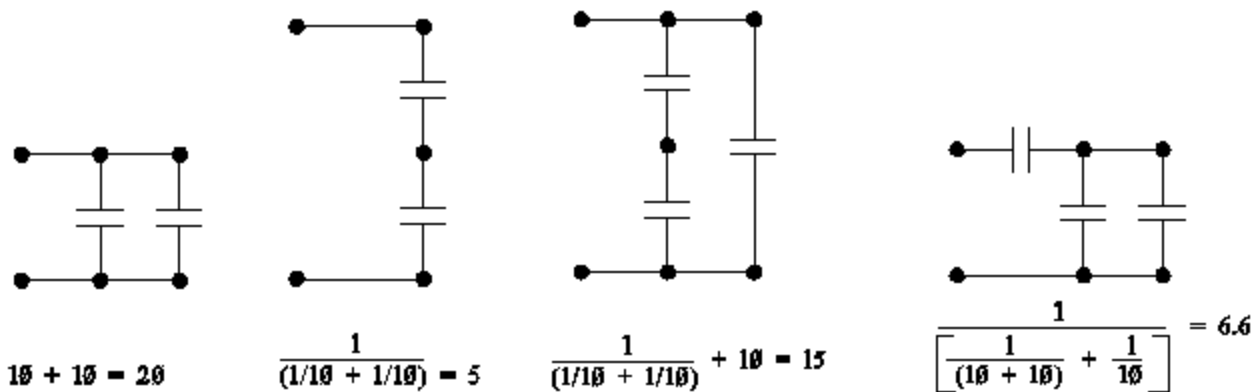


The drawing above shows a balanced static phase converter with a starting circuit. The starting circuit provides enough current to the motor to get it started, but then must be disconnected to prevent too much current from flowing through the motor after it starts. There are more rudimentary phase converters, but this design provides better performance with lower running currents.

## Getting Started

The first step is to select the capacitor sizes that will be needed. This is generally just trial and error, as the capacitor sizes will depend on the motor. I went to an electronic surplus store and located several capacitors for a couple of dollars each. These capacitors should be rated for at least 250 volts AC. For my 1 Hp lathe, I ended up using a 5 uF (microfarad) cap between L1&L3, and a 12.5 uF cap between L2&L3, and about 80 uF for the starting capacitor. These numbers should be a good starting point, in that their ratio should remain similar for larger motors. For my 5 Hp rotary converter, these numbers are 25 uF for L1&L3 and 50 uF for L2&L3, which is approximately 5 times larger than those for the 1 Hp converter.

At the surplus store, I located capacitors ranging from 1, 3, 5, 10, 12.5, 15, and 20 microfarads in the 250 volt range. What you will want to do, is get several capacitors of different sizes so you can fine tune the converter. Keep in mind that you can make a capacitor smaller or larger by combining it with other capacitors. Two capacitors connected in parallel will add to each other, and two capacitors in series will "get smaller".



Explaining how we add capacitors together is a little complex, so I am hoping that most of this can be understood by example. From the lefthand circuit in drawing above, two 10 uF caps in parallel will total 20 uF. We just **add** their values together. In the next circuit, we have two capacitors in series. Two 10 uF caps in series will total 5 uF. For series connections, we add their **reciprocal** values, and then take the reciprocal of that. For combination **series/parallel** circuits, we look at the circuit as two separate problems. In the next sample, we have two caps in series giving us 5 uF as before, which is then in parallel with another cap, so the total is 15 uF. In the last sample, we have two caps in parallel giving us 20 uF, which is then in series with another, and the result is 6.6 uF. Using these various combinations, we can get nearly any size capacitor we want. I used 10 uF capacitors for this example, but they don't need to be the same size. Take the third sample as an example: this would be the same as a parallel combination of a 5 uF and a 10 uF.

I have to admit, that when I bought capacitors for the lathe, I was way off the first time. I picked up a bunch of 20 uF caps, but these were too large. Because I bought enough of these to build converters for two lathes, I had enough of them to make some complex combinations during the initial sizing. After I found out the final sizes, I went back to the store and picked up smaller capacitors for the final assembly. If you think about it, even making a mistake in your initial purchase is still cheaper than buying a store bought phase converter.

### Initial Setup

To start out with, I would set up the converter using the numbers provided above. For a 1 Hp converter, I would use 5 & 12 uF caps between the lines, and whatever capacitors are left over are used for the starting circuit. If the 5 and 12 aren't available, use whatever is close for now. For the initial capacitor sizing, the following rule should be helpful:

$$\begin{aligned}
 C_{L1-L3} &= 4 \text{ to } 5 \text{ times the motor horsepower} \\
 C_{L2-L3} &= 10 \text{ to } 15 \text{ times the motor horsepower} \\
 C_{\text{starter}} &= 40 \text{ to } 100 \text{ microfarads just for testing}
 \end{aligned}$$

For testing purposes, I used a standard light switch to control the starting capacitors. For some of the configurations, I did not have enough capacitors left over to provide a sufficient starter. For these situations, I used a pull-cord (like starting a lawnmower) to get the motor started.

After you have the initial setup, it is time to turn the motor on. Close the switch for the starting circuit, and press the start switch. If the motor takes more than 2 seconds to get up to full speed, shut it down immediately. You can either add another capacitor to the starting circuit, or try using a pull string. If your motor turns backwards, then just reverse the wires on your motor. (At the motor, take any two of the three wires and swap them.) Once the motor is up and running, it is time to fine tune the capacitors.

### Tuning the Capacitors

To fine tune your capacitors, you need to check the voltages between each phase of the motor. The 3 phases

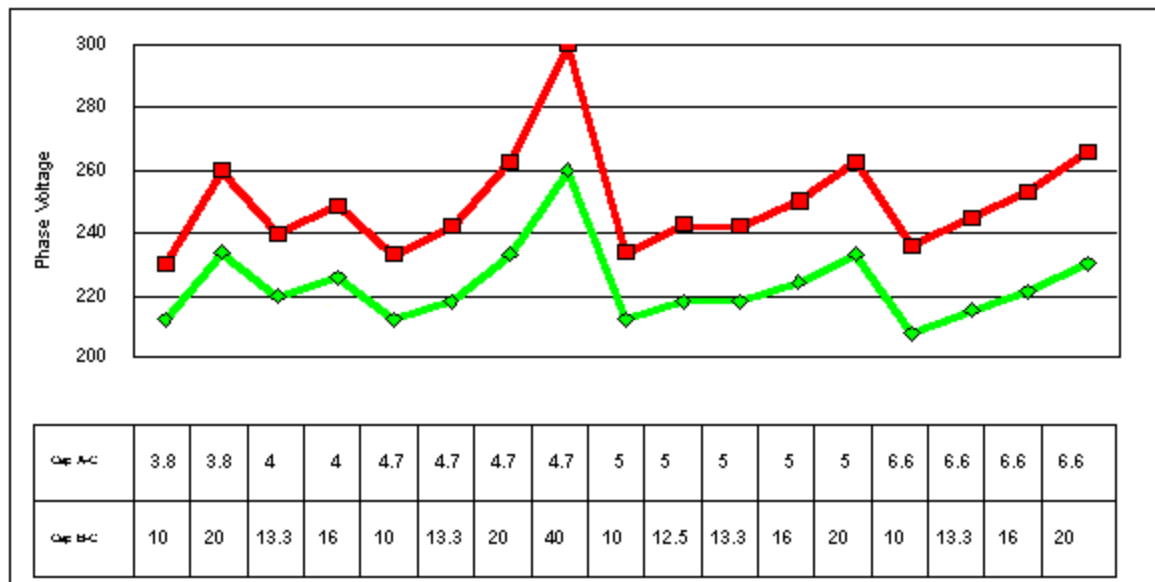
used by the motor are A-B-C, or also referred to L1-L2-L3. To check the phase voltage, place each probe from a voltmeter on the respective phase. Phase A-B (Phase A to B) will be 240 volts, which is the line voltage of your house. One of the phases will be low, and the other will be high. You will need to adjust the capacitors until these voltages get close to being balanced out. If you find one of these voltages extremely high, turn the motor off immediately. There are some configurations where one phase's voltage can exceed 350 volts. This will put high currents through the motor, and that is not good. Forgetting to turn your start circuit off is one example of this.

To determine the best configuration of a phase converter, I have found it best to create a data table and write down the various values. I first vary one capacitor's size larger and smaller from the initial configuration. Then I vary the other capacitor. You should be aware that when you connect a new capacitor to one which was just powered, there will probably be some sparks as one capacitor charges up the other. This is disconcerting, but it is normal. Make sure you turn off the power before rearranging the capacitors.

The data table below is from my lathe. This isn't the order I collected the data points in. Instead, I sorted the data in this table based on the capacitor size between (A) and (C), so that the information is more presentable. Unfortunately, I had tried a couple of larger combinations before I started writing down the results, so these are missing. All I can remember about these first trials was that I started with 20  $\mu\text{F}$  and 40  $\mu\text{F}$ , but the voltages were so far out of line, that I quickly realized I needed to use much smaller values.

A-C Caps ( $\mu\text{F}$ )	B-C Caps ( $\mu\text{F}$ )	A-C volts	B-C volts
3.8	10	230	212
3.8	20	260	234
4	13.3	240	220
4	16	249	226
4.7	10	233	212
4.7	13.3	242	218
4.7	20	263	233
4.7	40	300	260
5	10	234	212
5	12.5	243	218
5	13.3	242	218
5	16	250	224
5	20	263	233
6.6	10	236	208
6.6	13.3	245	215
6.6	16	253	221
6.6	20	266	230

To see this data better, I have created a graph which shows the relationship between the two voltages. Graphing the data isn't necessary, nor did I use this, but it may help you see how different configurations effect the outcome.



From the data table and chart, there are a couple of configurations which work fairly well. Notice that at no time do all three phases reach 240 volts. This would be a perfect conversion. The best I could attain was 240 volts from (A) to (C) with 220 volts from (B) to (C). While I could get more power out of my motor when the voltage from (B) to (C) was closer to 240 volts, this would make the voltage from (A) to (C) much higher than 240 volts, which results in too much current flowing through that set of windings.

These are the conditions I looked at when selecting the capacitor sizes:

1. I wanted the phase voltages to be as close to being equal as possible.
2. I did not want any voltage to exceed 240 volts.
3. While still adhering to items 1 and 2, I wanted to use the least number of capacitors.

With respect to item #3, even though the motor performance was best when using 4 uF and 13.3 uF, this required 8 capacitors to achieve this combination. Since the performance when using 5 uF and 12.5 uF capacitors wasn't much different, I chose this combination. This decision was made after the testing, when I returned to the store and located 5 uF and 12.5 uF capacitors. (I want this phase converter to be small enough to fit in a junction box bolted to the inside of one of the legs.)

### Configuring the Starting Circuit

The purpose of the starting circuit is to get the motor up to speed as fast as possible. The longer it takes to get the motor up to speed, the longer high currents will be present in the motor's windings. For the most part, the larger the starting capacitor, the faster it starts. My desire is to have the motor completely up to speed within one second with the least number of capacitors. Even though using a monstrous sized capacitor would bring the motor up to speed very fast, this would also run the risk of causing damage too. To select the right size, I just keep adding more capacitors to the circuit until the motor starts quickly.

What I find to be more intriguing is the potential for the starting circuit to be automatic. My rotary phase converter has been in service for about a year now, and there have been times when I forgot to shut the starter back off. There are three methods for activating the starter circuit: a manual on/off switch, a momentary contact switch (push and hold button), and two types of fully automatic switches.

### Manual on/off Switch

The simplest method for engaging the starting circuit is the use of a standard on/off switch. This requires the operator to turn the switch on before starting the motor, and turning it off after the motor is up to speed. The drawback to this, is that it requires the operator to activate and deactivate the switch. Failure to do either of

these will result in excessively high currents in the motor.

### Momentary Pushbutton

The momentary pushbutton is better, since you can't forget to turn your start circuit off when the motor is up to speed. With this, the start circuit is only engaged for as long as you hold the switch in. The drawback, is that the switch can be released too soon, before the motor gets up to speed. This would result in high currents flowing through the motor unless the start switch was again pressed. And if the switch was not released on time, currents would again be high after the motor gets up to speed.

### Off-Delay Timer

With most switches and relays, when you tell them to turn off, they turn off. With an off-delay timer, when you tell it to turn off, it hesitates for a little bit before it turns off. This is ideal for a starting circuit, where we only need it to be active for a second or so. With an off-delay timer, we would use the momentary push button to activate the relay, and releasing the button would activate the timer.

The benefit to this setup is that you can't forget to turn the starter off, yet it will always remain active long enough to get the motor started. The drawback to this setup is almost trivial. If the timer is programmed too long, then the starter will remain active slightly after the motor is up to speed. Unless you had a method for sensing the actual speed (RPM's) of the motor, this is the most foolproof method for operating the starting circuit.

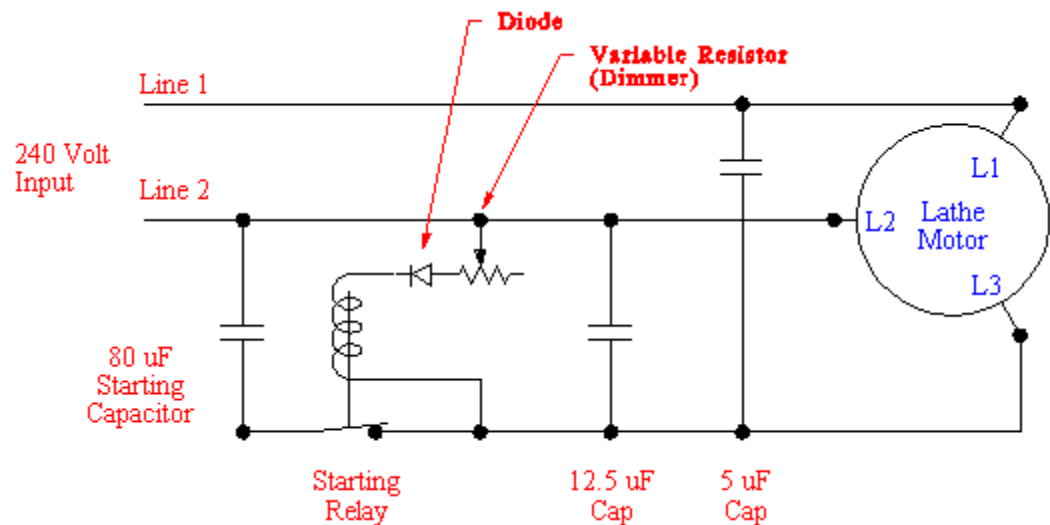
### Current or Voltage Sensing Circuit

***New Update:** Since the time this article was written, I have completed the self-starting aspect of my lathe's converter. The discussion below is a duplicate from the writeup on that project.*

How this works, is when I press the normal start button on the lathe, the starting capacitors are already engaged. As the motor comes up to speed, a relay senses the increase in the third phase voltage. As this relay becomes active, it opens a switch, which disconnects the starting capacitors. As a side effect, if I grab the hand wheel and slow the motor down, the starting circuit re-engages to bring it back up

to speed. This is what made me decide to make the unit self-starting. Before I completed the self-starting aspect of the converter, I loaded the motor just to see how much power I was getting. I slowed the motor too much, and it would not come back up to speed. I didn't want this to happen during normal use. The diagram above is the same as before, except I replaced the normal switch with a relay, and added a diode and variable resistor. A very significant benefit to this circuit is that it automatically compensates when the motor is slow to start.

After I managed to build the self-starting converter, I made a significant observation. When the lathe was set for low speed, the motor came up to speed quickly, as it's load was low. When the lathe was set at a higher speed, inertia made the lathe start slower, and it took longer to come up to full speed. This circuit compensated for the longer start-time, and remained engaged for a longer period of time. Had I used the "off-delay timer", this would not have been the case.



**Initial Concept:** While I was fine tuning the phase converter's capacitors, I noticed that the voltage from line 2 to the generated line 3 started out at 16 volts before I started the motor. As the motor came up to speed, this voltage gradually increased until it reached its final value of 220 volts. Since the voltage seemed to be related to the speed of the motor, I figured that if I could harness this variation, I could control when the starting capacitors were removed from the circuit. To do this, I needed to come up with a "voltage controlled switch".

**Relay:** The relay uses the normally closed contacts, which means that when there is no power to its coil, the contacts are touching. The relay's coil is rated for 120 volts at 60 Hz (AC power). Since I am feeding it with 240 volts (actually it is 220 volts in this case), I needed to reduce the voltage. Although I never bothered taking actual measurements, this relay would become active when the coil voltage reached about 70 volts. All I had to do was make sure that the coil's voltage reached 70 volts when the motor was near full speed.

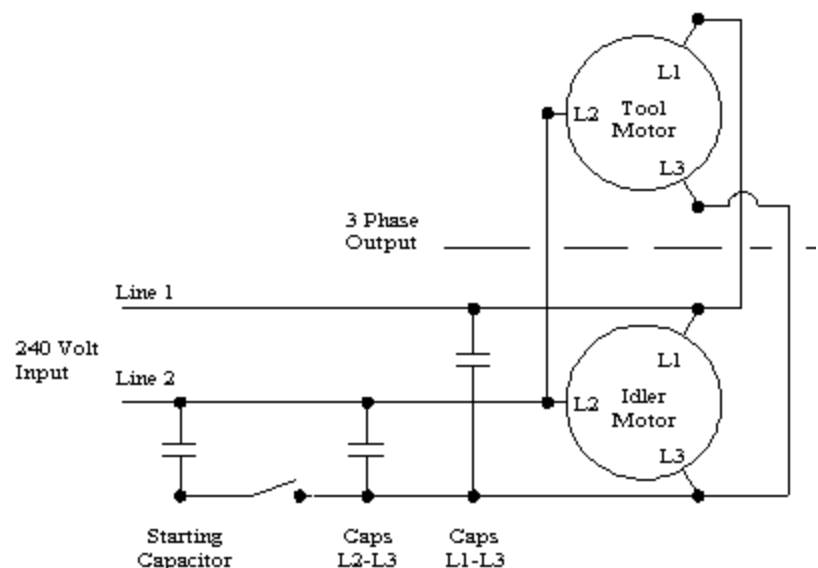
**Variable Resistor:** The variable resistor acts as a fine tuning control. Some of the circuit's voltage is expended across this resistor. By adjusting the amount of resistance in the dimmer, I control how much voltage the relay gets. I had already burned up a couple of normal variable resistors because they were not rated to handle this kind of current. It suddenly hit me that a dimmer switch for home lighting was cheap, and rated for this kind of power consumption. Since I couldn't find a common variable resistor with large power capabilities, I went to a home center and picked up a common wall dimmer.

As I adjusted the dimmer, the starter control would either turn off too soon, or not at all. By making these adjustments, I controlled how long the starter remained active with respect to the motor's speed.

**Diode:** I don't know why I needed this, but it was a necessary part nonetheless. My relay was rated to operate on AC voltage. A diode blocks part of the voltage which results in a "sloppy" DC voltage. Without this diode, the system was self-defeating. As soon as the start button was pushed, the starting capacitors resulted in a high enough voltage to activate the relay. The relay would then disengage the capacitors, but they were the cause of the higher voltage. As soon as the capacitors were disengaged, the voltage was too low to activate the relay, and the relay would re-engage the capacitors. The bottom line was that the relay would flicker on and off, but the motor would not start. I fully expected this to happen when I used a DC rated relay, but the AC rated relay shouldn't have done this. I can only surmise that it is because I cut the voltage in half by using the diode.

### The Rotary Phase Converter

With the discussion above on the static phase converter, there isn't much to explain about the rotary converter. The rotary converter is nothing more than a second motor in the circuit which is acting as a generator. With the static converter, the tool's motor performed this function, but at the cost of some loss of power. With the rotary converter, the idler motor is under no physical load, but it cleans up the signal a little. If you examine the drawing below compared to the first drawing, the only difference is that we added the idler motor.



The output of the rotary phase converter is closer to being a true 3-phase source than the static converter. This provides more power to the tool motor, and also brings it up to speed faster. The rotary converter is best served when you have a motor which is started and stopped frequently, and you need the full power of the motor. Furthermore, a single rotary converter can drive several different 3-phase tools.

Setting up the rotary converter is the same as the static converter described above. The only decision to be made

is the size of the idler motor. The idler motor needs to be larger than the largest tool which will be operated.

Since the static converter will provide a motor with 80% of it's normal operating power, and the rotary phase converter uses a static phase converter as a starter, your idler motor should be 125% of your tool(s) motor size. That is, if your tool is a 5 horsepower motor, your idler should be between 6 and 7 horsepower. It is always better to err on the high side, so I would use a 7 horsepower idler motor. If the converter will operate more than one tool, make sure the current rating of the idler motor is 125% of the sum of the tool motors.

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