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A LAYMAN'S GUIDE TO CONVERTERS & INVERTERS FOR SINGLE-PHASE SUPPLIES

Phase Conversion, Frequency Conversion and Motor Control

Phase conversion (with or without motor control) is a subject of growing interest to the user of machinery in the home workshop, particularly as the cost of inverter technology has dropped dramatically in the last 5 years.

Trying to get realistic advice as to what is available, what machine modifications are necessary and what performance can be expected is a little more difficult. This guide is designed to help you negotiate the various issues raised.

There is great confusion surrounding the differences between the two distinctly different technologies available for operating three-phase motors from a single phase supply: ***Phase Converters and Inverters.***

The traditional "analogue" ***Phase Converter*** (static or rotary) is based on the "Steinmetz" capacitor principles first applied by the American, Charles Steinmetz, in the late 19th century. The old adage "you can't get something for nothing" holds true for phase conversion like anything else. There is, always has been, and always will be an element of artificiality about the supply a phase converter produces. Despite the idiosyncrasies associated with the nature of the supply, phase converters continue to offer a proven and reliable compromise for people wishing to operate three-phase machinery in single phase environments.

- A ***Phase Converter*** varies the voltage in the conversion (240v single-phase to 415v 3-phase) but fixes the frequency (50Hz) so there is no motor control available. The supply remains a.c. throughout the conversion.
- A ***Phase Converter*** is a so-called "Linear Load". There are no electro-magnetic compatability issues (EMC). No power quality issues. No Harmonic distortion. No filters required.
- As the output from a ***Phase Converter*** is 415v, the converter retrofits directly to a machine that is wired for 415v three phase operation so no machine modification is necessary.
- The output from a ***Phase Converter*** is flexible and (within reason) can be applied to a variety of different machines whether operated one at a time or simultaneously.
- ***Phase converters*** are available to support any motor requirement, provided there is enough single phase supply available to support the three phase demand. TRANSWAVE Converters are available to 22kW/30hp. Larger ratings are accommodated by paralleling two units together.

See our ***TRANSWAVE Converters – FAQ (Frequently Asked Questions)*** sheet for further details

So an Inverter is also a Phase Converter?
Yes. "Digital" Inverters offer a 21st century approach to the dilemma of operating three phase motors from a single-phase supply. These days, most people who are aware that a device exists to operate three phase equipment from single phase tend to know about inverters and assume that the concept has superseded the traditional "analogue" static or rotary phase converter. However, the two products will always co-exist as the technologies service different market requirements.

In contrast to the "analogue" static or rotary phase converter:

- A "digital" ***Inverter*** fixes the voltage in the conversion (240v single phase to 0-240v 3-phase) and also varies the frequency (e.g. 0-400Hz) thereby offering motor control. The three phase supply at 240v is created by rectifying the ac supply to dc and inverting it back to ac (Hence the name ***Inverter***).
- The involvement of dc means that inverter supplies are defined as "Non-Linear". The input and output supply is subject to EMC regulation as the conversion process affects the a.c. single phase supply network. Current harmonics are present as a direct consequence. **RF** (**R**adio **F**requency) mains filters are generally required to ensure your contractual obligations to the electricity supply company are not compromised.
- As the output from an ***Inverter*** is 240-v 3-phase, an inverter cannot be accommodated without machine modification.
- The output from an ***Inverter*** can only be applied to one motor.
- Inverter manufacturers **do not offer product for single-phase supplies in excess of 3kW** to ensure compliance with European Power Quality Standards such as BSEN 61000-3-2:2006 and BS EN 61000-3-12:2005. For similar reasons inverter manufacturers do not offer product with an output voltage that is different to the supply voltage (e.g.: 240v input, 415v output).

Can I retrofit an inverter to my existing single phase machine?
Motor control is a three phase motor technology available for operation from both single phase and three phase electricity supplies. A single phase input inverter offers the facility to electronically vary the speed of *a three phase* motor from a single phase supply by varying the frequency of the supply to the motor. ***It is not possible to vary the speed of a single-phase a.c. motor*** so if your machine is currently single-phase you will have to change the motor.

So are all 3-phase motors compatible with the output of an inverter?
Generally, yes. Most small single speed three-phase motors are wound for operation from **either** a 380/415v **or** a 220/240v 3-phase supply. A typical "dual-voltage" motor plate will indicate a voltage rating such as **"V 220-240 Δ / V 380-415 Y"** together with two current ratings. The lower current will refer to the higher voltage, the higher current to the lower voltage.

STAR CONFIGURATION – In the "Y" or "Star" configuration, the motor will run on a three phase supply from 380v to 415v phase to phase. The "Y" sometimes appears as a three-pointed star.

DELTA CONFIGURATION – In the "Δ" or "Delta" configuration, the motor will run on a three phase supply from 220v to 240v phase to phase. The "Δ" sometimes appears as a "D"

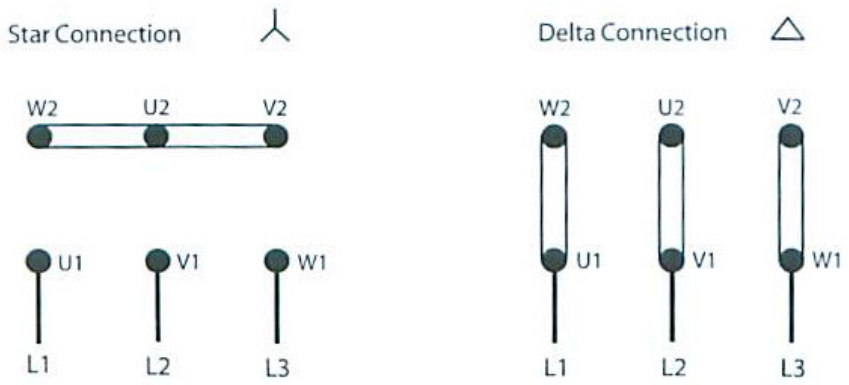
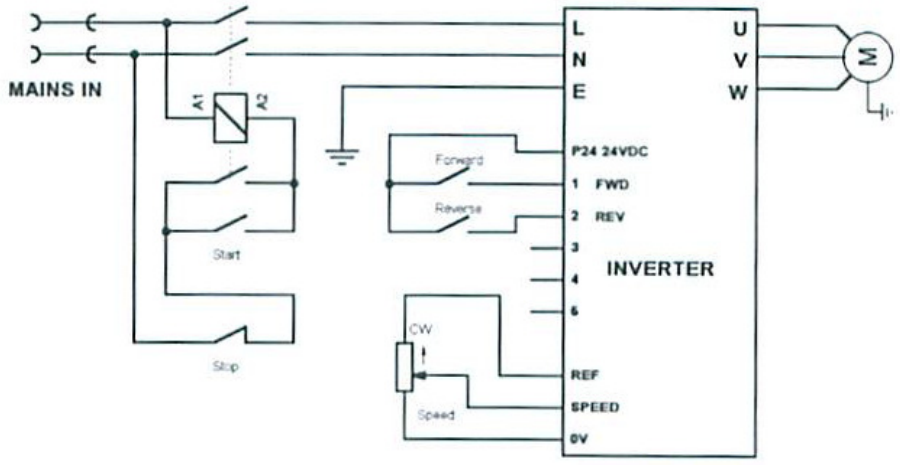


Fig. 1 above shows a typical motor terminal arrangement for the star configuration. Three terminals are linked together with a set of three brass/copper links. The other three terminals (commonly marked U1, V1 and W1) are then connected to the three phase 415v supply (L1, L2 and L3).

Fig. 2 above shows a typical motor terminal arrangement for the delta configuration. The three metal links are simply removed and rearranged. The other three terminals (U1, V1 and W1 as before) are then connected to a three phase 240v supply ***or the output of an inverter/frequency converter***.

If the motor plate does not display a 240v three phase connection facility, it may still be possible to reconfigure the voltage rating from 415v to 240v three phase. Seek advice from a local motor repair or rewind company. A pole-change three phase motor (displaying more than one synchronous speed e.g. 1400rpm/2800rpm) can only be connected for 380/415v so is usually incompatible with the output of a single phase inverter. This type of motor would have to be changed to a single speed, dual-voltage motor to facilitate us of an inverter.

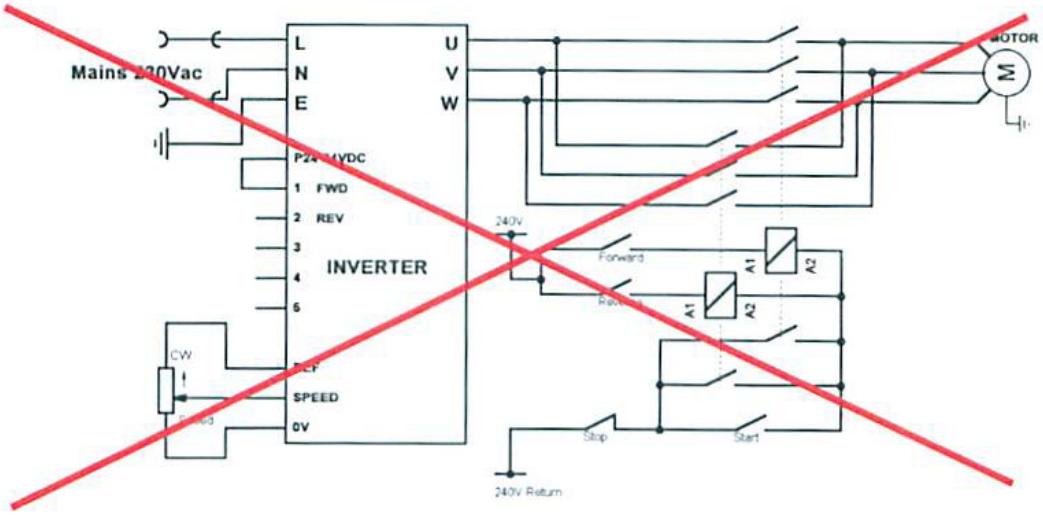
How do I connect a machine to the output of an inverter? Once an existing three phase motor has been reconfigured from 415v operation (STAR) to 240v operation (DELTA), the equipment wiring loom (start/stop/forward/reverse/feed/coolant/limit switches etc) has to be disabled and is made redundant. The reconfigured motor is connected directly to the output of the inverter and the single phase supply is connected to the input of the inverter.



Most inverters offer “local” control in the form of small buttons for start and stop, a potentiometer or up/down arrow for speed adjustment and possibly a forward-reverse facility. For some people these buttons are an acceptable means of controlling the motor; however the majority find the buttons too small and impractical.

Another option is to consider a remote control station/pendant (see image below) for a minimum additional outlay, which offers the basic control functions in an acceptable form. The pendant connects directly to the inverter control terminals and comes with a 2 metre length of cable so it can be mounted in an appropriate area of the machine. The inverter itself can then be put out of harm’s way.

The motor only must be connected directly to the inverter output so controls should not “make and break” the supply to the motor under any circumstances. Be wary of ancillary motors such as coolants and table feeds. These are likely to have to be disconnected completely and fed from an alternative source, as are lighting circuits and control transformers.



It is possible to rewire a machine wiring loom to the inverter control terminal rail so that existing switchgear/levers/limit switches etc can be used. Seek advice from a competent electrician as there is often a lot of work involved.

What performance can I expect from the motor once it has been connected to the inverter?

The speed of an induction motor is directly related to its supply frequency. The frequency from your single phase supply is fixed at 50Hz, so if the output from the inverter is set at 50Hz the motor will operate at its synchronous speed (e.g. 750-1000-1500-3000rpm). Any mechanical ratios will operate at plated mechanical speeds. Your inverter is simply acting as a phase converter under these circumstances.

The relationship between frequency and speed is linear, so if the frequency of the supply to the motor is reduced by 50% (to 25Hz) the motor speed is reduced pro-rata. So, theoretically, if your inverter offers a range of 0-200Hz, your machine can now operate between zero speed and four times motor speed!

Understandably this leads to an assumption that belt/pulley changing is a thing of the past! Unfortunately, there is a relationship between the frequency at which a motor operates and the power/torque it can deliver. Inverters come in all shapes, styles and ratings – voltage/frequency, torque-vector etc. Like most things, you get what you pay for. The more money you spend, the more performance you are likely to achieve. For small machine tool applications, inverters should be used in conjunction with, rather than as a direct replacement for, an existing mechanical variation of speed. It is better to achieve a 50rpm shaft speed from a 100rpm geared speed at 25Hz than a 250rpm geared speed at 10Hz.

Users of "entry-level" inverters, typically available for about £100 plus VAT, are recommended to pre-set the frequency window between 20Hz and 75Hz to ensure that the level of torque available is acceptable. So-called vector inverters enhance the torque performance at low frequencies compared to traditional voltage-to-frequency inverters.

At particularly low frequencies, it may be necessary to consider the implications of secondary motor cooling since the fan built into the motor could lose its ability to cool the motor effectively. The frequency window outlined above typically eliminates this requirement. At higher frequencies than 50Hz, it is in the user's interest to check that the integrity of the driven motor/ machine will not be compromised at the higher speeds involved.

Added benefits of using an inverter are a soft-start in the form of a controlled acceleration over a time determined by the machine-user. Similarly, there is a controlled deceleration option, dc braking and "reverse-on-the-fly", a particularly useful feature when tapping or screw-cutting. Once you have programmed the software parameters to meet your requirements, the parameters do not need to be changed again.

So will the inverter be affected by swarf, coolant splash or dust?

There is an international classification system for the sealing effectiveness of enclosures of electrical equipment against "foreign bodies" (i.e. tools, dust, fingers) and moisture. The classification system uses the letters IP (Ingress Protection) followed by two or three digits.

Degrees of Protection - First Digit

The first digit of the IP code indicates the degree that persons are protected against contact with moving parts (other than smooth rotating shafts, etc.) and the degree that equipment is protected against solid foreign bodies intruding into an enclosure.

0	No special protection
1	Protection from a large part of the body such as a hand (but no protection from deliberate access); from solid objects greater than 50mm in diameter.
2	Protection against fingers or other object not greater than 80mm in length and 12mm in diameter.
3	Protection from entry by tools, wires, etc., with a diameter of thickness greater than 1.0mm.
4	Protection from entry by solid objects with a diameter or thickness greater than 1.0mm
5	Protection from the amount of dust that would interfere with the operation of the equipment.
6	Dust tight.

Degrees of Protection - Second Digit
The second digit indicates the degree of protection of the equipment inside the enclosure against the harmful entry of various forms of moisture (e.g. dripping, spraying, submersion, etc.)

0	No special protection
1	Protection from dripping water.
2	Protection from vertically dripping water.
3	Protection from sprayed water.
4	Protection from splashed water.
5	Protection from water projected from a nozzle
6	Protection against heavy seas, or powerful jets of water.
7	Protection against immersion.
8	Protection against complete, continuous submersion in water.

Inverters are mass produced by a finite number of major multi-national electrical and electronics companies. The vast majority are supplied to OEM's for incorporation into electrical control panels. For this reason most inverters are supplied in an IP20 enclosure and should be located away from swarf and dust. If an inverter is enclosed to avoid contact with dust or swarf, the enclosure has to be sized correctly to ensure acceptable levels of heat dissipation. The manufacturer's manual usually outlines minimum enclosure requirements. Clearly this will add to the cost of the overall project. Some manufacturers offer entry-level specification inverters in an IP65 enclosure for an additional cost.

If part or all of your workshop supply incorporates an earth-leakage circuit breaker (ELCB), residual current device (RCD) or residual current circuit breaker (RCCB), check before wiring the inverter to the supply as you may experience nuisance-tripping resulting from additional earth leakage introduced by the RF filter used. Typically, inverters fitted with the RF filters internally ('integrated filter design') have moderate to high earth leakage in the order of 6 – 15mA and some much higher!. If the circuit already has some existing level of earth leakage current, adding this extra component when employing a filtered inverter may take the total to >30mA hence the trip operates. Also, a typical 13A socket supply should typically have less than 3.5mA leakage as the earth connection is deemed non-permanent. In this case, a low earth leakage mains filter (<1.5mA) is used in conjunction with the inverter and so this is compatible, this also then means the risk of nuisance tripping is greatly reduced. Otherwise, connection of the inverter could be via a fused switch outlet (with the earth permanently connected).

So how much does an inverter cost?
Sizing an inverter for your application is very straightforward. Simply look at the motor plate and make a note of the full load current at 240v three phase. This current rating determines the size of inverter you require. Inverters start at about £95 + VAT for ratings of 3A which covers most motors up to about 0.5hp/0.4kW. An inverter with an output of 11A costs anything from £200 to £380 + VAT depending on performance. A remote control pendant is likely to cost about £60 + VAT.

Power Capacitors Limited can supply inverter packages (IMO iDrive & Jaguar CUB/VXR) as follows

- Inverters between 0.4kW/0.5hp and 2.2kW/3hp
- Inverter and remote control packages for compatible motors between 0.4kW/0.5hp and 2.2kW/3hp priced from £182 including VAT and delivery
- Inverter and inverter compatible motor packages between 0.18kW/0.25hp and 2.2kW/3hp priced from £183 including VAT and delivery.
- Inverter, remote control and inverter compatible motor packages between 0.18kW/0.25hp and 2.2kW/3hp. priced from £241 including VAT and delivery.

Motor Packages are available for both metric and imperial bodied motors. Full details and specifications are available on request.