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ENERGY OPPORTUNITIES FOR AGRICULTURAL SYSTEMS AND FOOD SECURITY PROJECT

POWERING THREE-PHASE ELECTRICAL DEVICES FROM A SINGLE-PHASE SOURCE

Technical Brief #1

Introduction

Field work during the Energy Opportunities for Agricultural Systems and Food Security Project (E4AS), found that access to 3-phase electrical power was a limiting constraint to value chain development in the Kenyan dairy sector.

Unfortunately, most electrical supply across the developing world is not 3-phase, it is single-phase (for explanation of the difference between the two, see text box next page). The E4AS project found that this lack of 3-phase supply significantly restricts the use of more efficient 3-phase equipment by agro-processing firms. Beyond very small scale, most industrial equipment, including dairy or any other agro-processing equipment, have three-phase motors that require three-phase supply.

Electrical utilities in most countries can provide a 3-phase connection, but it can require significant financial investment, months of bureaucratic hurdles and coordination of electrical installation. This was the situation faced by some of the dairies visited by E4AS. They were faced with significant delays in opening and significant additional costs from the public utility company to extend three-phase supply to their operation locations. This brief summarizes several simple and inexpensive alternatives to create or simulate three-phase electrical supply at point of use.

This brief is the first of four practical guides developed by the **Energy Opportunities for Agricultural Systems and Food Security Project** (E4AS). Funded by USAID's Africa Bureau with field work in Senegal and Kenya, E4AS is implemented by Green Powered Technology in partnership with ACDI/VOCA. The objective of E4AS is to expand and focus information related to how clean energy (CE) and energy efficiency (EE) can strengthen post-harvest value chains and reduce loss in sub-Saharan Africa, while also contributing to low emission development strategies (LEDS) and incorporating gender-aware strategies. Visit www.agrilinks.org/post/clean-energy-productive-use-post-harvest-value-chains-integrated-literature-review-field-work to access additional briefs and an integrated literature review with field work findings.

Options for providing 3-phase power from a single-phase source

Several relatively simple and inexpensive alternatives exist to provide 3-phase power where only single-phase service is available. These alternatives include:

- Static 3-phase Converter
- Rotary 3-phase Converter
- Digital 3-phase Converter
- Variable Frequency Drive (VFD)

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Before considering one of these choices, it is recommended to evaluate the feasibility of replacing 3-phase motors with single-phase motors. If a substitution is possible, this may be the least expensive alternative. However, this may not be possible due to motor mount sizing, special mounting brackets, special shaft sizing or design, overall space, or the required horsepower rating. If that is the case, then consider one of the four converter technologies discussed below.

3-Phase vs. Single Phase

Electric current is the flow an electric charge. There are two primary types of electrical current: Direct and alternating (DC and AC). Direct current moves in one direction, alternating current periodically reverses its direction depending on its frequency. Alternating current is available as single-phase (typically for residential applications) and as 3-phase (typically for industrial applications).

When using alternating current, in a single-phase circuit, power is equal to the product of voltage, current and the phase angle between them. In a 3-phase circuit this product is multiplied by the square root of 3, or 1.73.

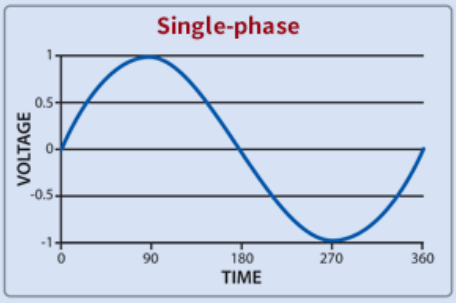
As a result, single-phase circuits require 1.73 times more current (Amps) to provide the same amount of power:

Single-phase:	Power = V x I x ø
3-Phase:	Power = V x I x ø x 1.73

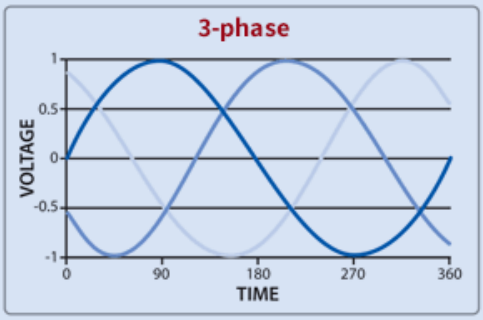
Since current carrying capacity is directly related to the size of the conductor, this means that for a single-phase circuit, more conductor material is required at a higher cost.

In an alternating current electric circuit, voltage and current take the form of sine waves (see below). For single-phase power this occurs with a single oscillating wave—hence the name. For 3-phase power there are three waves, staggered by 120 degrees to allow more consistent delivery of power.

In the case of single-phase delivery there are times when then the voltage or current is equal to zero. Due to the equation above, this results in instances when power is also equal to zero. This occurs with each oscillation of the wave, between 50-60 times per second. This is suitable for home, small business applications and for motors up to about 5 HP. However, most motors used with industrial machinery require 3-phase electrical power to ensure consistency of power supply. When power is repeatedly lost at micro-intervals under a single-phase application, motors must rely on their own inertia to coast and continue to operate. This impacts overall power output causes wear to the motor.



With the wave form of single-phase power, when the wave passes through zero, the power supplied at that moment is zero. The wave cycles 50-60 times per second depending on your location.



3-phase power has 3 distinct wave cycles that overlap. Each phase reaches its peak 120 degrees apart from the others so the level of power supplied remains consistent.

Three-phase power smooths these losses to ensure the peak level of power never drops to zero. Motors that operate with a 3-phase supply do not require the same rotational mass to coast when there is no power, can deliver more power for a given physical size, and are generally less expensive and more efficient for a given horsepower than a single-phase motor.

Static 3-phase Converter

A static converter is the least expensive alternative for 3-phase conversion. It has no moving parts; however, it needs to be sized to match the motor size (i.e. horsepower). The major disadvantage of a static converter is that it reduces a motor's available horsepower by about one third. It also has difficulty in starting motors with high starting loads (e.g. compressors, dust collectors, large fans, etc.). To overcome this, a lightly loaded motor can be started first to act as an electrical flywheel to improve the starting ability of other motors. An "idler" motor (a spare motor connected to the same system) can also be used to provide this electrical flywheel, but this adds to the overall system cost.

Note, not all motors can run using a static phase converter. Static phase converters are not recommended for welders, heaters, two speed motors, air compressors, pumps, fans, CNC machines, plasma cutters, refrigeration trucks, blowers, large flywheels and large lathes[1].

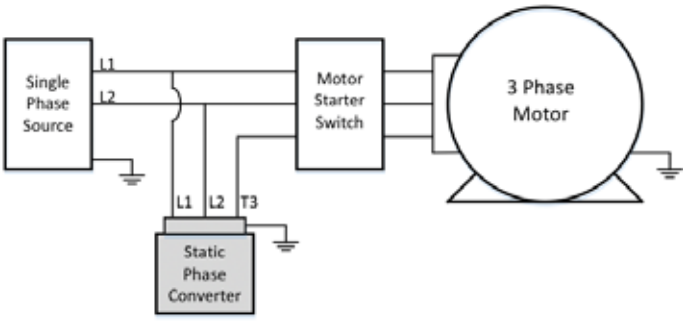


Figure 1. Schematic of 3-phase static converter installation

Typical single-phase to 3-phase static converters from American Rotary Phase Converters (left) and Phase-A-Matic (right)

Rotary 3-phase Converter

A rotary converter functions as both a motor and a generator using a single-phase motor to drive a generator to produce 3-phase power. A rotary converter looks like a large motor with a large junction box attached. It is more expensive than a static converter but doesn't have the starting and reduced power problems that occur with a static converter. A major advantage is that a suitably sized rotary converter can be used to supply 3-phase power to all—or multiple—3-phase motors in a facility.

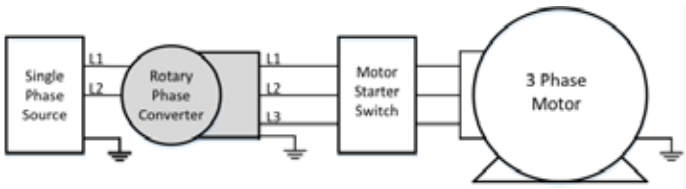


Figure 2. Schematic of 3-phase rotary converter installation

Typical single-phase to 3-phase Rotary Converters from North American Phase Converter Co. (left), Phoenix Phase Converters (center), and American Rotary Phase Converters (right)

[1] *How to size a Static Phase Converter* - www.northamericaphaseconverters.com/how-to-size-a-static-phase-converter

Digital 3-phase Converter

(often called 3-phase Inverter)

A digital phase converter uses a rectifier and inverter to create a single voltage. This is done using power electronics, added to the two legs of the incoming single-phase source. The new single voltage can match both the voltage and frequency of the incoming single-phase power, resulting in an output that is a well-balanced 3-phase sine wave, not a stepped waveform typical of a variable frequency drive (VFD). Digital converters are more efficient than rotary converters. In contrast to a standard rotary converter, a digital converter only uses power when a load is present and has minimal internal power use. The digital 3-phase converter cannot vary frequency and motor speed like a VFD (discussed below), which may be a better choice as cost are relatively the same.

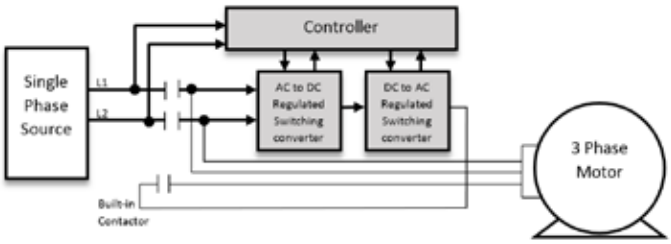


Figure 3. Schematic of digital 3-phase converter

Typical single-phase to 3-phase Digital Phase Converters from North American Phase Converter Co. (left), and American Rotary Phase Converters (right)

Variable Frequency Drive (VFD)

A Variable Frequency Drive (VFD or VSD or electronic 3-phase inverter) changes single-phase power into direct current and then inverts the direct current to 3-phase power. This is done using electronic controls to simulate 3-phase alternating current.

The electronics in the converter allow control of motor speed, torque and direction of rotation, and often allow for a soft start to bring the motor up to speed gradually. Since it must be programmed, a VFD typically is dedicated to running only one motor. VFDs can be more affordable that rotary converters for lower horsepower motors, however above 10 HP the savings decline (see relative cost chart).

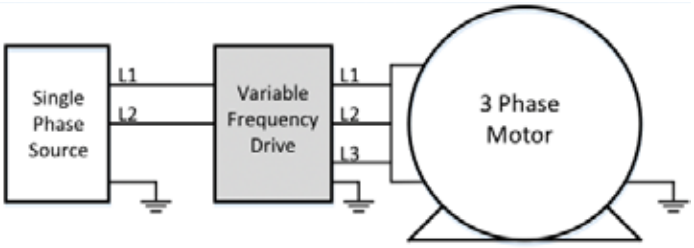


Figure 4. Schematic of Variable Frequency Drive

Variable Frequency drives from DURApulse (left), and Hitachi (right)

Relative Costs

The following relative costs are based on currently available equipment in the USA. The ranges in pricing reflect equipment from different manufacturers and suppliers in early April, 2018.

	MOTOR SIZE				
EQUIPMENT TYPE	**3 H.P.**	**5 H.P.**	**10 H.P**	**15 H.P.**	**20 H.P.**
Static 3-phase Converter	$180 - 500	$300 - 600	$550 - 750	$750 – 1,000	$750 – 1,200
Rotary 3-phase Converter	$450 - 1,000	$450 - 1,500	$820 - 1,900	$1,250 - 2,500	$1,350 - 2,500
Digital 3-phase Converter	$400 - 600	$500 - 800	$1,500 - 2,250	$2,000 - 3,000	$2,500 - 4,000
Variable Frequency Drive	$450 - 600	$600 - 850	$1,750 - 2,500	$2,500 - 3,200	$2,750 - 4,000

Prices are in US Dollars and are based on equipment available from several different suppliers in April 2018.

Phase Converter or Variable Frequency Drive?

A **phase converter** is the easiest "plug and play" solution. It requires the least programming, can be selected based on the motor size, and is simple to install. It is most suitable for 3-phase motors where speed and torque control are not required (e.g. refrigeration equipment, freezers, etc.) and where a machine has numerous low voltage internal controls. **Variable frequency drives** are well suited for phase conversion when control of speed, motor torque and soft starting are needed for such applications as pumps, fans, compressors and process machinery.

Voltage

Phase converters are not transformers. Unless a transformer is included in the system, outgoing 3-phase voltage will equal the incoming single-phase supply voltage. Therefore, a transformer may be required to match the supply voltage required for the 3-phase application.

Suppliers

There are numerous suppliers of phase converters and VFDs. The following list provides the website address of some examples of suppliers:

www.phoenixphaseconverters.com

www.americanrotary.com

www.northamericaphaseconverters.com

www.phase-a-matic.com

www.schneider-electric.us

eaton.com

technolectric.com (Kenya)

sollatek.co.ke (Kenya)

www.parker.com