High power computing and networking systems are not new. What is new is that more and more of these systems are requiring more power than can be easily provided by a single-phase ac power feed.

This article reviews the two main ways of providing the requisite dc power from three-phase ac power sources. The first uses true three-phase ac-input power supplies, while the second, more common method, uses three single-phase ac-input power supplies with paralleled dc outputs and with their inputs wired to present a balanced load to the three-phase ac power source. This method allows the use of low cost single-phase ac input power supplies, but demands that a choice be made between simple hardware with complex installation, or more complex hardware with simple installation.

### THREE-PHASE CONFIGURATIONS

There are many different configurations of three-phase ac power sources around the world. The two main configurations – the delta connection and the wye, or star, connection – are illustrated in Figures 1 and 2.

Delta configurations generally do not have a neutral connection and the protective earth is separate from the phase leads. There are a number of variations, including phases that are centre-tapped to form a neutral line, and open delta configurations where only two of the three phases are powered.

Wye configurations typically include a neutral line (N) connected to the common point (3 phase plus neutral for a total of four wires). In addition, the common point of the three phases is connected to protective earth (PE) ground to form a five-wire connection (3 phases, N, and PE) as shown in Figure 2.

As well as the numerous phase configuration variations, there is a wide variation in available mains voltages. Table 1 shows the most common configurations of three-phase ac power that are of interest to OEM manufacturers serving the global market.

### TRUE THREE-PHASE POWER SUPPLIES

The simplest means of configuring a system to operate from three-phase ac power is to use a power supply with a true three-phase input. In this case, we are talking about power supplies with active power factor correction of the input currents and not a simple six pulse rectifier input. Figure 3 shows a conceptual diagram of the type of three-phase input ac-dc power supply typically used in computing, networking and telecommunications applications.

One key advantage to this approach is that the input power connections are straightforward – Phase A connects to one input terminal, Phase B to another and Phase C to the third. Other advantages include the fact that the input currents are always well balanced across the three phases and that it is easy to do configure systems for operation from redundant ac power feeds, as well as for N+N redundancy.

In spite of these advantages, true three-phase input power supplies are not very common, primarily due to their high cost and complexity. One source of complexity is the control scheme needed to control the six switches to ensure that sinusoidal input currents are maintained on all three phases. For single-phase input ac-dc power supplies there are many simple and low-cost control ICs, some with a price as low as $0.15 in high volumes. These devices are easy to use and do not require complex installation.

### Table 1: Typical three-phase ac power configurations

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Voltage (Vac rms) Phase-Neutral</th>
<th>Voltage (Vac rms) Phase-Phase</th>
<th>Region Typically Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wye (3P + N + PE)</td>
<td>230</td>
<td>400</td>
<td>Europe</td>
</tr>
<tr>
<td>Wye (3P + N + PE)</td>
<td>120</td>
<td>208</td>
<td>North America</td>
</tr>
<tr>
<td>Delta</td>
<td>N/A</td>
<td>208, 230</td>
<td>North America</td>
</tr>
<tr>
<td>Open Delta</td>
<td>100-105</td>
<td>200-205</td>
<td>Japan</td>
</tr>
<tr>
<td>Wye (3P + N + PE)</td>
<td>230-250</td>
<td>400-440</td>
<td>Australia</td>
</tr>
</tbody>
</table>

1 One phase with grounded centre-tap to make the neutral
advanced control or programming knowledge to use them effectively. Unfortunately, no such ICs exist today for three-phase input power supplies. Most controllers for three-phase input power supplies are DSP-based solutions that cost at least $2.00.

Another consideration is component cost. Looking at Figure 3, we see that $V_{\text{CAP}}$, the voltage at the output of the power factor correction stage, is $\sqrt{2} \times V_{\text{phase-to-phase}}$. For operation from the 120/208Vac wye configuration that is common in North America, this is not a problem, because $V_{\text{CAP}}$ would only need to be a little more than 300Vdc. However, for operation from the 230/400Vac that is common in much of the rest of the world, $V_{\text{CAP}}$ must be 600Vdc or more for proper operation of the power factor correction.

This is a problem because the capacitors, MOSFETs and other components rated for operation above 600V are not commonly used in the industry and, therefore, incur a cost penalty. This cost penalty is compounded by the fact that high power equipment needing three-phase input is often produced in relatively low volumes – from a few hundred to a few thousand systems per year.

Another disadvantage is the loss of output power capability when power from a single input phase is lost. In this case, the power supply is effectively operating from a single phase. The output power that can be delivered to the load is reduced to one third the normal value. This is true of any arrangement of power supplies that operate with a delta input. These disadvantages – mainly the extra complexity and higher cost – have led system OEMs to generally adopt another approach to power systems from three-phase ac power.

With the need for higher power supplies increasing, ways to use a true three-phase input power supply without requiring higher voltage rated components are being investigated. There is little or nothing that can be done about the need for higher voltage components in the ac-dc conversion stage. The output voltage needs to be greater than the peak of the input voltage for the power factor correction stage to work properly. However, two circuit techniques are used to design the dc-dc conversion stage so that higher voltage components are not needed. Both of these techniques make use of capacitive voltage dividers to reduce the 600-800Vdc output of the ac-dc stage.

The first technique involves the use of multilevel converters; for computing and telecommunications applications, these generally use clamped diode and flying capacitor topologies. These can work well and use 400-500V rated semiconductor devices and capacitors. The disadvantage is that there are more semiconductor devices with a more complex control. Of particular concern is the need to avoid imbalance in the capacitor voltages due to component variation or changes in the converter loading.

The other technique is to use two power supplies with their inputs connected in series and their outputs connected in parallel, as shown in Figure 4. Again, there is the challenge of preventing imbalance in the capacitor voltages due to component variations, such as those that cause one of the dc-dc converters to operate at a higher duty cycle and higher average input current than the other. This problem is manageable, but it does require some care with the overall control of the two converters. Also, the total parts count of the two converters will be higher than that of a single converter of the same total output power capability. The smaller, lower voltage and lower current components of the two dc-dc converters make up much of the cost difference.

It will be interesting to see, in the years ahead, how far these techniques can go to make true three-phase input ac-dc power supplies economical, robust and easy to design.

**USING THREE SINGLE-PHASE POWER SUPPLIES**

The most common approach to powering systems from three-phase ac power is to use three single-phase ac input power supplies. Each supply operates with its ac input connected from phase to neutral or from phase to phase. The dc outputs of all three power supplies are connected in parallel (Figures 5 and 6). These power supplies are typically designed for a worldwide ac input voltage range of 100-240Vac nominal (85-264Vac full design range).
This approach offers a number of significant advantages: each of the power supplies uses a well known technology and is a low cost, low complexity product; and the input current among the three phases can be well balanced (±5-10%) under normal operation.

One key disadvantage is that in N+M redundant applications, each increase in M requires three more power supplies. To implement 1+1 redundancy and maintain input current balance requires adding three power supplies for a total of six power supplies. However, the lower cost and complexity of the single-phase ac input power supplies has more than offset this disadvantage to date.

Option 1: Complex System
Manufacture, Easy Install

Looking at Figures 5 and 6 we can see another disadvantage to using three single-phase ac-dc power supplies. The input wiring schemes are very different for wye and delta sources. It is not possible to have a single wiring scheme for both. For systems wired at the factory and shipped as ‘plug and go’, this means that the type of ac power at the end user’s site must be known and the system configured for that power.

The first problem with this is that the ac power configuration at the installation site may not be known, and even if it is, the supplier must be able to provide many different configurations of the same system, varying only in their ac input configuration. This means that for every system configuration the supplier intends to provide (variations such as number of processors, memory capacity, disc drives, I/O type and capacity), there must be at least two times (and probably more like three or four times) as many variations in order to account for the ac power configuration. This places a huge design and manufacturing burden on the supplier and means that customers must ensure that they order the correct configuration.
Option 2: Simple System Hardware, Complex Installation

It is possible to ship a system with the inputs to the three power supplies completely undedicated (Figure 7). Once the system is delivered to the installation site, the input power leads can be connected as needed for the local power configuration.

One advantage to this configuration is that single-phase (two- and three-wire configurations) can also be easily accommodated. This makes it possible to manufacture only one version of the ac power configuration for use anywhere in the world. From the design, manufacturing and logistics point of view, this represents huge savings. However, these savings are offset by the need to have a skilled electrician make the connections from the site ac power to the system.

Option 3: Simple Installation, Complex System Hardware

While a system that can be configured at the installation site for any ac power configuration, single or three-phase, is very attractive to some OEMs, others have concerns. For example, suppose the installer mistakenly wires these power supplies from line-to-line in Europe. The 400Vac input in this case would probably destroy the power supplies, as they would only be rated for 264Vac maximum continuous input voltage. Damage can be prevented with input overvoltage detection and protection circuits, but this adds cost and complexity.

The solution is use ac input adapter assemblies. This requires that the customer order the correct input assembly for their type of three-phase ac power (wye or delta, and of course single-phase variations) but once the proper choice is made, installation is simple. The adapter assemblies contain the necessary wiring to connect the input power terminals to the three (or 3N) power supplies in the proper fashion.

In principle, this is no different to the factory-wired situation with which we started. In many cases, only three input assemblies are needed (three-phase wye, three-phase delta and single-phase). System OEMs often find this a much more manageable situation, both for manufacturing and logistics complexity, than manually pre-wiring each rack or cabinet. Each of the various ways that a system can be powered from three-phase ac power has its advantages and disadvantages, in both technical and business issues. No universal recommendation of one method as being best for all applications can be made. Each system OEM will have to decide for themselves which approach is best for their customers.