Abstract - The popularity of multi-axis drive systems continues to grow and has recently been boosted by the mechatronic push from mechanical solutions to electronic drive solutions. An example of this would be the migration from a single motor line shaft to a multi motor shaftless solution which adds performance and machine flexibility while decreasing mechanical maintenance and machine limitations. When the additional advantages of size, cost, and power sharing capabilities are considered over stand alone drive systems it is evident current drive trends will develop around multi-axis drive solutions. Converting, printing, packaging, paper machines and machine tools are just a few of the various applications that have standardized on multi-axis designs. In many of these applications, servo and vector axis are used in tandem to allow for the optimum solution to each task.
I. INTRODUCTION

Before we look into details of multi-axis drive systems lets first take a look at the typical stand alone AC drive. The power design of today’s Pulse Width Modulated AC drive is made up of three sections. The input section is the rectifier which converts single or three phase AC voltage into DC voltage. The DC link is the middle section which contains a capacitor bank to smooth and buffer the DC voltage. And last the fast switching inverter section which chops the DC voltage into an AC signal suitable for an inverter duty rated AC motor.

Multi-axis drive systems are characterized by a common DC bus design. A shared rectifier is used to convert the AC power supply into a DC bus which is common to the parallel connected motor modules (inverters). Using a common rectifier for the drive system vs. individual rectifiers for each drive reduces the size and cost of the drive system by using a single set of line components (i.e. contactor, reactor, fuses,) versus individual components for each drive. Additionally, power sharing between the different axis on the DC bus allow these components and rectifier to be sized based on the maximum current draw of the system not the summation of the individual motors. This commonly results in a more size optimized and energy efficient design since motoring and generating loads are sharing energy across the DC bus.
II. BENEFITS

Further advantages of using multi-axis drive systems over stand-alone drives include less wiring since only one set of line components are required. This leads to a substantial decrease in the required cabinet space and assembly time as well. These benefits all add up to more cost effective designs in manufacturing multi-axis drive systems. Once in operation common DC bus drive systems are also more efficient than a system of stand alone drives. This is because power sharing occurs on the DC bus between axis that are motoring and generating simultaneously. The drive system is more efficient, because it uses less power from the rectifier when the generating units send power to the DC bus to be used by the motoring units. Converting lines with tension zones are a good example of a power sharing application. When rolls are stopping or “hold back” against a web to generate tension, power is generated by the motor and sent to the DC bus. This power is used by motoring axis connected to the common DC bus and reduces the power demand on the rectifier. On stand-alone drives this generating power is usually transferred into heat across a braking resistor which is not only a waste of energy but very costly with today’s energy prices. See Figure 5 below with an example of a multi-axis system at a point in operation with over 175 amps flowing through the motors but only 55 amps being drawn from the power supply. This is typical for web handling applications which usually incorporate several tension zones through out the machine.

![Figure 5 Power Sharing on Common DC Bus](image)

Increased engineering flexibility due to economies of scale is an additional benefit of using multi-axis drive systems. Many enhanced rectifier options such as Regenerative Rectifiers or Active Front Ends provide many advantages over common rectifiers but are more costly. Individually to use this technology on smaller stand-alone drives would prove too costly for many applications. Used as a single supply for a multi-axis system the benefits can easily out way the initial cost for a line regenerative drive system. With highly regenerative systems or high performance systems which need a static DC link even through torque reversals and power dips multi axis systems are almost always more cost efficient.
III. NEW TECHNOLOGY

As the trend to use multi-axis drive systems grows, many drive manufacturers are designing features to accommodate common DC bus configurations. A top priority from users is ease of connection to the DC bus. The most efficient designs use built-in bus bar connections or internal connection jumpers to configure the DC bus. These connections require little labor and no panel space in the small and medium size drive systems.

![Figure 7 Internal DC Bus Connections](image)

Characteristic now of multi-axis designs is the side-by-side mounting for a more efficient cabinet layout. Also adding to this ever important cabinet space limitations are the increased variations of cooling. A typical cooling variation on the market is external fan cooling which places the heat sink and fan out the back of the cabinet. New on the market is cold plate cooling which opens up numerous designs for cooling including different water cooled options. In the side-by-side design when two axis of the same current rating are used double motor modules are used which compact the density of two axis into one motor module. Another feature that reduces labor and space in the cabinet manufacturing is integrated DC link fusing for the inverters.

Powerful multi-axis controllers tend to be the design of choice and allow for separation between brains and power. These controllers not only perform the drive functionality but can incorporate motion task as well to offer a coordinated drive based motion control solution. To add to the ease of use and commissioning of multi-axis systems Plug & Play functionality is becoming common. A back plane connection or serial link is used to connect all the modules together so that upon initialization they will be preprogrammed back to the controller. Today this concept has been expanded beyond the drive devices to include such components as remote I/O and even motors. Gone is the day when the parameters of every device had to be set, and in are electronic type plates with all relevant data of the devices available to the multi-axis controller.
One significant new design for small, multi-axis drive systems is the added design capacity to the rectifier section in certain stand-alone AC-AC converters. Manufacturers are now even doubling the standard capacity of the rectifier section required for stand-alone units to power additional inverter sections (DC – AC units), thus eliminating the need for a separate rectifier unit. An example of this is shown in Fig. 7, where a 10hp AC-AC converter is supplying the power to two 5hp inverters along the DC bus link. These systems offer a very compact and cost effective solution that incorporates all the benefits of a common DC bus system.

![Diagram of common DC bus powered by a converter](image)

**Figure 7 Common DC Bus powered by a Converter**

Avoid drive system designs that connect the DC links of Stand-alone drives together but maintain the individual AC rectifier feeds. These parallel feeds can lead to extensive drive system failure if there is a short on a motor or DC link. Another problem this design presents is overload of the rectifiers on smaller drive units when the individual AC supply in-feeds are used.

Designed correctly a multi-axis system not only cuts down the number of components used in the drive system but also can minimize the range of spare parts needed since one larger line component is used instead of several of different ranges.
IV. TYPICAL APPLICATIONS
Applications across many industries and power ranges use common DC bus drive systems. The growth in the motion control industry is also feeding the use of multi-axis drive systems with their extremely compact packaging requirements and fast torque cycles from motoring to generating. The multi-axis drive systems also fit in well with the mechatronic philosophy. This philosophy allows us to replace a large mechanical system like a line shaft with several smaller individual axis. In the new mechatronic machines starting and stopping individual axis with the machine running is preferred over the old days where the complete line shaft had to be stopped. Clutching axis in an out allows easy change over of stations or recipes while the reduction in mechanical components reduces limitations of the machine. Safety Integrated functionality like Safe-Off or Safe-Stop has been expanded with Safe-Brake, Safe-Ramp, and Safe-Retraction.

In larger hp applications such as rod mills and cranes intermittent duty cycles and power sharing of common DC bus drive systems will generally allow a rectifier to be sized for the system that is quite smaller than the complete sum of the inverter ratings. One can imagine the cost and space savings of using a single 500hp rectifier vs. three 250hp units. The economies of scale also make it more affordable to use a single larger line regenerative system such as an Active Front End vs. several smaller units with the same technology.

V. CONCLUSION
Multi-axis drive systems are an increasingly popular method to provide customers with compact, efficient, and cost-effective drive solutions. Compact, due to the reduction of panel space required, efficient, due to the ability to share power on the DC bus, and cost-effective, due to a combination of design features. From small multi-axis systems to large process lines, common DC bus systems are now more popular than ever.