

Common Bus and Line Regeneration

Addressing VFD applications when Regenerative Energy is Present

Steve Petersen, Drives Technical Training
Yaskawa America, Inc.



Variable frequency drives (VFDs) are implemented on a huge variety of applications due to their high performance, reliability, and energy savings. However, as with everything, there are some shortcomings with VFDs. The input diode bridge on most VFDs consists of six diodes. These diodes make up the converter portion of a VFD and rectify the 3-phase AC input to a fixed DC voltage. The current flow in the converter portion is typically unidirectional. This is a non-issue in a majority of applications. An issue arises when an application has regenerative energy present. Regenerative energy is present when a motor is braking or overhauling due to the load. This causes the motor to act as a generator with the energy flowing back into the VFD. The diode bridge will stop current from flowing back to the line; thus charging up the DC bus capacitors and potentially causing faults due to high DC bus voltage. In this article we will address this challenge by comparing various solutions which use line regeneration and common DC bus arrangements. The differing available solutions also entail varying benefits and opportunities for reduced space requirements, cost reduction, energy savings and increased reliability.

Common DC Bus

An application consisting of as few as two VFDs can benefit from a common DC bus. Sometimes called a shared bus, a common bus is established by simply interlinking the DC bus between VFDs via a fused connection (Figure 1). The key benefit of a common bus is the sharing and balancing of power. For example, take a system with two VFDs and two motors; one motor may be in a motoring state while the other motor is in a regenerating state*. During this condition the motoring VFD will consume the regenerative power instead of pulling from the grid. A reminder, two common conditions which can cause regeneration are an overhauled motor or when a motor is braking. In this article, 'regenerative' energy can also be called 'braking' energy. For simplicity we will just stick with the term 'regenerative.' There are multiple ways to establish a common DC bus, each with its own strong points. However, there is no sole 'best' method, as applications can vary wildly and system needs and cost must always be considered.

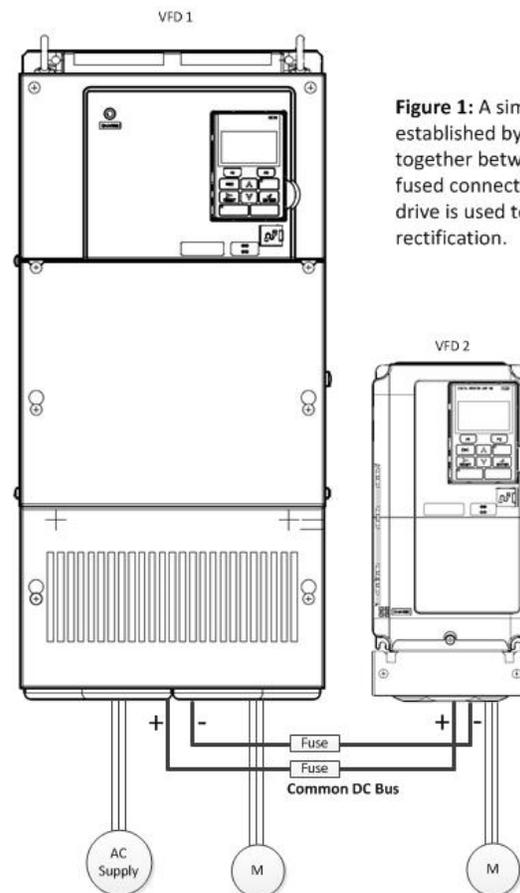
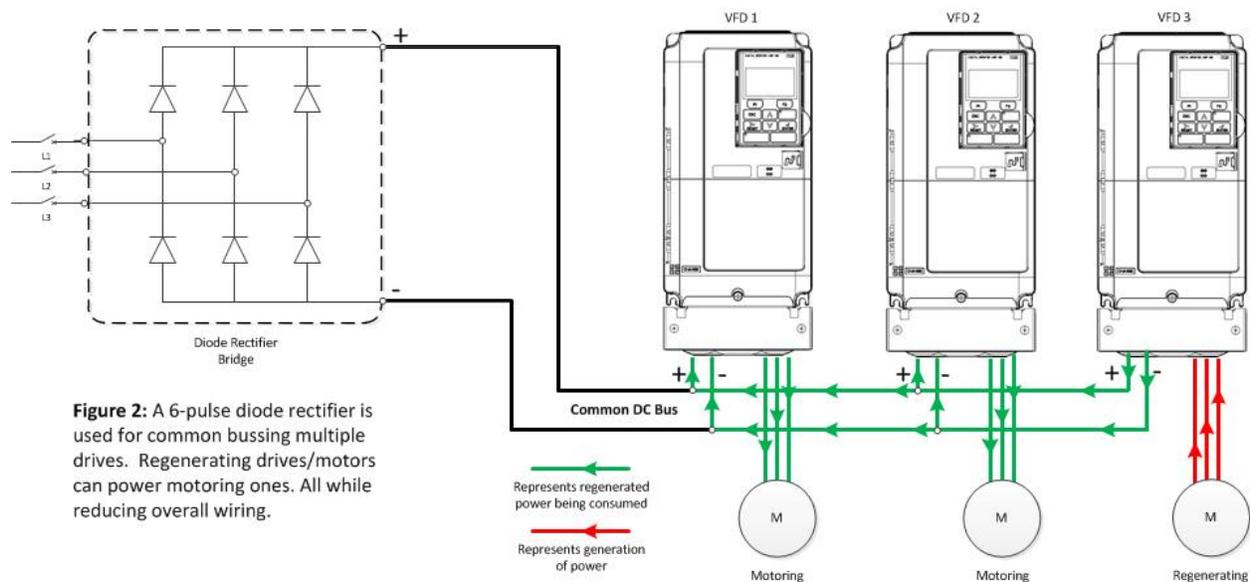


Figure 1: A simple common bus is established by linking the DC bus together between two VFDs with fused connections. An oversized drive is used to supply the AC to DC rectification.

*Motoring – when an electric motor is converting electrical energy into mechanical energy to perform work

Regenerating - when a motor is overhauling or braking it acts such as a generator. Mechanical energy generates electrical energy

A large stand-alone 6-pulse diode bridge rectifier can be purchased to establish a common bus. The diode bridge is used to rectify the AC input power to DC. The diode bridge must be sized appropriately to power all the connected VFDs and loads. The diode bridge is identical to the converter section of many VFDs. Inherently it is unidirectional, meaning that excess regenerative energy cannot be sent back to the grid. Motoring loads must be greater than regenerating loads to keep the voltage of the DC bus at a safe level. When regenerating loads is greater than the motoring loads then a common dynamic braking package or line regeneration must be implemented. Alternatively, when the amount of regenerative energy present is low you will find that wiring is simple and also reduced compared to a standard AC setup. (Figure 2)



Line Regeneration

If it is necessary to return excess regenerative energy to the grid this is where line regeneration comes into play. When excess regenerative energy is applied back to the line it is called line regeneration. To accomplish this, a regenerative converter is implemented. This converter is wired into the common DC bus just like the existing drives. This converter takes in excess DC from the bus and outputs a six-step waveform back to the grid. This results in reduced operating costs due to recycling the regenerative power back to the supply. The capacity of the regenerative converter is determined based on the total regenerative energy present.

Instead of using a stand-alone diode bridge rectifier to provide a system with DC power, it may sometimes prove beneficial to use a larger VFD. A VFD has a built in rectification circuit on its front end. A common bus can be established by sizing the VFD to supply DC power to the connected VFDs and

motors. This topology is reflected in Figure 3. Note that when comparing this setup to Figure 2, the stand-alone rectifier is eliminated. The second VFD is being powered from the DC bus of the first one. This makes wiring simpler while keeping costs down. An industrial centrifuge is good example of application which would benefit from a common DC bus. A centrifuge consists of a main drive, which turns the drum, and a back drive, which turns the auger at a speed slightly slower than the drum to separate fluids or solids. The back drive is typically a smaller capacity than the main drive. In this application, the back drive is in constant regeneration since it is acting as a brake. This braking energy can be used to power the main drive, which is motoring. When the main drive needs to stop there is a huge inertial load present. This causes the regenerative energy to be excessively high during deceleration and warrants the need to send the power back to the grid through a regenerative converter.

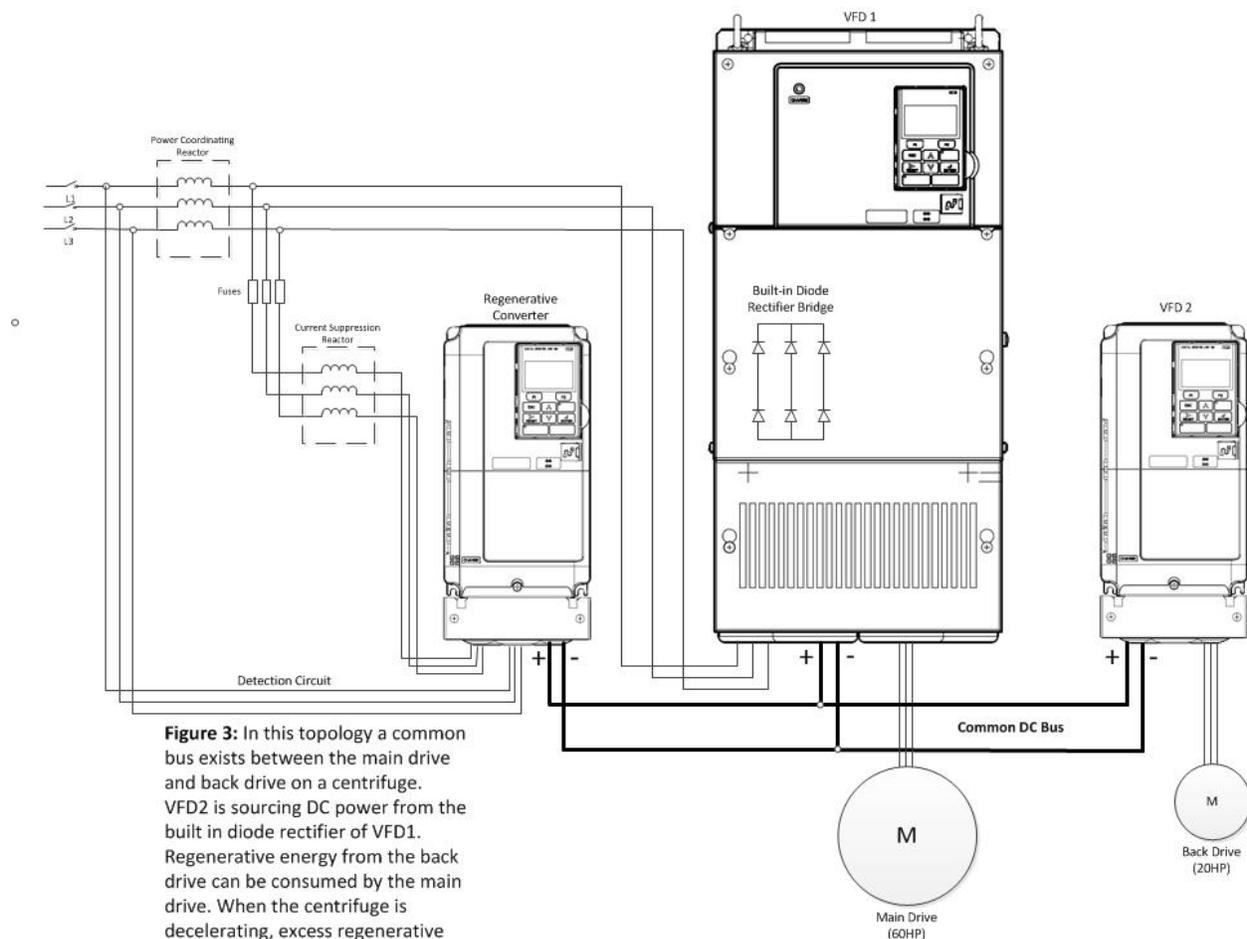
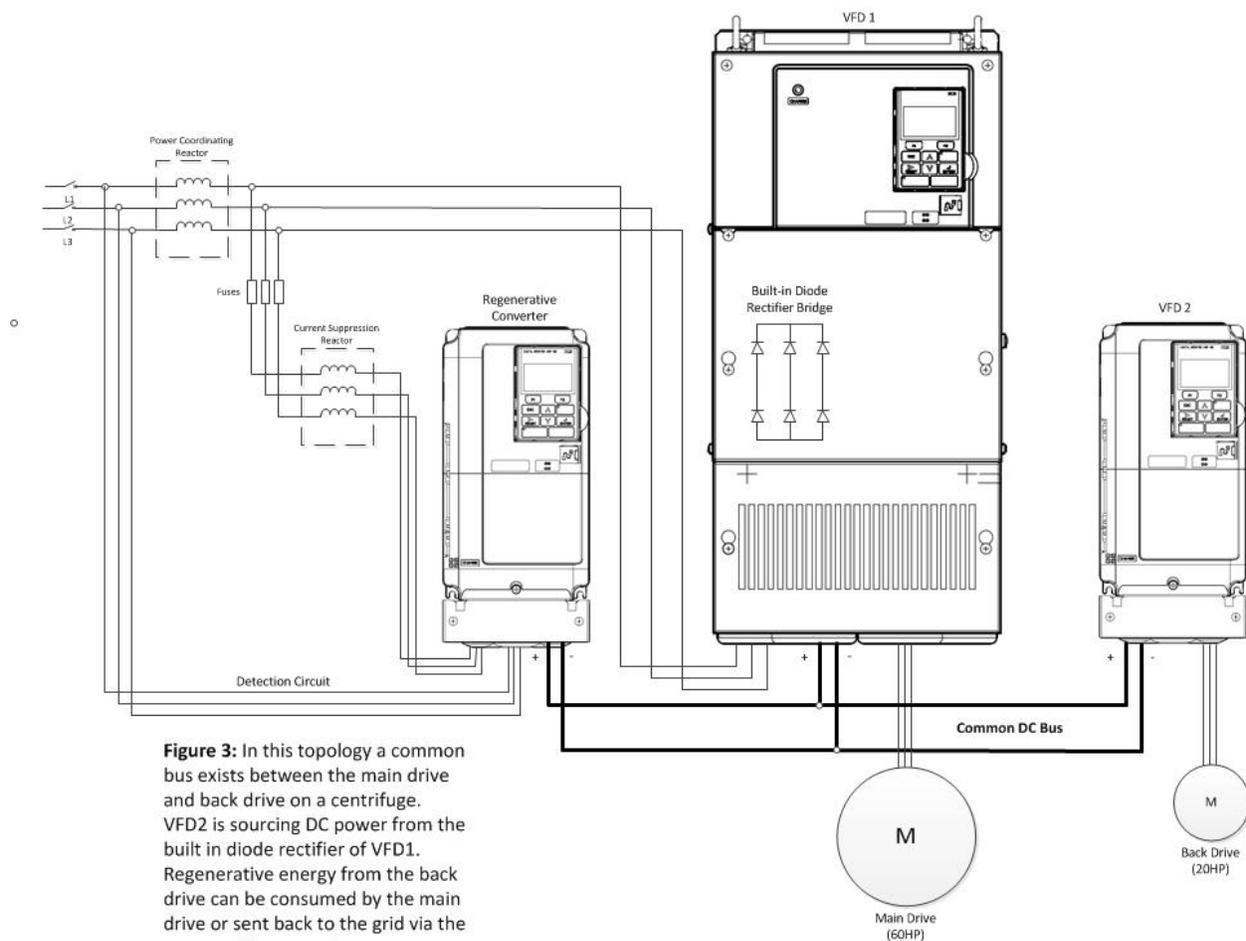


Figure 3: In this topology a common bus exists between the main drive and back drive on a centrifuge. VFD2 is sourcing DC power from the built in diode rectifier of VFD1. Regenerative energy from the back drive can be consumed by the main drive. When the centrifuge is decelerating, excess regenerative energy is sent back to the grid via the regenerative converter.

Costs and space requirements are always a top priority. These are directly proportional to the amount of regenerative energy present. Therefore it is extremely important that an engineer confirms the amount of regenerative energy on a given application. Knowing this, the engineer can then either opt to oversize the larger VFD to increase bus capacity or utilize a regenerative converter to apply energy back to the grid. If the amount of regeneration taking place is low a dynamic braking setup will be the most cost effective solution. Dynamic braking simply burns off the excess voltage onto a bank of resistors.

If it has been determined that a regenerative converter is necessary, take note of the additional devices which are required when using it. (Figure 3) The reactors are necessary to limit current being supplied back to the grid and also provide additional impedance between the AC source and load devices. There is also a detection circuit which is wired directly from the converter to the power supply. This circuit is used to detect the power supply phase order and voltage levels. Whenever a common DC bus or line regeneration is being considered, it is absolutely necessary to follow the manufacturer's wiring requirements for each device in the system. Pay particularly close attention to fusing recommendations, peripheral devices, power up sequencing, and maximum lengths for DC bus lines.



Harmonics and Active Front Ends

The input diode bridge on a VFD conducts the line current in a discontinuous (non-linear) fashion. This is due to the input diodes only conducting during the peak voltage amplitude of each input phase. The result is a rippled voltage waveform, in turn causing input current distortion and harmonics applied back to the supply.

A regenerative converter is always wired in parallel to the VFDs on a common bus. The VFDs diode bridge is not isolated from the supply. This means that the converter will not help mitigate harmonics generated by the diode bridge. Typically, when harmonics are a concern, passive front ends consisting of various reactors, filters, and multi-pulse transformers are implemented. These techniques will decrease harmonics but cannot handle line regeneration. Additionally, passive front ends tend to be both expensive and bulky.

To mitigate harmonics while also allowing for line regeneration, a regenerative active front end (AFE) must be used. A regenerative AFE is wired in series with the VFDs being powered from it (Figure 4). Harmonics are low due to passive filtering and reactors paired with the AFE in combination with a pulse-width modulated (PWM) switch array on the input of the front end. Fly back diodes on the insulated gate bipolar transistors (IGBTs) are used to rectify AC to DC for powering one or multiple drives. Additionally, the IGBTs use PWM to reconstruct an AC sine wave by 'switching' the DC bus voltage back onto the supply when regenerative energy is present, making the AFE bidirectional.



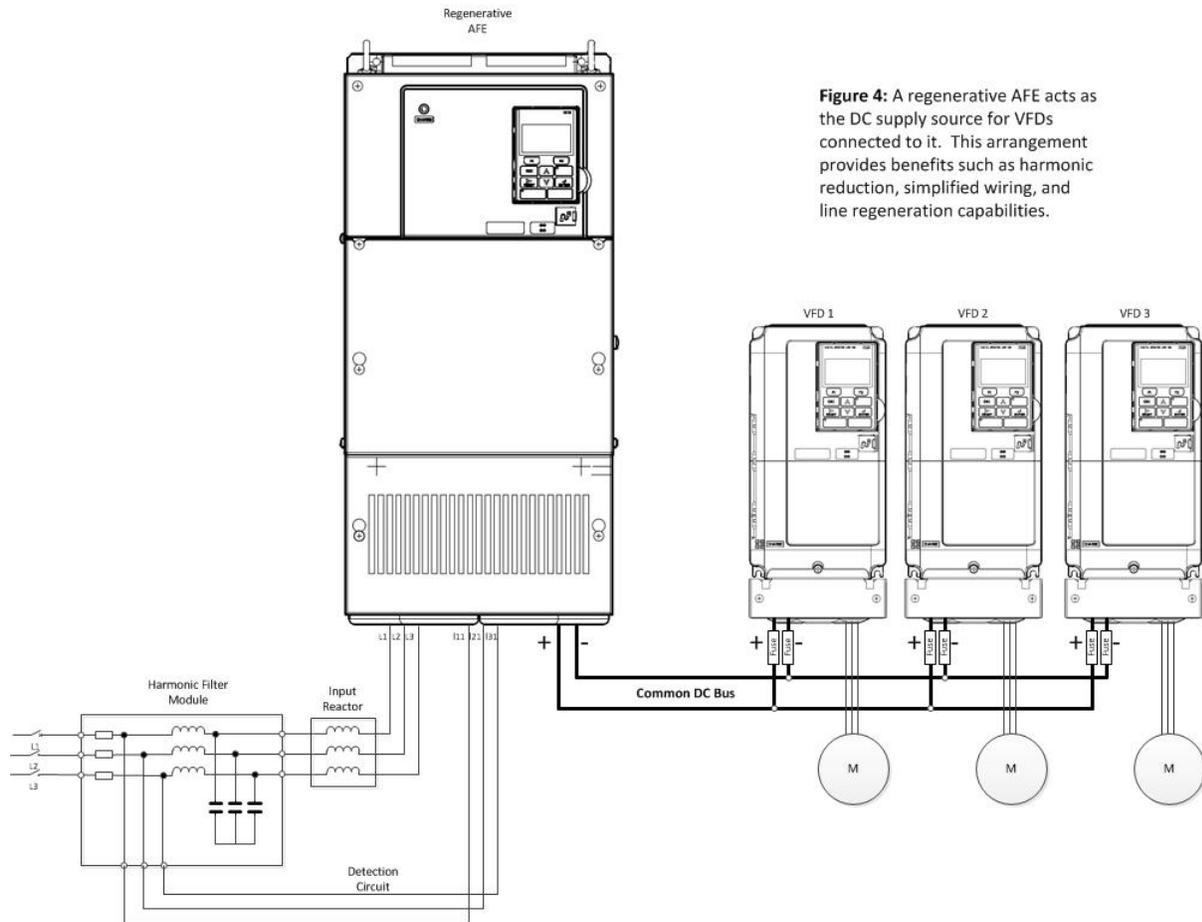


Figure 4: A regenerative AFE acts as the DC supply source for VFDs connected to it. This arrangement provides benefits such as harmonic reduction, simplified wiring, and line regeneration capabilities.

Sizing a regenerative AFE is a matter of simple addition. Add up all VFD capacities which will be powered by the AFE. For example, an application is running four 45 kW VFDs and would like to know what size regenerative AFE to select.

$$\text{Formula: } 45 \text{ kW} \times 4 = 180 \text{ kW}$$

Using very simple math we find that the AFE must be rated for at least 180 kW. This rating is required since the AFE is being used as a power supply for all of the connected VFDs. This differs from the regenerative converter mentioned earlier which was sized based solely on the amount of regenerative energy present.



Conclusion

Deciding upon which components and setup is right for your system will take some research and evaluation. The amount of regenerative energy present, harmonic content, and cost should all be considered and prioritized. Upon selecting and implementing a common DC bus arrangement substantial energy savings and benefits can be realized.

