BATTERY CIRCUITS FOR STATIONARY APPLICATIONS DESIGNED FOR THE LONG HAUL

Matthew Theriault
Designer
Hindle Power Inc.
Easton, PA

SCOPE AND PURPOSE OF THE PAPER

We now have 100 years of experience with high voltage battery strings powering loads in the utility industry. Over the years, the utility industry has learned the same lessons as the telegraph and telephone industry that shaped the modern telecom market, but they were all trying to achieve the same result. The battery's job in both applications is to supply power to the critical controls when the primary ac power fails. My intention in this paper is to provide an overview of the separate components, their function, and interconnections between these devices. These designs are not new or difficult for the designer to create, but often the battery is treated as a rigid component instead of an organic living creature that needs feeding and care throughout its life. Like a dynamic organism, it has a beginning of life, a middle age and a death.

Over the years I have learned that each designer gives more weight to one design aspect over another. Safety, reliability, cost, simplicity, standardization, component availability and size are all considered and balanced by the designer. However, often the repairing and ease of maintenance are either forgotten or placed at the bottom of the list. As I point out the different designs, I hope to illustrate the need to design for the future service and care of these systems from the start.

The purpose of the presentation is not only to describe the different circuits, but also to reduce the troubleshooting nerves of panic-stricken owners. It is one thing to have to deal with a delivery time of a battery or battery charger, but it's quite another to discover that they need to slash apart the substation to add a temporary component.

Although some lower voltage DC buses like 12V, 24V, and 48V are used in substations, this paper will concentrate on the 130 Volt buses that are the most common in the utility world. The telecom world uses mostly 48V systems that have one of the poles connected to building ground. This is OK for the lower voltages but the 130V is designed to be floating with reference to building ground.

PARTS OF THE DC BUS IN UTILITY INDUSTRY APPLICATIONS

The typical utility dc bus consists of a battery charger, a string of batteries, and a dc distribution panel wired out to the loads. Dc cabling runs can be found throughout a sub-station or power plant. Some systems contain redundant battery chargers on one battery. Other installations contain two redundant batteries and chargers, creating two independent dc buses. Some have two 130V battery banks in series and feed, not only two 130V buses, but also a combined bus of 260VDC load. In the past, a substation would operate loads such as control relays, breaker coils, and some alarm lamps. A power plant can use the DC bus for lubrication pumps for the turbine, DC to DC converters, inverters, and countless other controls and alarms. The loads are nearly the same in a modern substation built today, except the dc bus is also powering more complicated electronic equipment and communications hubs for remote operation.

The battery

Most common battery types in these applications are either wet, Lead Acid or Nickel Cadmium. The batteries typically range in size from 65Ah to several hundred Ah. I have seen a VRLA battery used in climate controlled substations/power plants, but most are wet cell batteries. One reason for this is that the temperature is not as well controlled in a remote substation and if the ac power fails neither heating nor cooling would be present. Also, new technologies are adopted carefully in the utility world. In most cases this is a good choice, due to the importance of the grid to society.

Because we rate the batteries as the most important component in the dc bus system, it is vital to pay attention to the health of the battery. Many kinds of products are available to warn of battery failure. But it is equally important for the user to know how long the battery will operate the load when it’s needed. Battery chargers are typically packed with alarm relays and lamps to indicate the battery’s health to the user, but many users depend on testing the battery. This test is a load discharge test and requires the batteries to be electrically removed from the circuit, discharged and recharged.

Battery and battery charger used in a switchgear application.

The battery charger

This ac to dc power supply is used to supply the power plant's dc loads while the ac supply is active. In most cases the battery charger is a constant voltage power supply sized to provide the required load current and recharge the batteries once they have been discharged. While the ac is present the battery is just idling with only enough current being exchanged to maintain the battery's float current.

In some cases the loads demand large currents for a short time; in this case both the batteries and battery charger act as shared sources. Since the battery charger is connected to the battery it makes the most sense to install options that monitor the dc bus's condition. Dc metering, showing the dc bus voltage and current, is almost always present. High/low voltage, AC failure, battery charger failure alarms and indicators have also been added from the earliest installations. Some folks want to know when the battery starts to discharge. Circuits that measure the direction of current in and out of the battery and provide an alarm have also been installed into the battery charger for this purpose. This battery charge/discharge option places the battery charger into the hub of the dc system, where the central wiring is located at the battery charger.

In modern times the electronic loads have become more complicated and users need a battery charger that behaves more like a battery. Increased filtering circuits have been added to the battery charger to reduce the ac ripple and simulate the dc voltage of a battery. This kind of filtering is called a Battery Eliminator, taken from the old radio days for a power supply that replaced the battery, and is often requested by utilities. Although the power supply behaves more like a battery in this case, the battery still serves the critical function of delivering large amounts of current when needed.

DC distribution

This is often done through a panel board of breakers or fuses powering each device (loads). The batteries and the battery charger can be added through separated breakers as the input to the panel board. The loads are viewed as the output. This is a simple way of connecting and protecting both the batteries and the loads. The distribution breakers protect against a shorted line to the load or the failed load itself. One of the battery's jobs is to deliver sufficient current to trip a single breaker without having the voltage drop for the rest of the dc bus. The battery charger usually is not big enough to do this job by itself. Sometimes equipment is powered by remote controls and the dc bus is directed to a switchgear enclosure. Inside the switchgear contactors and relays then feed dc voltage to remote locations as required.

Loads used in substations

The loads are all the components that are powered by the dc bus. The most important load found in a substation is a medium or high AC voltage circuit breaker controlled by the dc-power that disconnects and reconnects the outgoing/incoming ac line. Other loads are used for remote monitoring of the substation's dc and ac health. These loads are typically small during normal operation and when the battery is needed it only needs to operate relay coils for a short time. But for long ac outages, the battery is needed to continue operations for at least 8 hours.

Loads used in a power plant

Normal operational loads in a power plant are larger and more varied than in a substation. Inverters, DC to DC power supplies and numerous pieces of control equipment are powered by the dc bus. Whether the power plant is fueled by coal, gas, or hydro the dc bus is spread throughout the plant. In the case of the gas-powered plant, electricity is made with a gas turbine that requires a large oil pump protecting the turbine if it's being started up or cooling it down. In this case, the batteries are quite large to provide extended discharge times to run these pumps. In general, because a power plant's components are so expensive, the dc bus is often duplicated for redundancy.

DC disconnect

This switch device opens the battery connection, often fused, to protect the cabling. Safety disconnect switches are also installed on other pieces of equipment throughout the building. I recently needed to install an alarm option into a battery charger connected to a dc bus. The battery charger was wired directly to the battery and in order to service the equipment we were unable to proceed without shutting down the entire protective system.

Steering diodes

This set of diodes steers current into a load from two or more battery banks. It also prevents one battery bank's current from passing into any of the other batteries. This device allows the user to remove and maintain one bank and battery charger while the other bank/charger powers the load. The load will not have an interruption of the dc bus during this repair or inspection.

DRAFTING THE SYSTEM

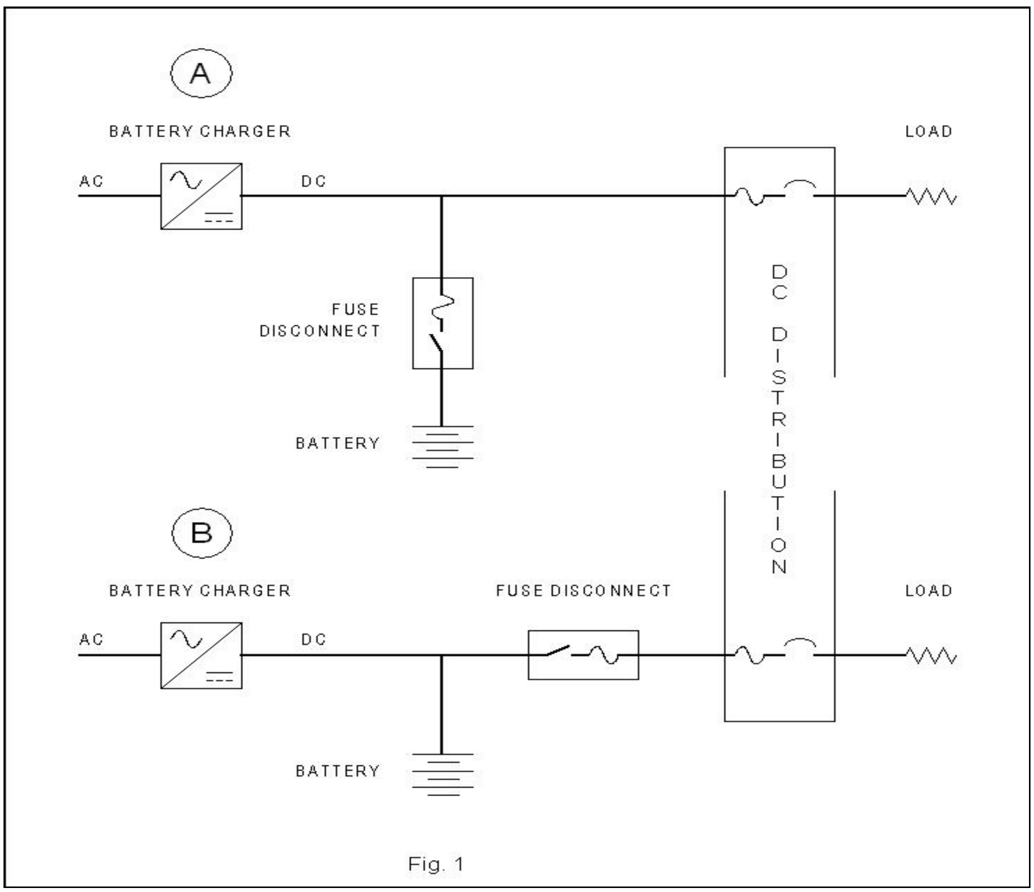
Often a single-line drawing for the dc bus in a substation is used to define the system. I see many of these single-line diagrams for power plants and substations in the planning phase. This works fine for ac wiring and for grounded dc buses, but it is best to show the floating dc bus with both positive and negative connections to enable sound decision making. This is because most of the switching equipment and protective devices are two poles. How they are connected to each other affects the folks that do the isolating, diagnostics, and final repairs.

Let's look at a typical substation dc bus as a one line

Figure 1 shows one battery, one battery charger, a fused disconnect and a distribution panel. The role of the fused disconnect is to protect the wiring from the enormous currents the battery is capable of delivering.

Circuit A is the most common I have seen. The rationale of this design is that the wiring will be better protected from the battery, and also the battery charger can be kept in the circuit if the battery is disconnected.

Circuit B is designed with the idea that the battery/ battery charger is a source set; the battery disconnect is moved up to protect the cabling from this set to the distribution panel. Sometimes the battery is connected through the battery charger and then goes to the load. Depending on the location of the battery, battery charger, and the disconnect, the single-line of circuit B might be how it is wired. Either way it is important that someone is alerted if the battery disconnect or a fuse opens for any reason so they know that the batteries have been removed from the circuit. The one line does not give us enough information to determine the importance and reasoning behind how we wire the circuit.



One line diagrams of a simple dc bus

Moving from the one-line to the two-line drawings

Now let's look at Figure 2, which shows the dc bus as a two-line drawing. Taking Circuit A from Figure 1, we have redrawn the system showing both the positive and negative lines. Neither drawing reveals the problems we can encounter once we are using and maintaining the system, although more complex systems will show the designer functions that would be missing in the one-line drawing. The reason I show this is to illustrate that by viewing either the one-line or the two-line drawings the designer does not see the differences the actual wire connections can make in the design. It is not until we choose and draw the wire diagram of the substation that we can see a difference in the connections and how they will affect the user over time.

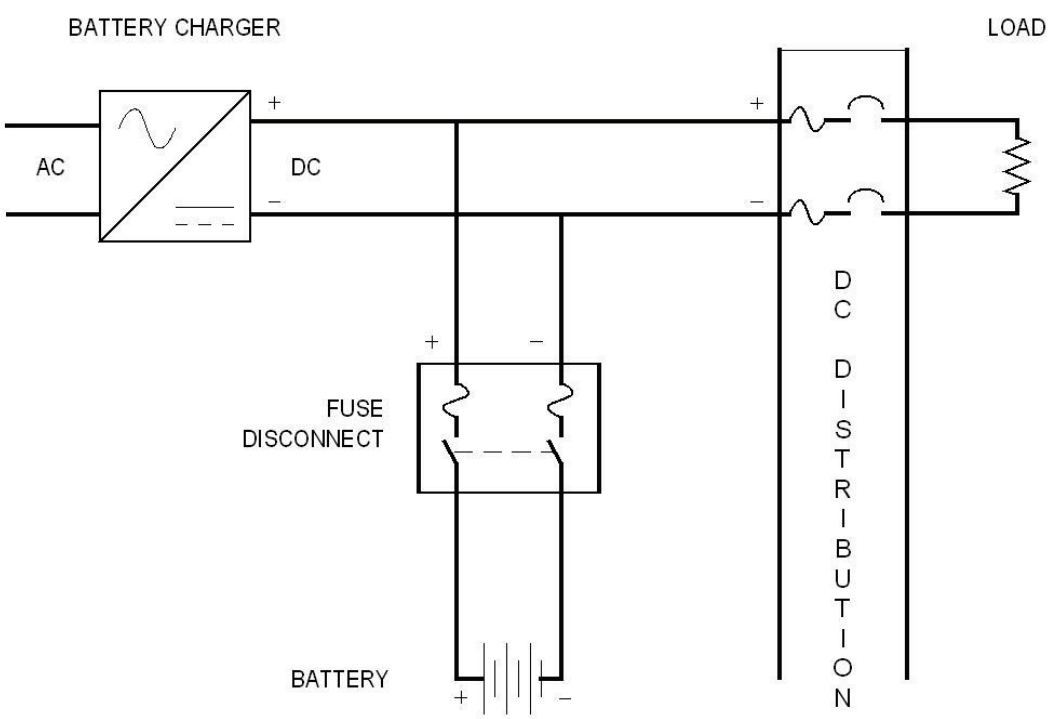


Fig. 2

The two line of Figure 2 shows a clearer view of the electrical connections, but not the wire connections.

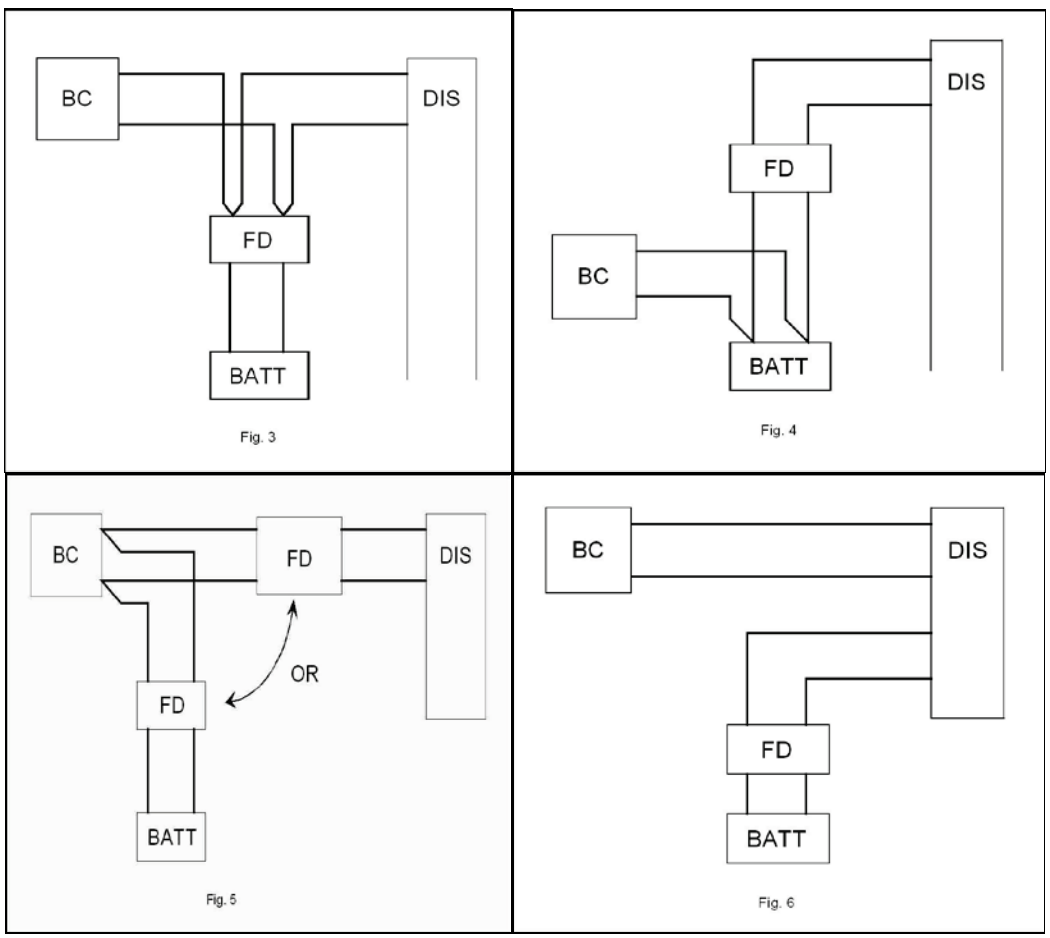
Designing the cabling using wiring diagrams

Figures 3 through 6 shows simple wire diagrams for the same dc bus. I have seen all of these designs used in the cabling connections of the dc bus in different substations.

All of these designs will work and seem safe and logical to the designer. But let's think about the maintenance guy who now needs to test his batteries, change cells, or modify, calibrate, or replace the battery charger. Over the battery's 20-year life, this will be done so often that the designer should consider it from the beginning. Adding extra input breakers to the distribution or test connectors to allow a second battery or battery charger to be easily added would simplify the maintenance person's task. In some cases, as soon as he starts to work on any of the components, he finds he has to rip apart the wiring and disconnect either the battery, battery charger or both to repair the system. This not only takes time, but carries a risk to the staff and the utility, because it leaves the loads unprotected.

The last diagram, Figure 6, shows the battery charger and battery going to a distribution panel. This design works the best for future repairs and maintenance. The battery charger includes a breaker or fuse to protect the bus from in internal failure. The battery charger is often current limited so the distribution breaker can be over sized if needed.

Why do designers choose diagrams like Figures 3, 4, and 5? As stated above, all three work fine. Furthermore, most designers consider the battery the hub of the circuit, so they tie the battery charger directly to the battery and the distribution or load is wired directly to the battery. There are advantages to this if the battery charger is measuring discharge current. Another advantage is that the ripple of the dc bus will be lowered if the battery charger is connected directly to the battery. This makes the battery disconnect the important part of the dc system becoming the hub of the dc bus. These are all important considerations, but can cause extra work, risk of injury or loss of power, and owner anxiety over the life of the system.



FD=Fused Disconnect BC=Battery Charger DIS=Distribution panel

Figures 3-6 show four alternative ways to wire the same dc bus

DESIGNING FOR REDUNDANCY

Adding Redundancy

Dc systems, being important to the survival of the grid, are designed to predict failure of any one component, while still sustaining the dc bus. Because components are duplicated, it is easier to repair each element. These redundant designs will be discussed in this next section, starting with the most simple and moving to the more complex.

Adding multiple battery chargers

The telecom industry's dc bus voltages of 24Vdc and 48Vdc were inherited from the original dc buses used in early telephone signal systems. Most of these modern telephone sites are unmanned and remote. These dc bus voltages lend themselves to a battery charger that consists of switching power supply modules that are mounted into a common backplane. The backplane can be loaded with more power supplies then what is needed to power the loads, as if it includes a spare in case one module fails. An alternative is to have independent battery chargers on one battery. You could go crazy and add another backplane full of battery chargers to protect against the backplane failing, or add another battery. This would duplicate all the components providing the dc bus power. In a telecom application these dc system are interrelated into one module or rack. Batteries, distribution and battery chargers are mounted together with pre designed internal cabling.

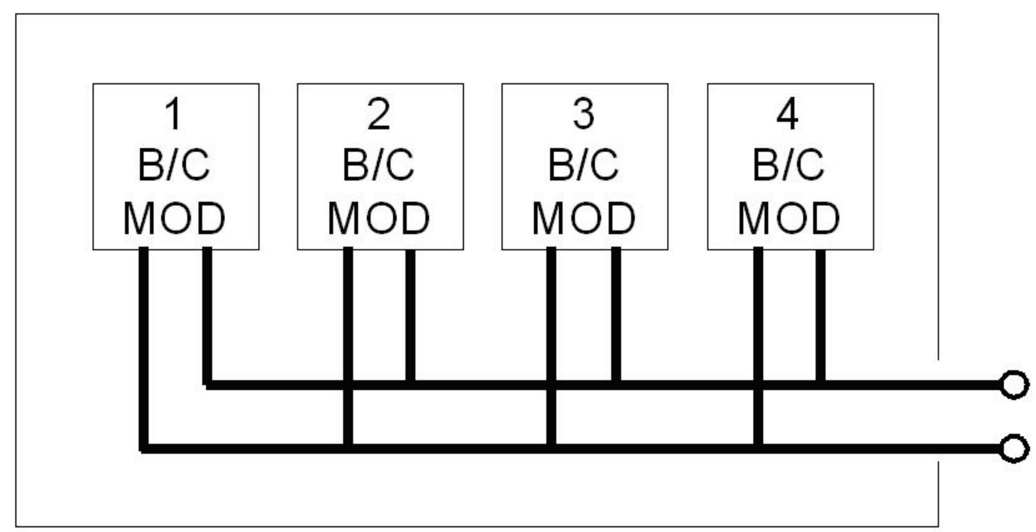


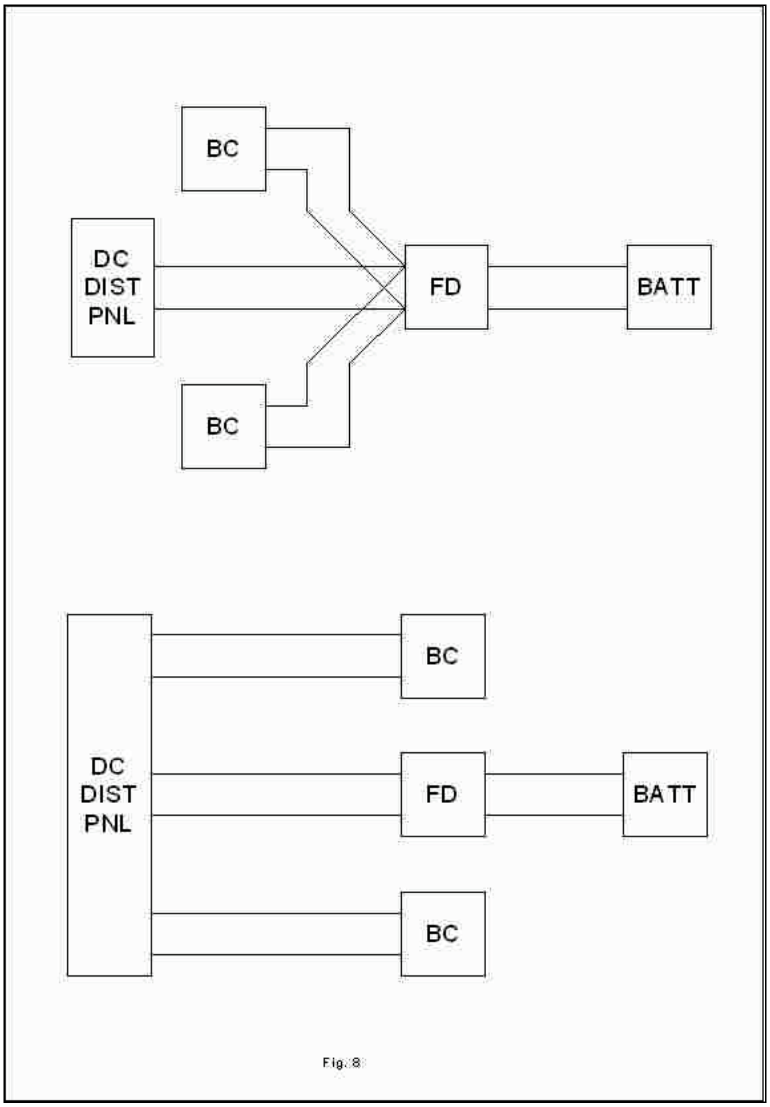
Fig. 7

Paralleled battery modules wired in a backplane for redundancy

Redundancy cont…

This same concept is used in the utility industry, where two separate battery chargers are connected to one battery. If one charger fails, the other charger is in service until the failed charger can be repaired or replaced. Since in normal operation the two battery chargers' output voltages will not be the same, one battery charger would carry the load current and the other battery charger would idle at zero current. In these cases, users wanted to know if the battery charger with no output current was operational, so a feature called Forced Load Sharing has been added. This forces the battery chargers to split the load current equally. A low current alarm was added to indicate a battery charger failure.

Figure 8 shows two different two-line drawings of the wiring of the dc bus. The top drawing shows the Fused Disconnect as the hub of the battery charger's connections. Below is the preferred connection, placing the distribution panel as the hub of the circuit.



Dual battery chargers and one battery

Redundancy cont…

To increase redundancy, two different battery banks, each with its own battery charger can be installed. This approach protects the load from a single battery failure that would bring down the whole system. But, since the batteries are connected together in parallel, a shorted cell or cells would cause current to flow from the healthy battery to the failed battery. The battery would still be only one component that could fail: all this approach achieves is to double its size.

By placing diodes, as shown in Figure 9, in the positive connection between each battery/battery charger set and the load, we can steer current from battery (A) without exchanging current with battery (B) or battery (B) without passing current into battery (A).

These diodes, which I call "Steering Diodes" (also known as a "Best Battery Selector"), are sized for the maximum current the load would demand. This design also allows a user to disconnect one of the batteries or battery chargers for servicing and keep the dc bus active to the loads. In some cases a breaker is added to allow one battery charger to charge both batteries. This is called a tie breaker. The tie breaker is left opened unless a battery charger is removed from service.

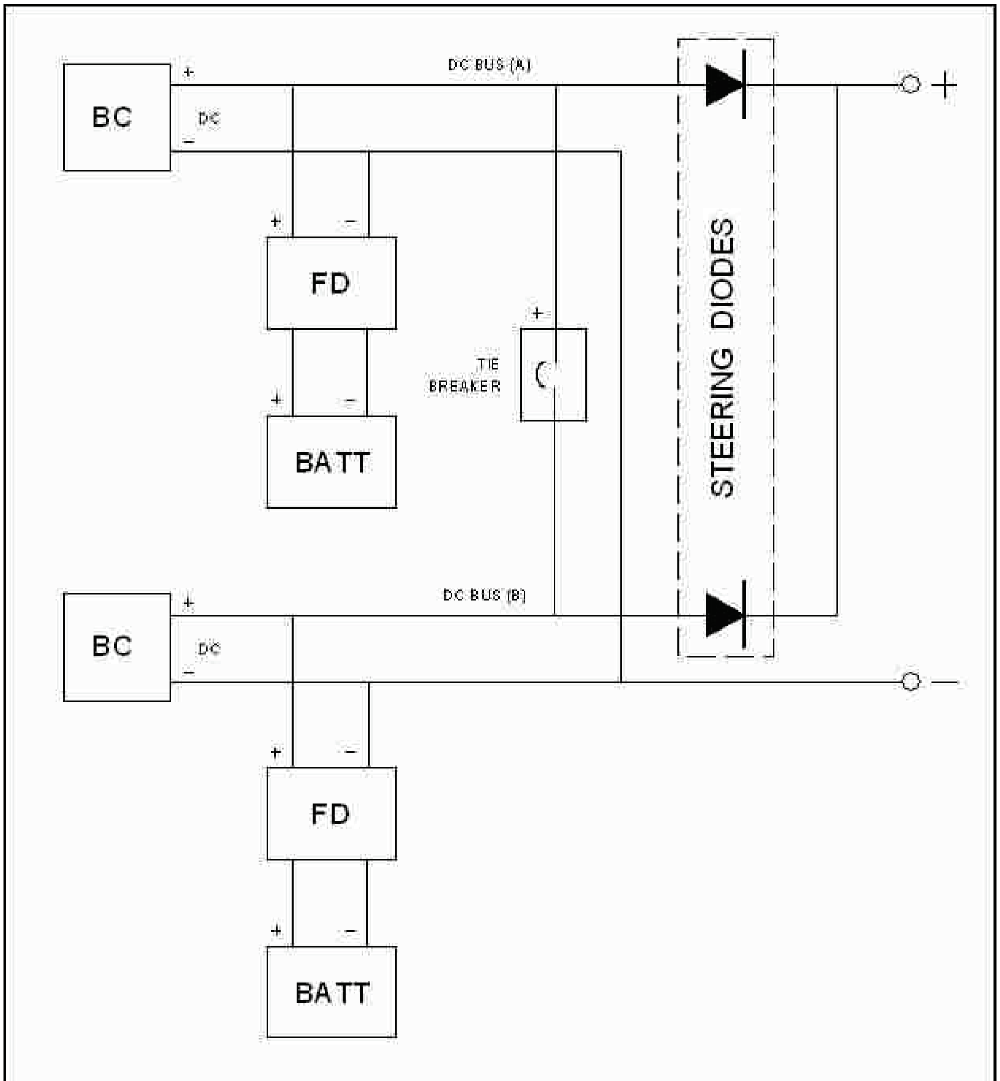


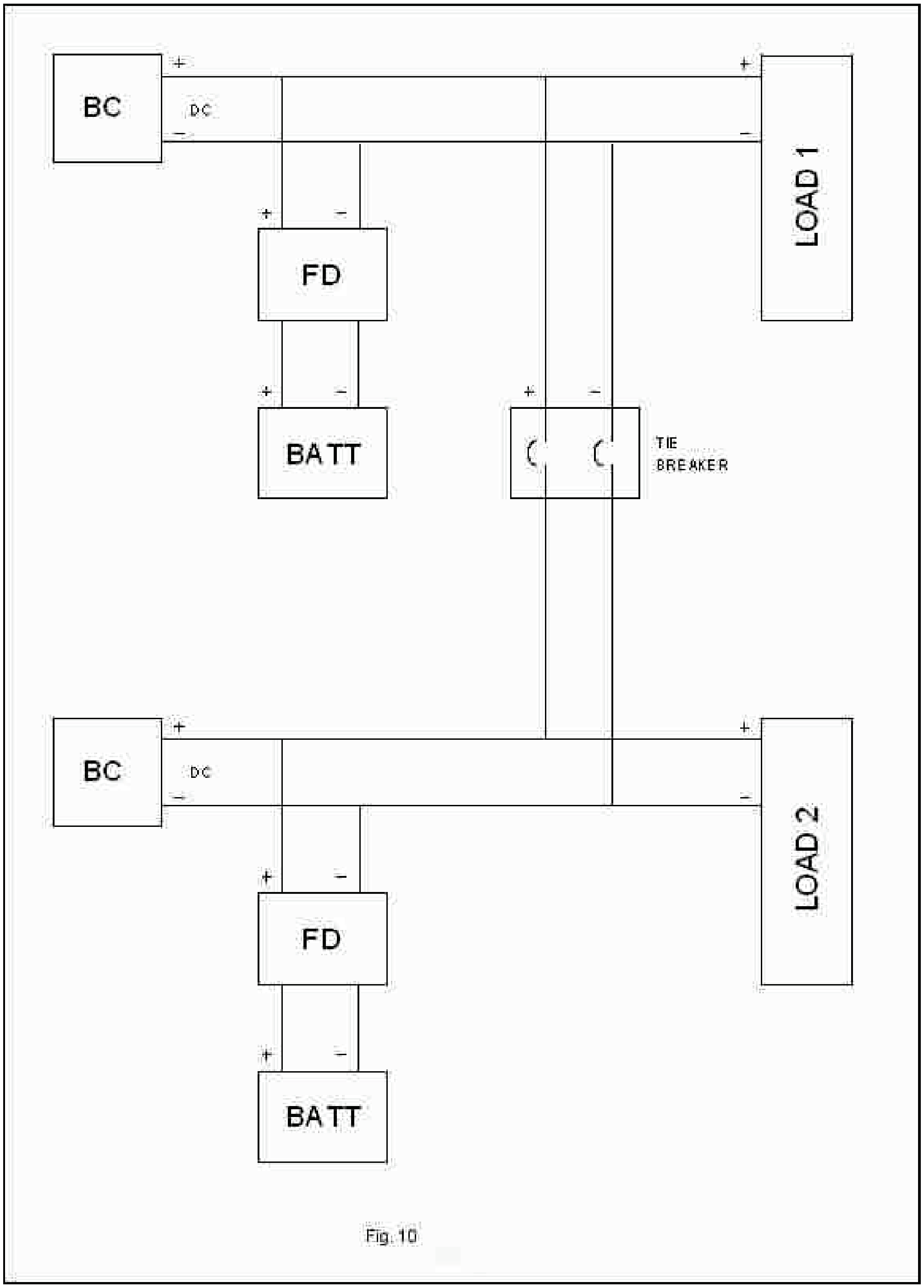
Fig. 9

Dual batteries and battery chargers with steering diodes

Redundancy cont…

Two batteries, two battery chargers, and two loads

In some cases the loads have been duplicated for redundancy. Figure 10 below just repeats the first simple layout (Figure 7). A tie breaker has been added to tie the two together if repairs are required. The battery chargers may need to be sized for both loads since they may end up supporting both loads through the tie breaker.

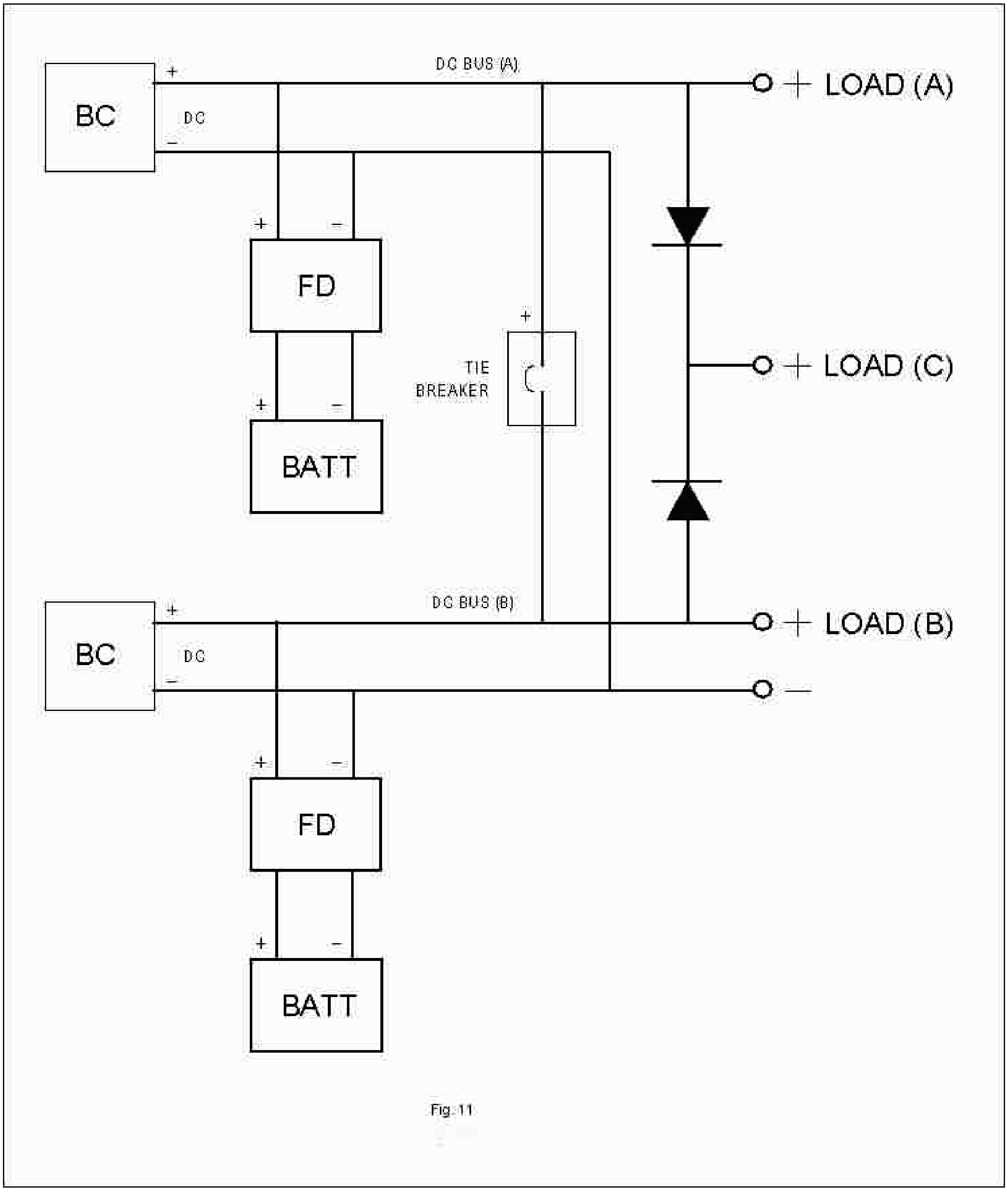


Two battery chargers and two batteries with tie breaker

Redundancy cont…

Two batteries, two battery chargers, and three loads

This common dc bus design is used in a power plant. The loads are duplicated and A and B buses are created. A third load set uses either the A or B dc bus as the source. The loads connected to this bus are the most important for control and protection. This design uses both the steering diodes from Bus A and Bus B to create Bus C. To increase redundancy even more, two battery chargers are placed on each battery. Adding a generator to provide an ac input to the battery chargers will keep the system operational longer than the discharge time of the batteries.



Dual battery chargers and batteries with three loads

DC BUS DESIGN TIPS
KEEP THE USER IN MIND

This presentation has provided an overview of the dc bus designs commonly used in the utility industry. These designs are particularly critical in this industry because of the widespread impact of a loss of ac power to the nation's electrical power grid. The designers of these backup systems must take a wide array of factors into account. Whether the design of a dc bus is simple or complex, it must satisfy a long list of criteria and designers often have to balance the items on the list carefully. I have tried to make the case for adding long-term maintenance to the top of that list. As the battery ages and requires attention, the battery service department staff will be able to perform their jobs more efficiently and safely if the bus was originally designed with maintenance in mind.

An Appeal to Designers

This section is written for the folks who design dc systems. Whatever one-line redundant dc bus systems you choose, I would urge you to spend time understanding users' needs as they maintain the bus over many years in the future. The following steps will help to keep everybody happy over the long term: the battery, the maintenance technicians, and the owners.

- Create the wiring diagram of the system in addition to the schematics.
- Think about protecting and removing each element.
- Remember that batteries added today may change in size and chemistry later.
- Battery chargers are increased in size to accommodate added loads.
- Design in extra space in all three dimensions of footprint.
- Add extra breakers, connections, or connectors for remote batteries, test equipment, and temporary battery chargers.
- Plan the floor layout to accommodate the spare battery or test loads.
- Build in building structure for lifting equipment above the batteries.
- Add disconnects and junctions at key locations.

The battery service department will be able to perform their job cheaper, faster, and safer.