# Designing More Reliable Battery Systems Using Steering Diodes aka Best Battery Selectors

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## INTRODUCTION

This paper discusses the use of diodes as protective devices when operating batteries in parallel. Diodes have been useful in performing many tasks such as rectification, voltage controllers, switching, lighting and as a part of radio tuners (variactors) by creating an adjustable capacitance used in a tank circuit. Diodes have many variations such as Schottky diodes which allow for lower voltage drops thereby making them uniquely useful for switching power supplies and certain microwave devices. LEDs or light emitting diodes for illumination, and zener diodes for voltage control are some other examples of diode circuit applications.

In this case we are dealing with diodes specifically designed for power handling. These diodes will operate in a pure DC mode and will be called upon to provide a blocking function. When properly applied the diodes within the BBS will be the unsung hero of any battery circuit that uses redundancy as the solution for greater reliability.

## Why Use Best Battery Selectors

The *(1)*NERC requirements allow for several approaches to determine battery reliability/availability. While all of the possible solutions have advantages and disadvantages, redundancy is clearly the easiest method to reckon with and redundancy is the method that is the simplest to define and understand. The key advantage of redundancy is simply stated; two batteries if properly designed and installed are always belter than one. Two batteries properly placed in parallel will require multiple failures before a catastrophe occurs. To achieve redundancy it requires that at least two systems are used. The question is; are two or more battery systems always better than one? The answer is; they may be as long as one system does not become a burden to the other.

**Using a redundant system with best battery selectors provides the following advantages;**

- Two systems minimum, each with the ability to accommodate the load.

- Proper system sizing would substantially reduce the battery and charger size for each individual battery used, as with 2 x 100% batteries in parallel they each could be smaller than if only a single battery is used. Further, if most applications were more carefully analyzed for actual load demand I am sure that many systems would see a noticeable reduction in battery and charger size.

    - Overall cost may be minimized since such factors as design margin and age factor may be eliminated since with two 100% batteries you would exceed the advantages normally associated with a single 100% battery that includes design margins and ageing factors.

    - With regard to the chargers they may also be sized smaller as they need to only recharge the duty cycle and provide for half the desired load current for the continuous load. Again no design margins should be added and ageing factors are always irrelevant in these cases.

- System integrity would be easier to determine as the battery that is failing in this arrangement would be able to indicate a lower bus voltage in comparison to the healthy battery.

    - The usual battery charger DC voltage monitoring should be adequate to determine many issues with the battery. Note that this does not completely replace normal preventive maintenance and monitoring that might be part of a normal routine. However a simple measurement of battery voltage differential would provide a gross indication of battery health.

*(1) See NERC Technical Paper on Protection System Reliability Draft 840, Redundancy of Protection System Elements, September 1997*

## Best Battery Selector Advantages Over Switching Techniques

Best battery selector systems have many distinct advantages. In overview these systems allow for the use of multiple batteries while ensuring that no single battery will be a burden on the system. The best battery selector is a passive device that requires no user intervention and will be an aid in ensuring circuit reliability and battery viability.

Unlike a mechanical transfer switch the best battery selector does not rely on a mechanical device or operator intervention for proper operation. When using a manual transfer switch, the operator must decide which battery to use and transfer the switch accordingly. Automatic transfer switches must monitor the voltages on both busses and determine that the primary bus is not good and then switch to the secondary bus. In both cases manual or automatic, a decision must be made by either a person or a device to determine which battery circuit is viable. In contrast the best battery selector does not require the user, operator, or switch to determine the viability of a battery. Physics determines which battery is viable and since both batteries are always in the circuit no manual or mechanical switching with regard to the battery selection occurs.

Another advantage of the best battery selector arrangement is that you may cascade more than two batteries for a single application. Transfer switches are limited to two circuits. Typically automatic transfer switches are choosing between two battery circuits and feeding a single load. When using best battery selector technology you may cascade as many batteries as the designer requires. While each diode will provide a 0.7V drop said voltage drop only applies for each individual battery feeding through its respective diode. This means that even though you may have multiple batteries in parallel with multiple diodes the actual voltage drop will be the 0.7V related to the individual string and not added since the diodes are in parallel.

## About Diodes

Diodes are commonly referred to as electricity's version of the check valve. In hydraulic applications a check valve blocks the flow of fluids in one direction and allows flow in the opposite direction. While some of the characteristics of the two devices are similar they are handled very differently by both designers and application engineers.

In simple electronic terms the diode is a device that allows current to flow in only one direction. The diode does this by consisting of a P-N junction (semiconductor device) wherein when forward biased (conduction mode) the diode allows all the current to flow except for approximately a 0.7V drop and when in reverse bias the diode drops all of the voltage inhibiting the current flow completely. This allows us to describe the diode as a self-actuating switch that is open in the reverse bias and closed in the forward bias. Unlike a mechanical switch which would drop maybe a few millivolts in the forward bias or closed mode the diode drops substantially more voltage, approximately 0.7V for this application using typical silicon power diodes.

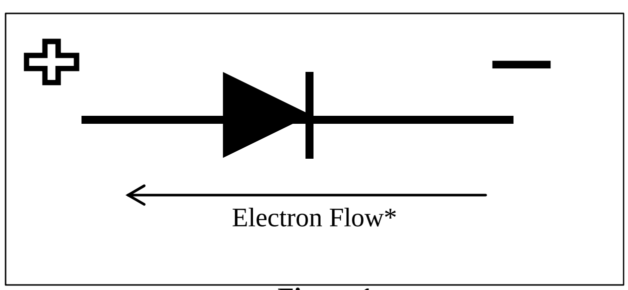


**Figure 1**

** Note: In Figure 1 the direction of current flow points against the direction of electron flow. It was reported that this symbol's arrowhead was developed by engineers who used conventional flow notation which shows current as a flow of charge from the positive (+) side of the voltage source to the negative (-). It is sufficient to say that if the polarity of the source matches this drawing you are in forward bias.*

## The Typical Best Battery Circuit Arrangement

For our application the diode we are referring to is a simple power diode.  This diode will operate in the circuit as a passive switch device that will bused in an OR mode so that it may combine the current from two or more sources while inhibiting any backflow to the source where the voltage is lower from the source where the voltage is higher.

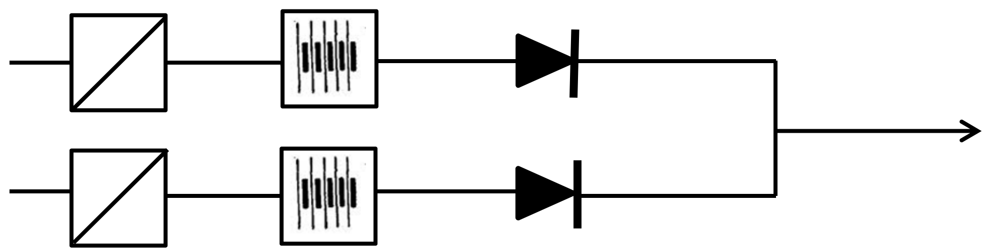

**Figure 2 – Typical 2 source ORing diode schematic using battery systems.**

In figure 2 the diodes allow current flow from either battery while inhibiting the flow between the two battery circuits.  Without these diodes the battery circuit at a lower voltage would invite current flow to it from the battery circuit that has the higher voltage.  Therefore the system with the higher potential will support the lower voltage system and thereby dispense energy in supporting the other system rather than in supporting the desired load.  When using these diodes if a battery system has a lower voltage or is open the system of higher potential would only support the load and not be permitted to feed the battery that is at the lower voltage.

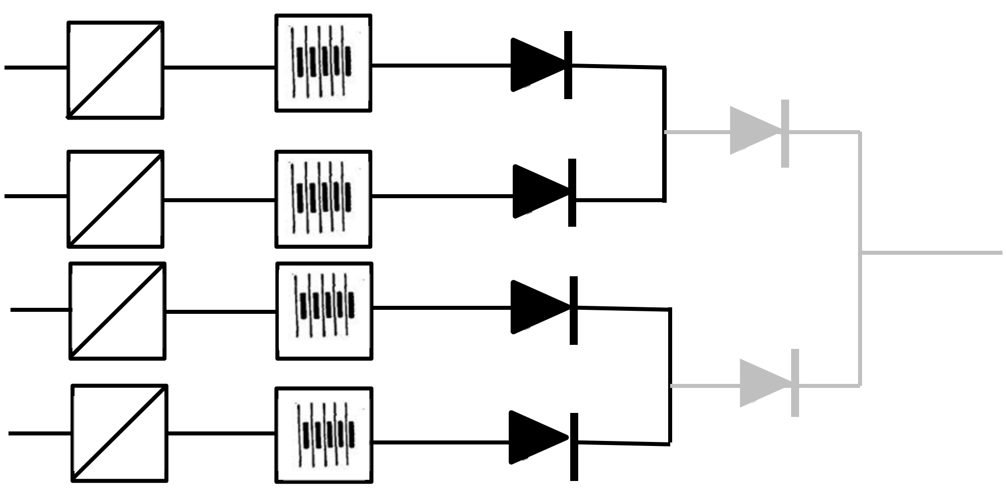

**Figure 3 – Typical 4 source ORing diode schematic using two cascade battery systems.**

Note that the BBS circuit as shown in Figure 3 may be repeated.  Best battery devices are limited to two or three circuits.  However these devices can be cascaded to accommodate additional strings if desired.  Using this arrangement as shown in Figure 3, the added diodes to the right in gray, may be omitted as their usefulness is questionable since it would require failures of the preceding diodes to require these additional diodes to be effective.  However if complete isolation is desired then the additional diodes and 0.7V drop needs to be accommodated.

## Applications for Best Battery Selectors

Best battery selectors are uniquely useful for all applications where parallel batteries are deemed advantageous. Best battery selector are useful for;

- Switchgear applications
- Engine Starting
  - Generators
  - Fire Pumps
- Communications
- Instrumentation and Control
- Lube oil pumps
- Turbine controls

In each of these applications there are certain special application requirements that need to be considered when applying best battery selectors. Some of the key considerations are described below;

**System Voltage –** Diodes are rated for an operating voltage and may be used accordingly. For example, if a diode is rated for a PIV of 300V it is required that the DC system voltage will not exceed the rated voltage of the diode. This diode rated voltage is referred to as the PIV or Peak Inverse Voltage. The reason for this designation of PIV is that it deals with applying AC to a diode. The diode's PIV is based on peak voltages where we usually express AC voltages in terms of the RMS value. However, the peak voltages are the actual peak voltages applied and that peak voltage must be considered when designing with diodes.

Applications engineers need to know the peak value when applying AC to the diode. For a battery application the peak voltage and the DC system voltage is the same. For AC circuits the RMS value is designed to provide you with a DC equivalent of an AC voltage, which is approximately two-thirds of the peak value. Therefore when using Best Battery Selectors for a DC circuit it is imperative that the PIV rating for the diode exceed the highest DC voltage which could occur on the DC bus. This includes the maximum possible equalize voltage that may be applied.

**Current Sizing –** Diodes will have a certain current carrying capability based on their design coupled with the design of the heat sinks used and whether convection or forced air cooling is used. To that end most manufacturers will publish multiple current ratings for their best battery selectors based on current and time.

Several items of designation are important to note about determining current carrying capability of the best battery selector, they are:

a) **Continuous Current Rating –** This is the current that the diode can accommodate continuously and would not cause any problems as a regular service rating. Typically, this is a rating usually given as the standard or advertised rating for the best battery selector.

b) **Momentary Current Rating** – The momentary current rating deals with the amount of current allowable for transient loads such as switchgear or engine start applications. In this case the current allowed can be quite high compared to the continuous current rating but may only be experienced for short periods of time.

**An Example of a best battery selection table**

A sample table has been provided below for reference purposes. Note that each manufacturer of best battery selectors would have their own versions related to their specific design.

**Table 1 – Sample best battery selector ratings**

| Continuous Current Rating | PIV | Battery Circuits | Current 1 Second | Current 30 Sec -18C | Current 30 sec 50C | Cooling Method |
|---|---|---|---|---|---|---|
| 50A | 300V | 2 | 1000A | 600A | 450A | Convection |
| 100A | 300V | 2 | 1000A | 600A | 450A | Convection |
| 200A | 300V | 2 | 1000A | 600A | 450A | Convection |
| 500A | 300V | 2 | 3500A | 2300A | 2000A | Convection |
| 50A | 600V | 2 | 1000A | 600A | 450A | Convection |
| 100A | 600V | 2 | 1000A | 600A | 450A | Convection |
| 200A | 600V | 2 | 1000A | 600A | 450A | Convection |
| 500A | 600V | 2 | 3500A | 2300A | 2000A | Convection |
| 800A | 600V | 2 | 3500A | 2300A | 2000A | Convection |
| 100A | 300V | 3 | 1000A | 600A | 450A | Fan |
| 200A | 300V | 3 | 1000A | 600A | 450A | Fan |
| 500A | 300V | 3 | 3500A | 2300A | 2000A | Fan |
| 1200A | 300V | 2 | 8700A | 8700A | 6800A | Convection |

**Best Battery Selector Options and Alarms**

Best battery selectors are passive devices that do not require any external power for operation. Diodes are extremely reliable components that do not require any maintenance for good operation. Fusing or circuit breakers are not typically used as they would offer weak points that could diminish reliability; although it is recommended that you have an ability to disconnect the battery from the BBS electrically before handling the live connections. For that purpose we would recommend use of a disconnect device that is not current limiting such as a non-fused mechanical disconnect, suitably rated.

Certain optional equipment and alarms may be added to best battery selectors that would enhance monitoring, these include:

- **DC Load Ammeter –** this ammeter would indicate load current as it would monitor the DC bus for load and provide a cumulative current at the output of the best battery selector.

- **DC Zero Center Ammeter –** this ammeter would be able to provide a zero center display of the current either charging the battery or the current being removed from the battery.

- **DC Load Voltmeter –** this voltmeter would monitor the DC voltage at the output of each best battery selector and provide for the differential bus voltage from the charger side of the battery and output of the best battery selector.

- **End of Discharge Alarm –** the end of discharge alarm would monitor the DC bus voltage at the output of the BBS and provide an alarm based on a predetermined set point that indicates the battery has been depleted based on end voltage.

- **End of Discharge Alarm with disconnect contactor –** this is the same as the aforementioned End of Discharge alarm but also provides a contactor suitably rated to remove the battery from the load for those batteries where a low DC bus voltage could damage the future integrity of the battery.

- **Diode Open Alarm –** this is a unique alarm that monitors each diode in the best battery selector. The diode open alarm uses a series/parallel diode arrangement and fuse to operate a relay contact if the BBS' diode opens.

## Terminology Associated with Best Battery Selectors

***Some of the common terminology for this paper includes the following;***

**Anode –** Positive side of the diode.

**Best Battery Selector or Steering Diode –** A device that uses diodes to isolate two current sources that prevents either source from back feeding into the other source. The term *best battery selector* specifically refers to using diodes to isolate two or more battery circuits while the term *steering diode* is more commonly used for isolating non-battery current sources.

**Cathode –** Negative side of the diode.

**Continuous Current Rating –** Refers to the current rating of the device or appliance that the device can handle without any time limit. This rating is usually also provided in terms of a maximum ambient temperature rating.

**Diode –** A device used to allow current to flow in only one direction with far greater ease than in the opposite direction.

**Forward Bias –** Refers to a diode circuit that is polarized so that current will flow through the diode freely.

**Junction –** The area within the diode that the P-type Material and N-type Material will contact the depletion region. The area of the diode known as the depletion region is the area where action of the component occurs. In forward bias this region is small or thinner allowing for current flow and when reverse biased this area becomes larger thereby inhibiting current flow.

**Maximum Device Voltage –** This voltage is the maximum voltage that the device arrangement is designed for. When applying best battery selector devices it is typical that the device can tolerate voltages that exceed the system voltage. For example a best battery selector may be capable of operating up to 300VDC applied to it but the actual circuit may be rated for only a typical 125VDC battery circuit that goes to about 145VDC at maximum. This would be considered OK. If the system were a typical 260VDC that could experience a bus voltage of perhaps 305VDC a BBS of a higher DC voltage rating is required.

**PIV Peak Inverse Voltage –** This is the maximum voltage that the diode can tolerate in reverse bias without breaking down the diode. For the purpose of this paper it is the same as maximum device voltage, as stated above.

**Reverse Bias –** Refers to a diode circuit that is polarized so that current flow is inhibited through the diode.

**Transient or Momentary Current –** This refers to the current that the device or appliance may experience for a predetermined time period where the applied current exceeds the continuous current rating of the device. This is usually expressed as a current in amperes, a time period usually in seconds, and an ambient temperature. All of these stated allowances must be met to ensure that the device operates without damage.

## Specifier's Guide

To specify a best battery selector the following information must be established.

- ✓ System operating voltage. The BBS must be adequate to accommodate the system voltage and the highest voltage to be accommodated.

- ✓ A careful evaluation of loads both constant and transient to ensure that the diodes within the BBS are adequate to the tasks required.
    - Be sure to carefully consider the intensity and duration of the transient loads so as to be within the tolerances of the BBS selected.

- ✓ Evaluate any desired protective devices. While battery circuits are used as a critical last effort to preserve power it is important to specify any passive protective devices (fuses or circuit breakers) to specifically accommodate faults and not to accommodate overloads. Trying to protect the best battery selector from overloads is not really the best goal for this protection.

- ✓ Any other option such as alarms or metering also needs to be added in to the specification.

## Conclusion

The use of a best battery selector will provide an extremely easy way to offer the added benefit of a redundant system with minimal effort and a high degree of reliability. It is also important to note that overall system size in most cases can be reconsidered and reduced to allow for the use of a redundant system that does not double the cost of a single system.

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