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Innovative Battery Solutions

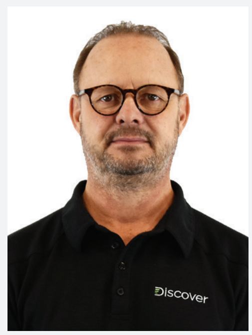
TECHNICAL GUIDE

Series, Parallel or Series and Parallel Battery Banks

Introduction

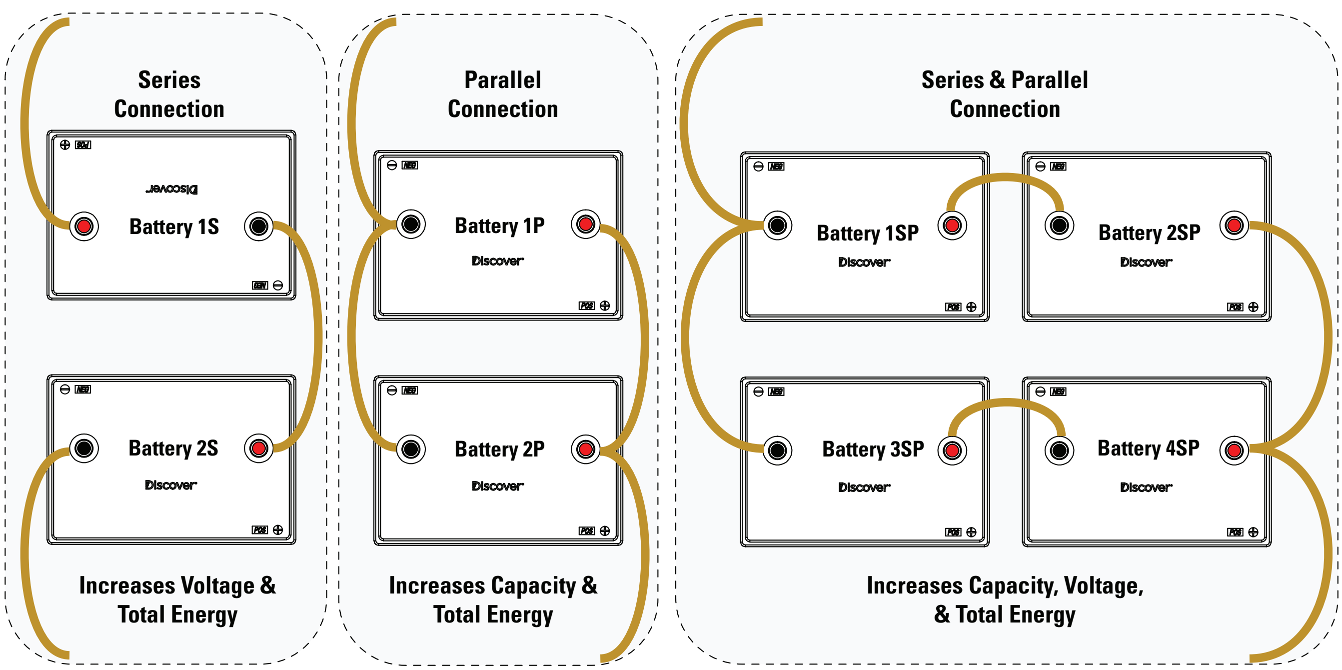
Battery banks are created by connecting two or more batteries together to support a single application. By connecting batteries into connected strings of individual batteries we create a battery bank with the potential to operate at an increased voltage; or with the potential to operate with increased capacity and runtime, or with the potential to operate both at an increased voltage and with higher capacity and increased runtime.

If you intend to utilise Series, Parallel or Series and Parallel battery banks you must make the connections amongst the batteries and in conjunction with the load and charging circuits in a manner that will prevent them becoming out of balance. Batteries improperly connected will experience uneven resistance to charge and discharge activity and will experience premature failure.



ABOUT THE AUTHOR

Darwin Sauer is the CEO and founder of Discover Battery, and CEO and Chairman of the Board of Discover MIXTECH Manufacturing Co. Ltd. He is a visionary, innovator and entrepreneur with over 35 years of experience in the industry, and the driving force behind Discover's MIXTECH lineup of batteries and the acquisition of the MIXTECH plant in Korea.



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How to connect lead-acid batteries in Series. Increasing battery bank voltage.

Batteries are connected in series when the goal is to increase the nominal voltage rating of one individual battery - by connecting it in series strings with at least one other individual battery of the same type and specification - to meet the operating voltage of the system the batteries are being installed to support. Connecting batteries in series incrementally adds the voltage and stored energy potential of each battery connected in the series string without changing the total amp-hour capacity of the completed battery bank.

Two 6 Volt batteries connected in series become a single 12 Volt battery bank by connecting the NEGATIVE (-) terminal of **Battery 1** to the POSITIVE (+) terminal of **Battery 2**. **DO NOT ATTEMPT to CONNECT** the last open POSITIVE (+) of **Battery 1** to the last open NEGATIVE (-) of **Battery 2**. This will cause a battery explosion or arch fault that will melt the terminals.

If there are only two batteries in the series string (as in the figure 1), we would then take a cable from the open POSITIVE (+) terminal of the first battery and a cable from the open NEGATIVE (-) of the second (last) battery in the string to the load and charger/power source.

Installers should carefully consider the use of BUS bars for permanent connections of charges and loads and/or easy disconnect cable ends for rapid interchanging between loads and chargers.

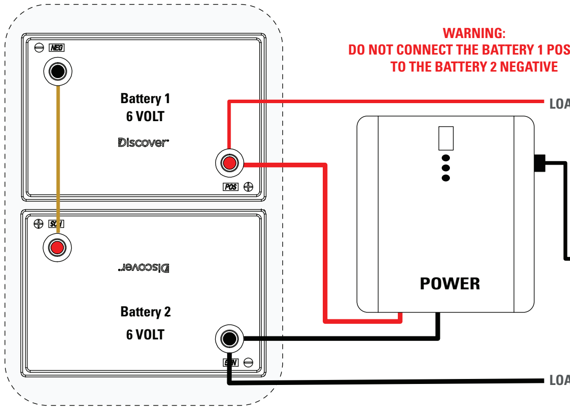

Figure 1. Series Connection 2 x 6V = 12V

The figure 1 series connection DOES NOT increase your amp hour capacity. This series connection only increases the total voltage (6V+6V = 12V) and the total stored energy potential in watts. If each 6V battery in the string was rated at 225 Amp hour (20Hr) to 100% DOD, the final battery bank rating would be 12V 225AH and would have a total of 2700 watts of stored energy to 100% DOD. NOTE: The Recommended depth of discharge (DOD) for high-quality deep-cycle lead acid batteries is not 100%. Most manufacturers recommend between 50% and 80% depending upon application.

"Volts x Amps = Watts":
One 6V-225AH (at the 20Hr rate) battery has 1350 Watts of stored energy potential at a 20-hour discharge rate. Two 6V-225AH batteries connected in series becomes a 12V-225AH battery bank with 2700 Watts of stored energy potential at a 20-hour discharge rate to 100% DOD. Connecting batteries in Series increases the battery bank voltage and total stored energy.

If you need even more voltage you will need to connect more batteries in series.

To do so, you continue this NEGATIVE (-) terminal to POSITIVE (+) terminal pattern of connection until you reach your desired nominal operating voltage (figure 2 illustrates four 6V batteries connected in series to achieve 24V). **DO NOT ATTEMPT to CONNECT** the open POSITIVE (+) terminal on **Battery 1** in the string to the final open NEGATIVE (-) terminal on **Battery 4**. This will cause a battery explosion or arch fault that will melt the terminals.

The NEGATIVE (-) of the last battery in the series will connect to your application load and/or the charger and the open POSITIVE (+) terminal of **Battery 1** will connect to your application load and charger/power source.

Installers should carefully consider the use of BUS bars for permanent connections of charges and loads and/or easy disconnect cable ends for rapid switching of the battery bank between loads and chargers.

The figure 2 series connection DOES NOT increase your amp hour capacity; it only increases

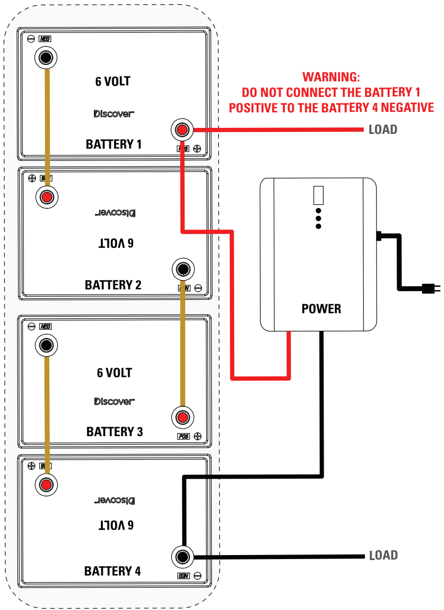

Figure 2. Series Connection 4 x 6V = 24V

the total voltage (6V+6V+6V+6V = 24V) and the total stored energy in watts. If each 6V battery in the string was rated at 225 Amp hour (20Hr) to 100% DOD the final battery bank rating would be 24V 225AH and would have a total of 5400 watts of stored energy potential to 100% DOD.

NOTE: The Recommended depth of discharge (DOD) for high-quality deep-cycle lead acid batteries is not 100%. Most manufacturers recommend between 50% and 80% depending upon application.

"Volts x Amps = Watts":
One 6V-225AH (at the 20Hr rate) battery has 1350 Watts of stored energy potential at a 20-hour discharge rate. Four 6V-225AH batteries connected in series becomes a 24V-225AH battery bank with 5400 Watts of stored energy potential at a 20-hour discharge rate to 100% DOD. Connecting batteries in Series increases the battery bank voltage and total stored energy.

The examples above used 6V batteries. If you use batteries with different individual voltages (2V, 6V, 8V, or 12V), the method of connecting POSITIVE to NEGATIVE as you progress through the string of batteries will be the same.

How to connect lead-acid batteries in Parallel. Increasing battery bank capacity.

Batteries are connected in parallel when the need is to increase the amp-hour capacity of a battery bank without increasing its voltage. This is very prevalent in the RV and Marine house battery world. Batteries are connected in parallel strings with other individual batteries to meet the required capacity or run-time of the loads the battery bank will need to support. Connecting batteries in parallel incrementally adds the capacity and stored energy potential of each battery connected in the parallel string without changing the voltage of an individual battery within the string.

In Figure 3, by connecting the NEGATIVE (-) terminal of **Battery 1** to the NEGATIVE (-) terminal of **Battery 2** and the POSITIVE (+) terminal of **Battery 1** to the POSITIVE (+) of **Battery 2**, two 6 Volt batteries connected in parallel become a single 6 Volt battery bank with two times the capacity and stored energy potential.

If there are only two batteries in the parallel string we would then take a cable from the POSITIVE (+) terminal of **Battery 1** to the charger. We would use the POSITIVE (+) terminal of **Battery 2** for connection to the loads. We complete the installation by connecting a cable from the **Battery 1** NEGATIVE (-) to the loads, leaving the **Battery 2** NEGATIVE (-) to be connected to the power/charging source.

Installers should always avoid connecting loads and charging/power sources to the same battery in a parallel string. Properly ensuring that loads and charging source connections are made to apposing ends of the string will ensure the bank stays in a more balanced state and can prevent premature battery failure.

The parallel connection shown in Figure 3 DOES NOT increase your battery bank voltage; it only increases the total capacity and the total stored energy potential. If each 6V battery was rated at 225 Amp hour (20Hr) to 100% DOD, the final string rating would be 6V 450AH *with 2700 Watts of stored energy potential at a 20-hour discharge rate to 100% DOD.*

NOTE: The Recommended depth of discharge (DOD) for high-quality deep-cycle lead acid batteries is not 100%. Most manufacturers recommend between 50% and 80% depending upon application.

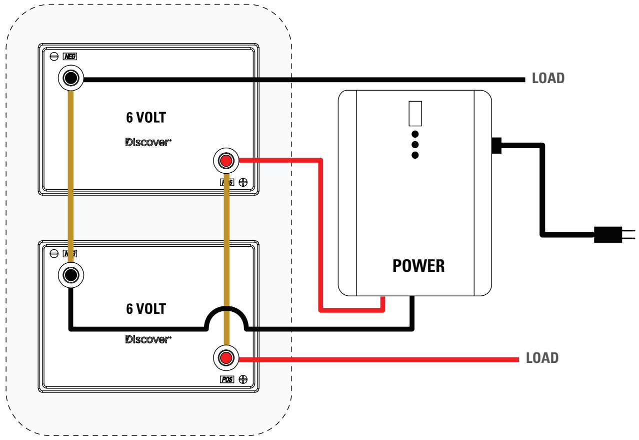

Figure 3. Parallel Connection 2 x 6V = 6V

"Volts x Amps = Watts":
One 6V x 225AH = 6V x 225AH or 1350 Watts of stored energy. Two 6V x 225AH in parallel = 6V x 450AH with 2700 Watts of stored energy.

The examples in Figure 3 used 6V batteries. If you use batteries with different individual nominal voltages (2V, 6V, 8V, or 12V), the method of connecting POSITIVE (+) to POSITIVE (+) and NEGATIVE (-) to NEGATIVE (-) as you progress through the parallel string will be the same.

Figure 4 is a diagram of two 12V batteries connected in parallel. This – popular in the RV and Marine industry - parallel connection DOES NOT increase your battery bank voltage; it only increases the total capacity and the total stored energy. If each 12V battery was rated at 150 Amp hour (20Hr) the final string rating would be 12V 300AH with 3600 Watts of stored energy when discharged at a 20-hour rate to 100% DOD.

"Volts x Amps = Watts":
One 12V x 150AH = 12V-150AH (20Hr) with 1800 Watts of stored energy potential. Two 12V x 150AH in parallel = 12V-300AH with 3600 Watts of stored energy potential at a 20-hour discharge rate to 100% DOD.

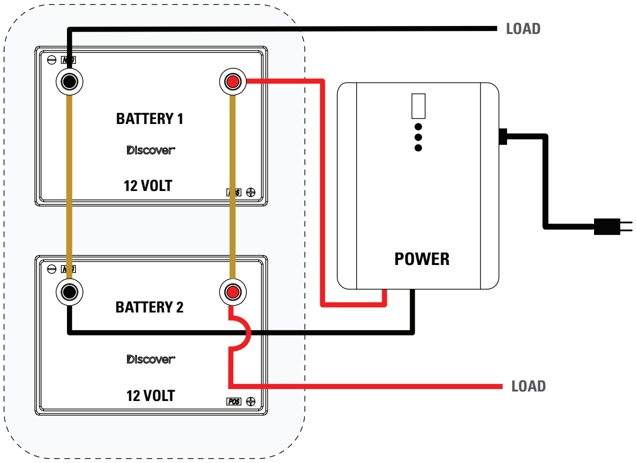

Figure 4. Parallel Connection 2 x 12V = 12V

NOTE: The Recommended depth of discharge (DOD) for high-quality deep-cycle lead acid batteries is not 100%. Most manufacturers recommend between 50% and 80% depending upon application.

If you need even more capacity you will need to connect more batteries in parallel.

To do so you would continue the NEGATIVE (-) to NEGATIVE (-) terminal and POSITIVE (+) to POSITIVE (+) terminal pattern of connection until the battery bank reaches the desired capacity (figure 5 illustrates four 12V batteries connected in parallel to build a higher capacity 12V bank).

Installers should always avoid connecting loads and charging/power sources to the same battery in a parallel string (See Figure 6).

This parallel connection DOES NOT increase your battery bank voltage; it only increases the banks capacity stored energy potential. If each 12V battery was rated at 150 Amp hour the final bank rating of the paralleled string would be 12V 600AH with 7200 Watts of stored energy.

"Volts x Amps = Watts":
One 12V x 150AH = 12V x 150AH or 1800 Watts of stored energy. Four 12V x 150AH in parallel = 12V x 600AH or 7200 Watts of stored energy.

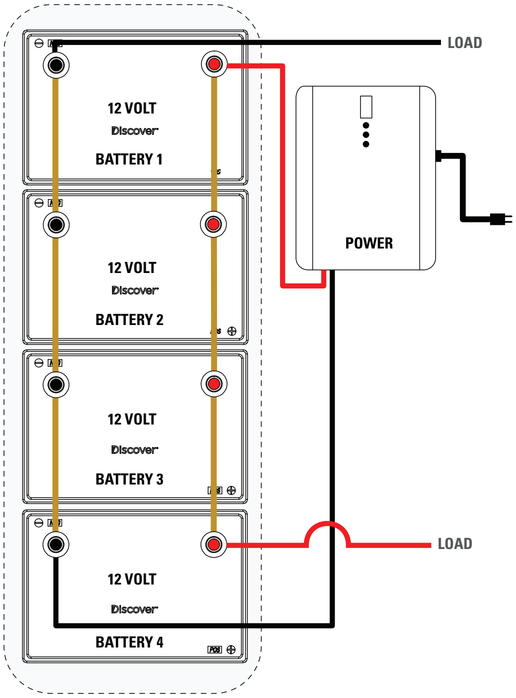

Figure 5. Parallel Connection 4 x 12V = 12V

How to properly charge lead-acid batteries that are connected in Parallel:

How batteries perform is all related to charge/discharge rates, to the temperature during the electro-chemical processes taking place during charge/discharge, to all of the inter-battery connections, and to a batteries age. Each of these are related to, or contribute to resistance. Resistance, and changes in resistance over time, come from the battery's internal component design, from changes in internal resistance during the charge/discharge electro-chemical process, from changes in temperature, and from resistance added to the circuit in the form of battery terminals, terminal connectors, and more. To achieve well balanced discharge and charge processes and to maintain a balanced battery bank, it is imperative that we do everything possible to ensure each battery is exposed to the same discharge loads and charging voltage, so we need to make sure that the resistance to either is the same at all points within the battery bank.

While it is against our recommendation to do so, it is possible to connect different types of batteries in parallel. However, if you do so, you can be sure the bank will fail prematurely because they will have different internal resistance variants to discharge and charge processes which causes constant out of balance depth of discharge and state of charge conditions.

When training our customer service groups on battery failure diagnostics, failure mode analysis and customer support, some of the questions they are trained to ask are:

1. How is the battery installed? Is it in parallel? Is it in series? Is it a series and parallel installation?
2. If installed in parallel, which battery in the string has failed?
3. Are all of the batteries in the string of the same type (AGM, GEL, Flooded, and Lithium), the same capacity, and the same age?
4. How are the batteries connected? Can you send me a diagram please?
5. When reviewing the wiring diagram, are all of the connector cables the same size and length?
6. Are all of the cable ends properly crimped and free of corrosion?
7. Do any of the battery terminals have more than two cable ends attached?
8. Are there any accessories tapping off of individual batteries in the string or are "all" loads being evenly applied?
9. Are there common Positive and negative BUS bars used in the installation?

Essentially all of these questions are related to the identification of potential points of resistance within the bank.

Figure 7 illustrates from BAD to BETTER, different ways to connect and organise loads and charge sources to ensure your parallel bank remains in balance and premature failures are avoided. To be clear, it is all about managing resistance so that each battery in the string is experiencing the same amperage during charge and discharge and is discharging and charging evenly.

DO NOT MAKE PARALLEL CONNECTIONS AS SHOWN IN FIGURE 6. This type of connection for loads and power/charge sources is guaranteed to leave the battery bank in an unbalanced position and will lead to early battery failure.

Generally, in addition to the need for a consistent number of interconnecting leads for each battery, the length and size (wire gauge) of the connectors should be the same. In order to maintain a balanced resistance across the battery bank, do everything you can to make sure that the length and wire gauge of each POSITIVE connector and its mirror NEGATIVE connector are the same. Even though GOOD, BETTER, and BEST configuration drawings have the appearance of uneven lengths you must do everything in your power to ensure your installation does not have different wire lengths and sizes.

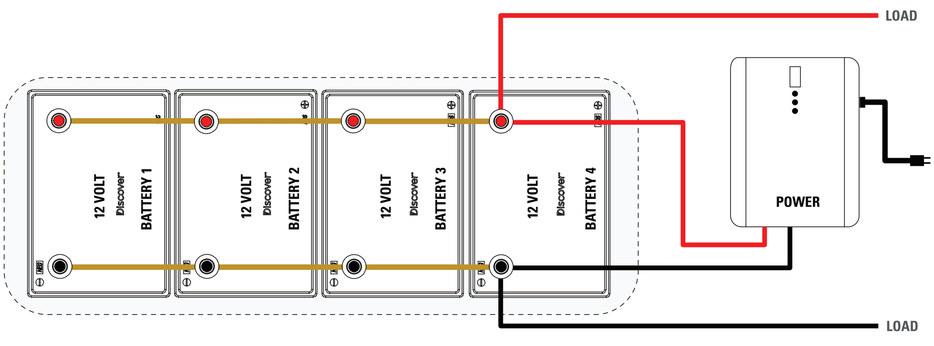

Figure 6. To avoid premature battery failure DO NOT make parallel load and charge / power connections this way.

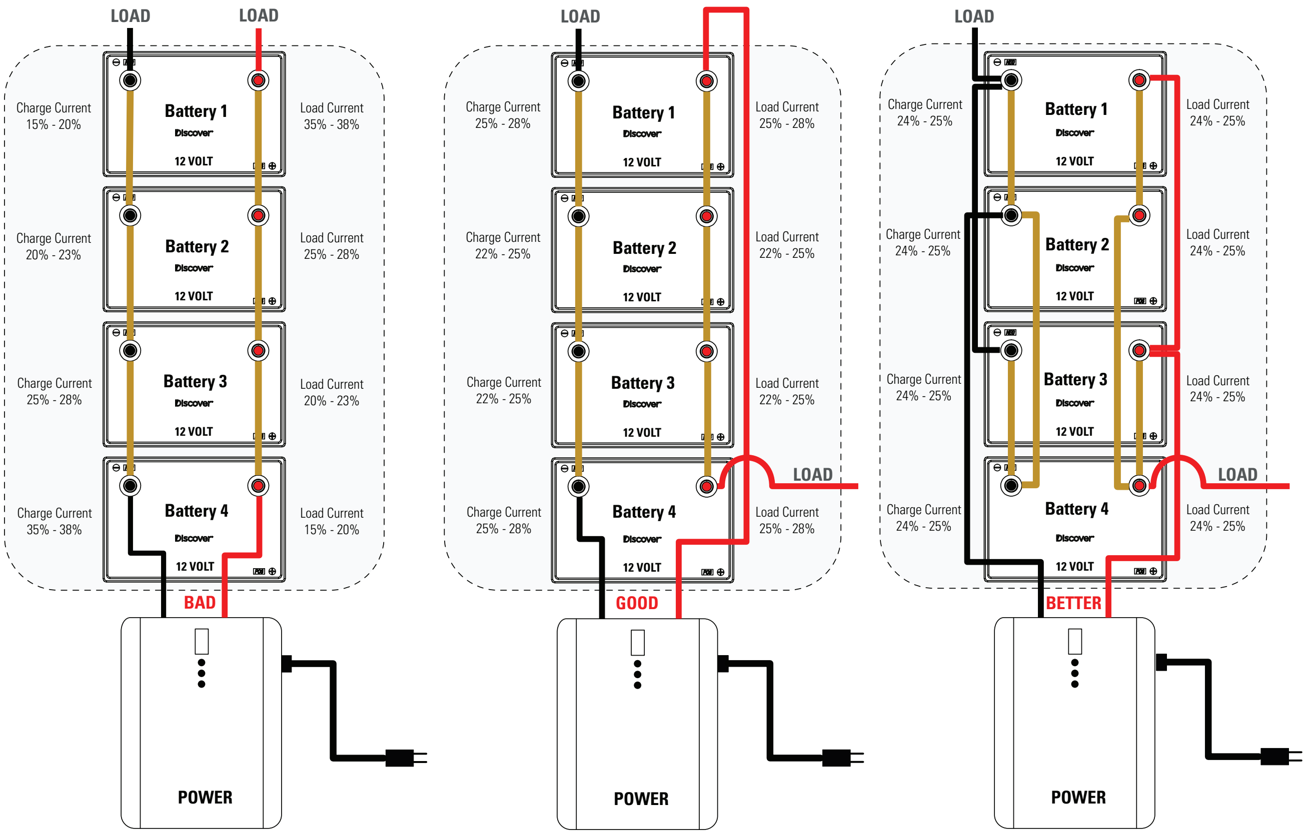

Figure 7. Cabling options for charging batteries in parallel

BAD parallel charging design: Because of uneven resistance levels, **Battery 4** in the BAD configuration in Figure 7 is going charge faster and discharge slower than **Battery 3,** which in turn will charge faster and discharge slower than **Battery 2,** which in turn will charge faster and discharge slower than **Battery 1**. The differences in internal resistance from **Battery 4** to **Battery 1** can generate a 50% difference in the amount of charge and load currents experienced amongst the batteries. This is not how you want to connect your parallel bank if you want to avoid premature performance loss and early battery failure. For additional independent verification/supporting materials visit IOTA Engineering. IOTA publishes some excellent technical papers (Balanced Charging).

GOOD parallel charging design: The GOOD wiring configuration in Figure 7 presents a better way of making connections to loads and chargers and will go a long way towards eliminating problems with unbalanced discharge and charge performance. By improving the distribution of resistance across all of the batteries and connections, each battery is allowed to maximise its performance and life. To achieve this improvement, you simply need to make your charge and load connections from either side (opposite ends) of the parallel bank. In this GOOD example, current will pass through three interconnecting leads with no more than a 15% difference between **Battery 1** and **Battery 2,** or **Battery 4** and **Battery 3**. This GOOD method of balanced charging can be used on both even and odd numbered battery strings.

BETTER parallel charging design: This BETTER method of wiring your parallel battery banks will result in the same amount of current being drawn from each battery during the discharge/charge process. It will maximize the performance and life of all your batteries as they will be charged and discharged evenly. This method of charging can be utilized when there is an even number of batteries (4, 6, 8, etc.)

BEST parallel charging design: The BEST method of wiring your parallel battery banks is to use POSITIVE and NEGATIVE BUS Bars as shown in Figure 8. Make sure the cable lengths and sizes between the battery terminals and the BUS bar and the batteries are the same. Do your best to make sure that the POSITIVE and NEGATIVE charge sources cable lengths and sizes are the same, and also that the cabling of the loads are of the same length and size. This BEST method of balanced charging can be used on both even and odd numbered battery strings.

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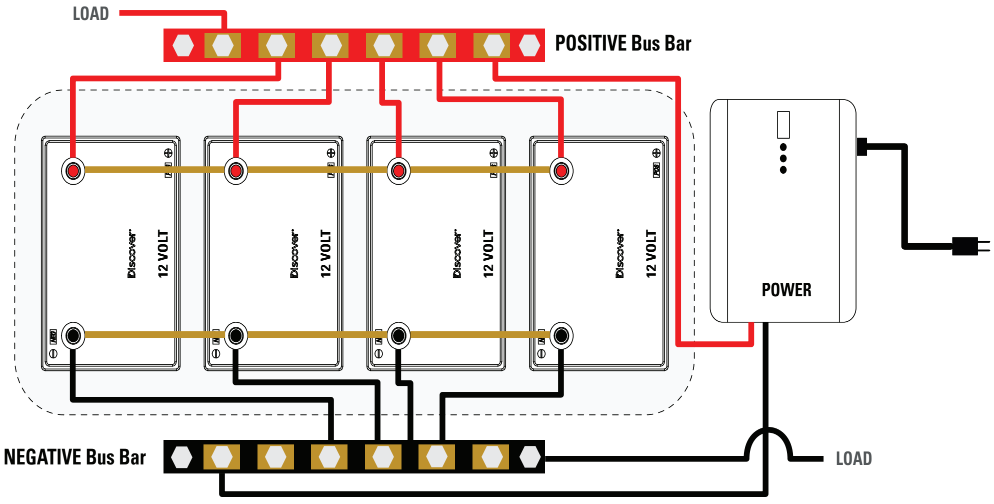

Figure 8. Parallel Connection 4 x 12V = 12V

How to connect lead-acid batteries in Series and Parallel. Increasing both battery bank voltage and capacity.

Batteries are connected in series to increase the nominal voltage rating – without increasing the capacity - of one individual battery to the operating voltage requirements of the application. Batteries are connected in parallel to increase the amp-hour capacity – without increasing the voltage - of an individual battery to the capacity or run-time needs of the application. Batteries can be combined in both series and parallel to build a battery bank that combines both an increase in voltage and an increase in amp-hour capacity.

Series parallel battery bank cabling/connections seem daunting at first, but with a little preparation and some practice on paper the process can be simplified and performed by anyone. It is good practice to label the batteries in each string. String one includes batteries 1A and 1B. String two includes batteries 2A and 2B.

Figure 9 is a diagram of a series connected string of 2 x 6V 225AH batteries connected in parallel with another series connected string of 2 x 6V 225AH batteries to create a 12V 450 AH battery bank with 5400W of stored energy.

"Volts x Amps = Watts":
One 6V x 225AH = 1350W. Two 6V x 225AH batteries connected in series = 12V 225AH with 2700W of stored energy. Two series strings paralleled together create a 12V 450AH battery bank with 5400W or stored energy.

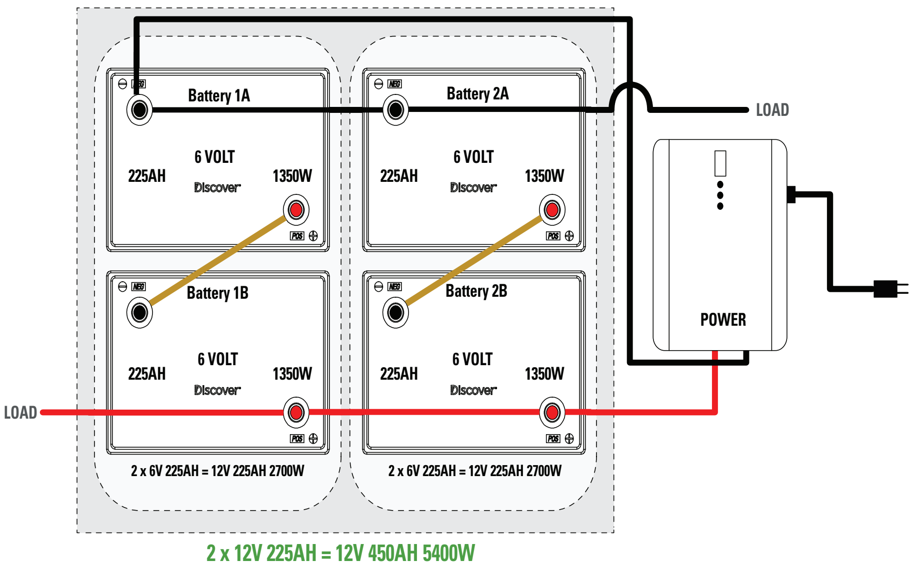

Figure 9. 12V Series and Parallel Bank using 2 strings of 2 x 6V 225AH batteries

Installers should always avoid connecting loads and charging/power sources to the same battery in a completed bank. Properly ensuring that loads and charging source connections are made to apposing ends of the string will ensure the bank stays in balance and can prevent premature battery failure.

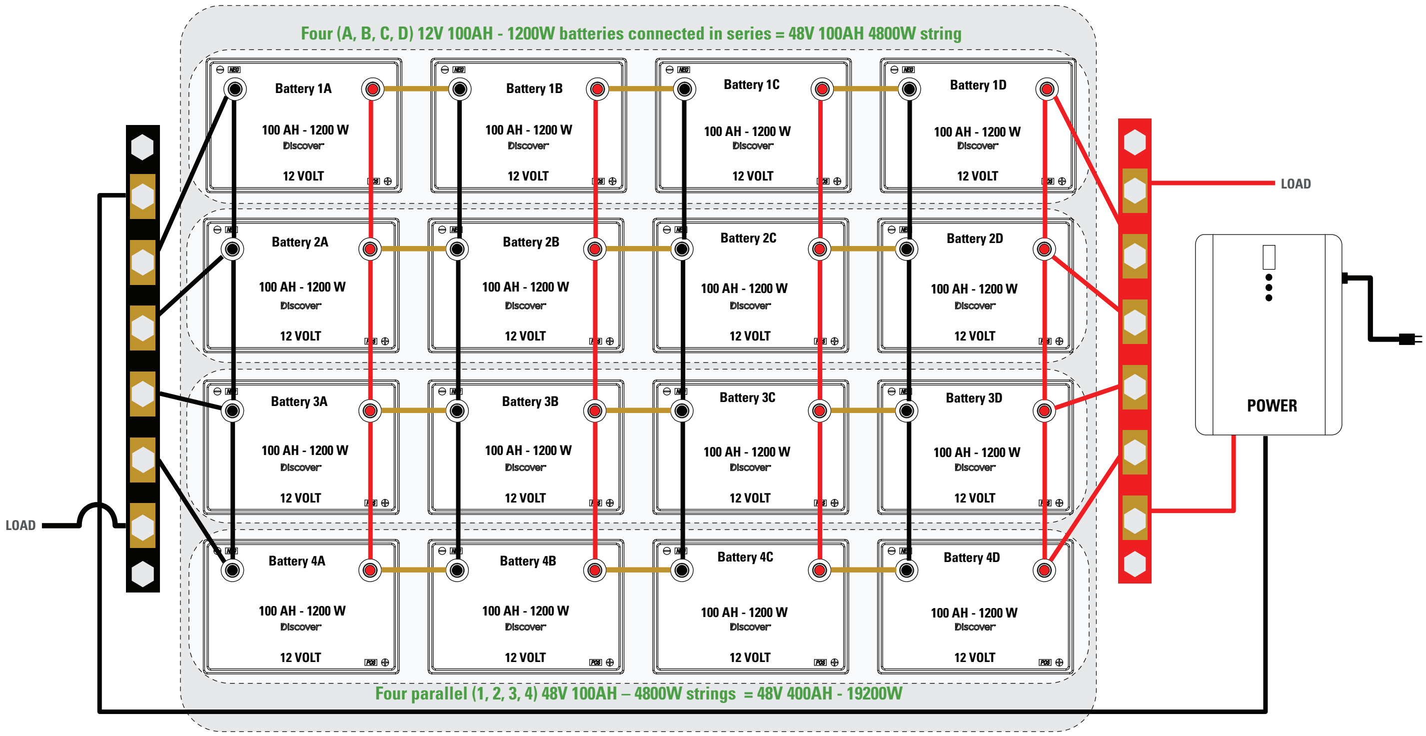

Figure 10. Four 48V series strings of 12V batteries paralleled and cross connected to prevent unbalanced batteries

Figure 10 is a diagram of a four 48V series strings paralleled to create both an increase in voltage and capacity. Each string is cross connected to promote a higher level of balancing across all batteries.

"Volts x Amps = Watts":
One 12V x 100AH battery has 1200 watts of stored energy potential. Four 12V x 100AH batteries connected in series = 48V 100AH with 4800 watts of stored energy. Four series connected strings parallel together create a 48V 400AH battery bank with 19200W or stored energy potential.

Installers should always avoid connecting loads and charging/power sources to the same battery in a completed bank. Properly ensuring that loads and charging source connections are made to apposing ends of the string will help the bank stay in balance, preventing premature battery failure.

Cross connections can be made to improve bank balancing even further. Make cross string connections between the NEGATIVE of **Battery 1A**, the NEGATIVE of **Battery 2A**, the NEGATIVE of **Battery 3A** and the NEGATIVE of **Battery 4A**. Do the same with the positive terminals of Battery 1, 2, 3 and 4. Repeat for B, C and D batteries.

CAUTION: Cross connecting series strings makes it more difficult to isolate one string from the bank for servicing. If you are in any way uncomfortable with understanding this, then you should consider Figure 11 for your larger banks of series and paralleled battery strings. The figure 11 battery bank will not be as equally balanced as the battery bank in figure 10, but the strings can be easily isolated from the other strings during servicing.

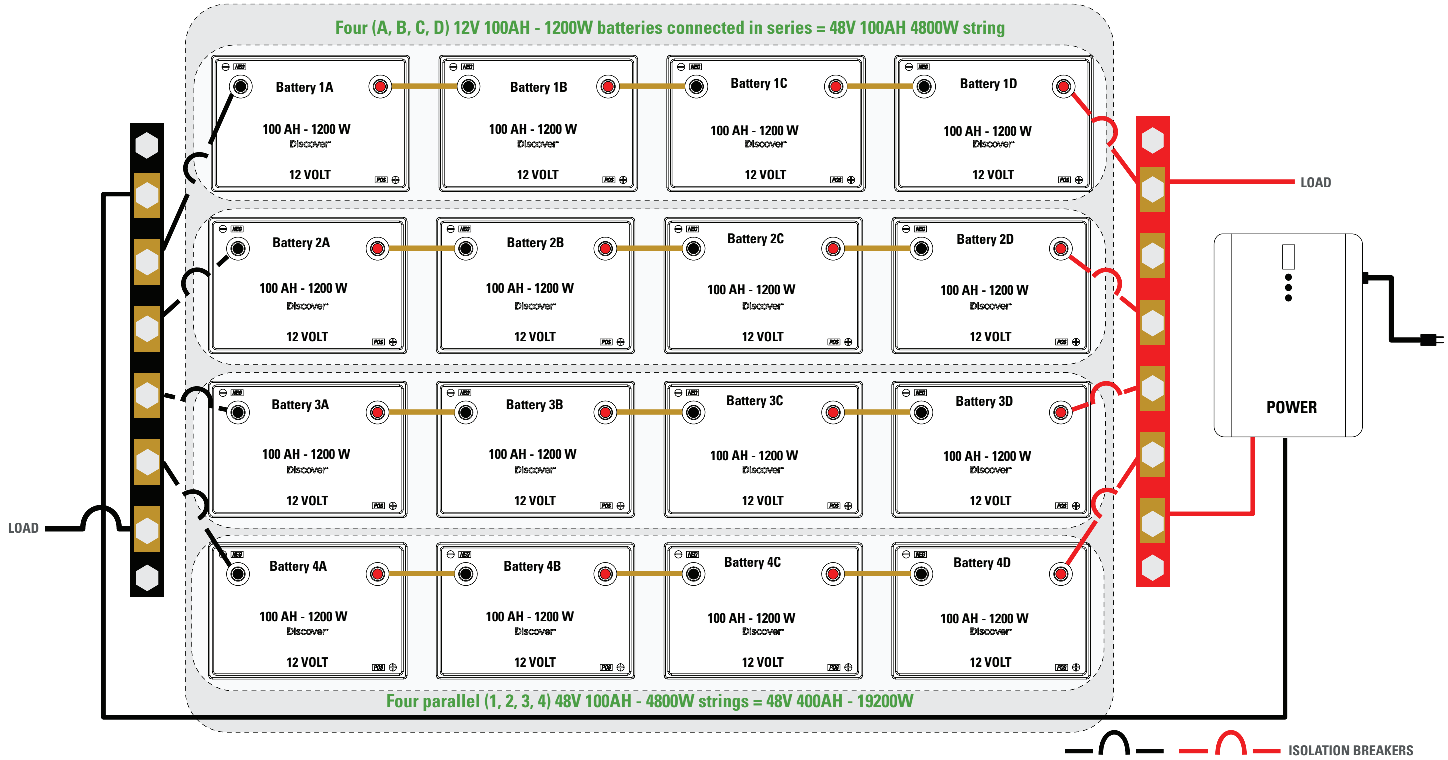

Figure 11. Four 48V series strings of 12V batteries paralleled onto a BUS with isolation breakers

Reversing the Trend: Easy steps to reverse lead-acid battery performance degradation and early failures:

Reverse the trend by installing Cost Effective and Proven Battery Sustaining Technology!

In addition to properly designing and cabling your battery bank, you should consider the installation of high-frequency pulse wave technology. This proven technology works independently of the electrical circuits connected to the batteries. They do not interact in any way! They are small and easy to install on a battery or battery bank. Once purchased, they are re-useable on one battery or battery bank after another as batteries are replaced. Pulse wave technology is also available in some chargers. These devices promote a high-frequency pulse across a battery's plates, working to keep the plates clean of sulfation and helping to sustain battery capacity and dynamic charge acceptance (DCA). Utilizing pulse wave technology along with proper charge maintenance practices is a proven way of eliminating premature capacity loss, battery failure and helps to reduce battery related costs. Charging with pulse wave technology has been proven to help discharged batteries recover allowing some batteries to be put back into service that might otherwise have been discarded. The Discover organization has deployed pulse wave technology that works. We are not sure about some of the products hitting the market recently as copycats, but you are free to contact a Discover dealer or representative for our definitive recommendation on product we "know" have worked for us and our customers for decades.

Reverse the trend by charging your batteries regularly to increase battery life and reduce operating costs.

You should be checking and recharging batteries. If you are using them regularly you should do it more often when opportunities like overnight stops, weekend breaks, or when inspections/repairs are happening. Instituting a practice of top charging batteries whenever possible, using an external charger if you need to, will not only reduce costs associated with premature battery failure, but can also lead to reduced fuel consumption of 1.5% to 3% for your generators and main engines.

Representation of a pulse wave