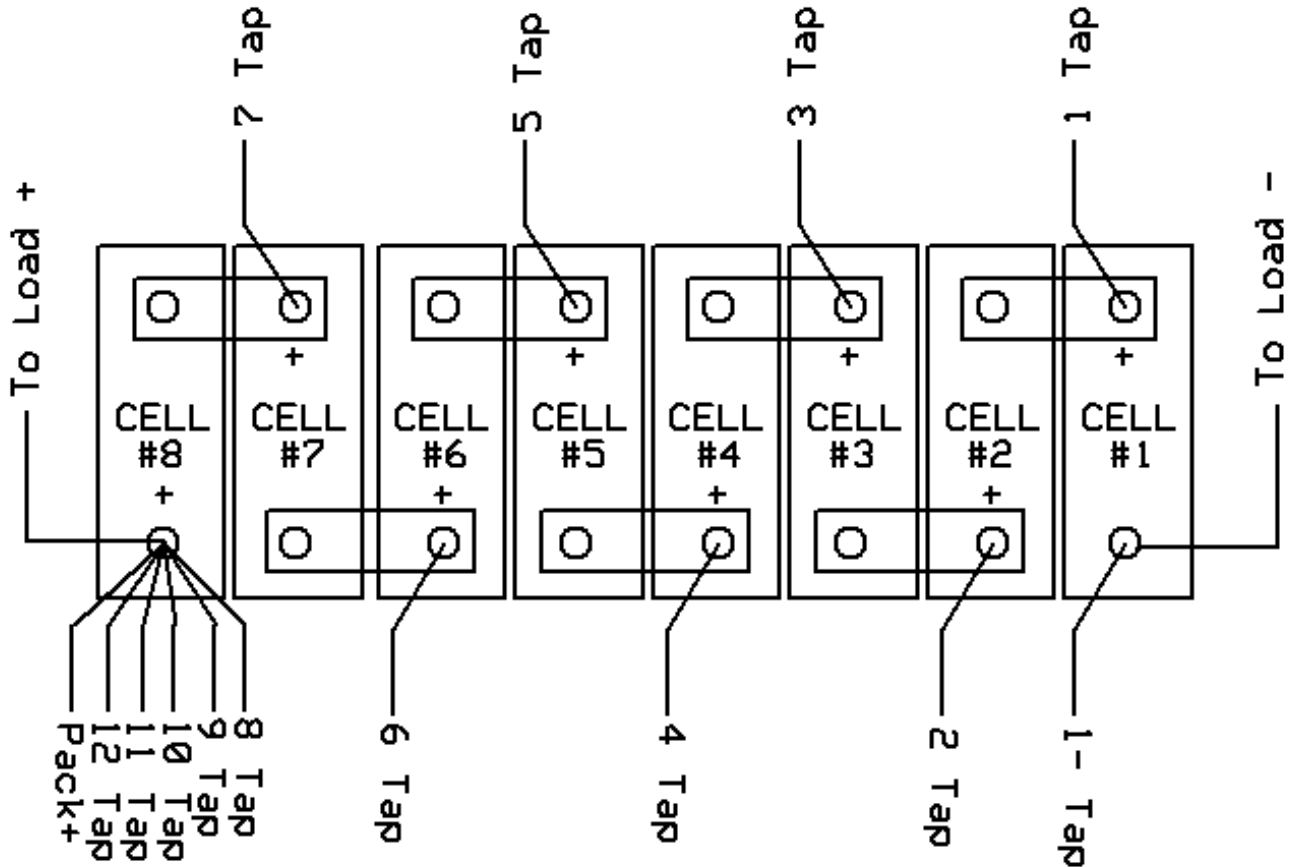**Parallel Strings**

Whenever possible, using a single string of lithium cells is usually the preferred configuration as it is the lowest cost and simplest means of assembling a lithium ion battery pack. However sometimes there are reasons why it may be necessary to use multiple strings of cells. Here are a few reasons that parallel strings may be necessary:

1.) Redundancy (only for specific applications)
2.) Hot swap capability (UPS applications, telcom, scalable systems, etc)
3.) When you must use a particular cell which is only available in a module with several cells in a string with no means of directly paralleling the cells.

Standard Battery Configuration

Below is a diagram of a standard 8 cell lithium ion string. Unless there are specific reasons for doing otherwise, this is the most desirable and simplest configuration:

In the above example, 8 cells are configured in a single string. This is an "8S1P" configuration. The "8S" indicates that there are 8 cells in series and the "1P" indicates that there are no paralleled cells. If each cell is 10 amp hours and 3.3 volts, the battery pack above would be 10 amp hours and 26.4 volts. For this setup, a BMS capable of monitoring 8 cells in series is necessary.

Standard Paralleled Cell Configuration

       Cells can almost always be paralleled directly together to create a larger cell. This is useful when a cell manufacture does not manufacture the correct size cell needed or sometimes can also be helpful when there are physical constraints. In some cases paralleling multiple smaller cells can also reduce the overall internal resistance and increase the power capabilities of the pack. The method of paralleling cells directly together as shown in the diagram below is generally the simplest and preferred method of increasing the capacity of the battery pack.
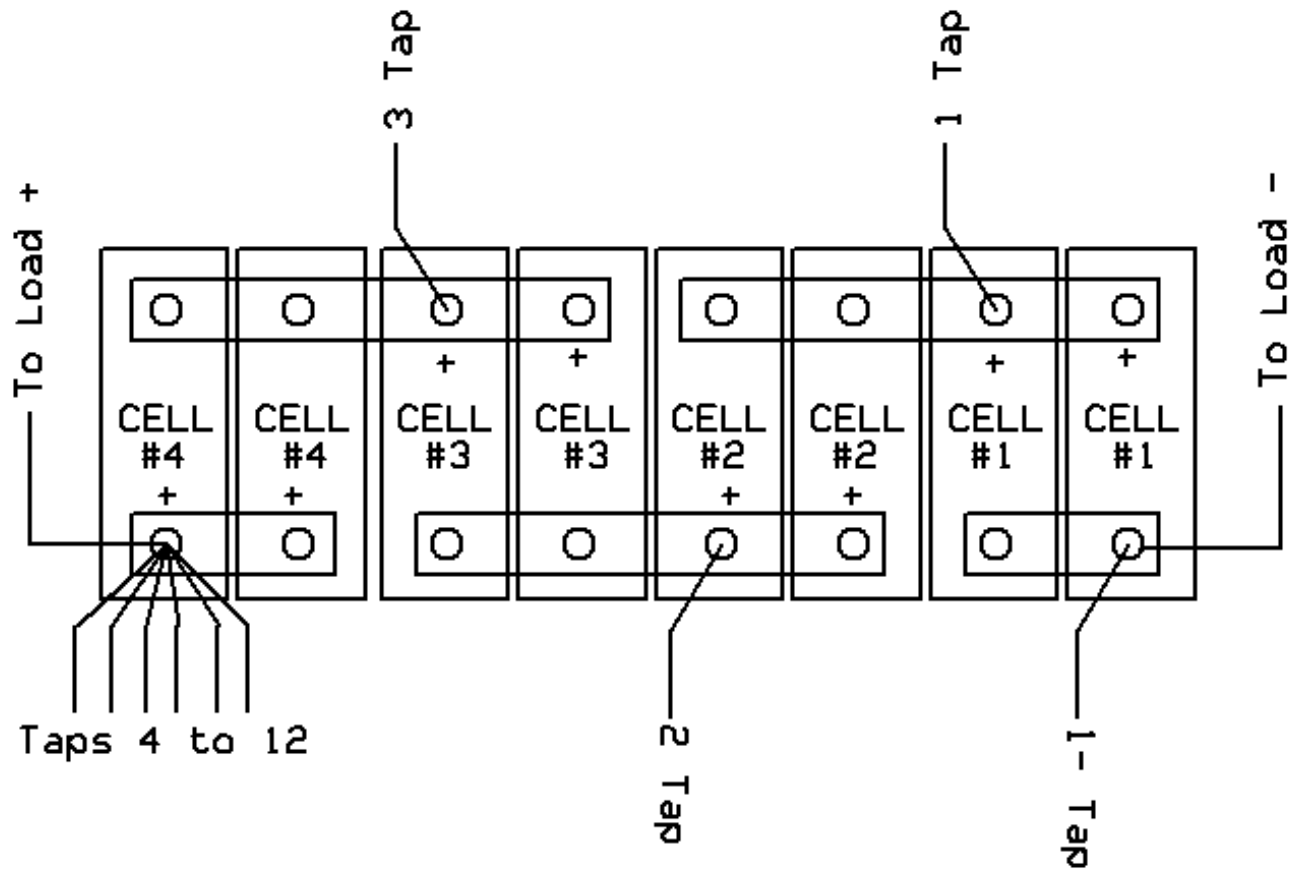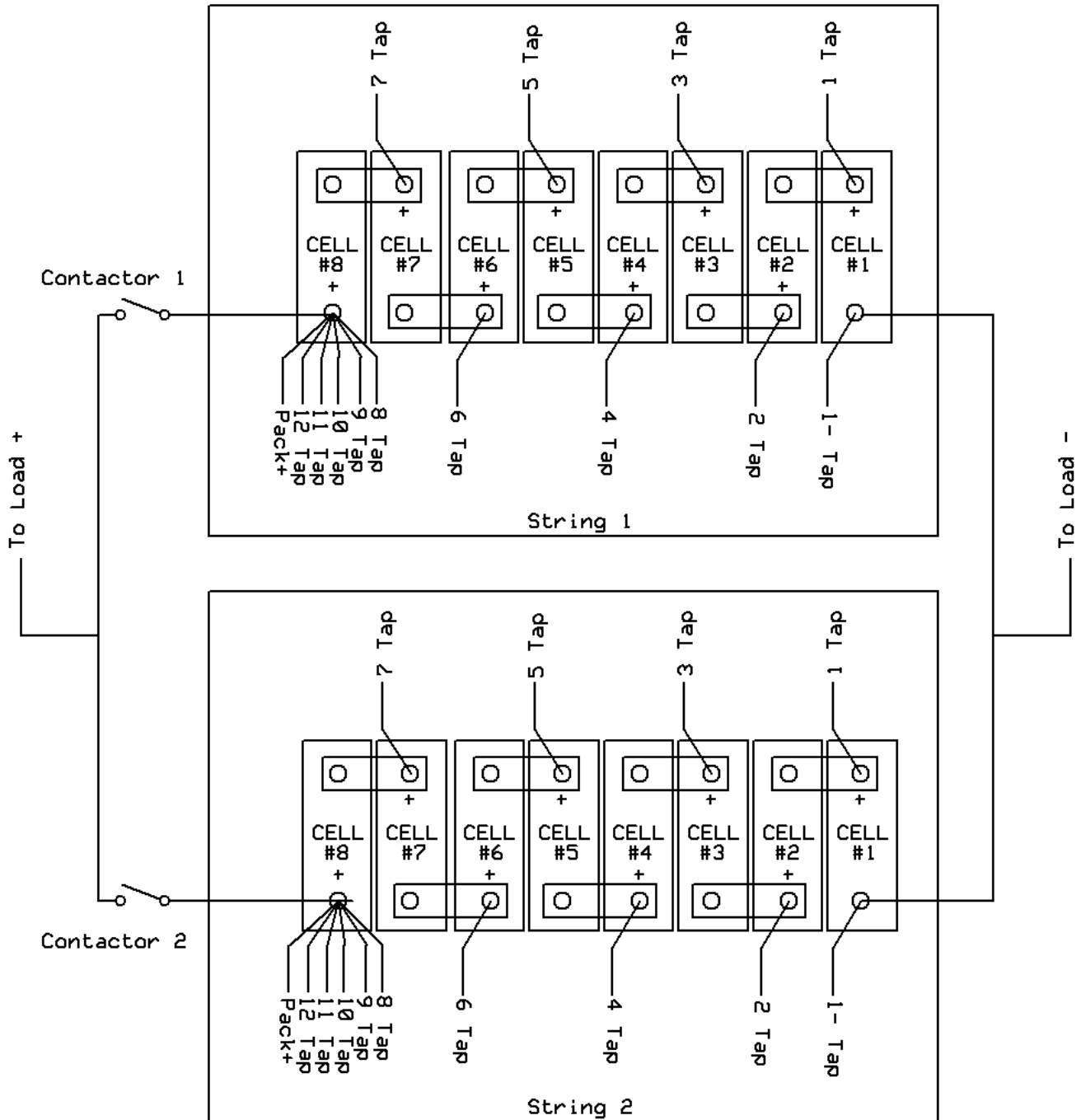

       In the above configuration, the amp hour capacity is increased without increasing the pack voltage. Even though 8 cells are used, because each cell is paralleled with one other cell, the BMS can treat each pair of cells as a single cell. The above configuration is a "4S2P" configuration. The "2P" indicates that there are 2 cells paralleled together, where-as the "4S" indicates that there are 4 of these pairs in series. If each cell is 10 amp hours and 3.3v, the battery pack above would be 20 amp hours and 13.2 volts. For this setup, a BMS capable of monitoring 4 cells is necessary.

Paralleled String Configuration

Paralleling strings together greatly increases the complexity of managing the battery pack and should be avoided unless there is a specific reason to use this configuration. In this setup, each string must essentially be treated as its own battery pack for a variety of reasons.

In a below example, 2 strings of 8 cells each are placed in parallel.

In the above configuration, two "8S1P" strings are paralleled together. With perfectly matched and perfectly balanced 10 amp hour, 3.3 volt cells, the above configuration would have a total of 20 amp

hours and 26.4 volts, however in reality, the total capacity of this pack will be less than 20 amp hours Additionally, because no two cells are exactly the same, different currents will flow through each battery pack, creating difference in state of charge between the two strings. Therefore, for full management with multiple strings, 1 BMS unit per string must be used, and in some cases, a multi-string controller must be used to manage the whole pack. In the above example, 2 BMS units, each capable of managing 8 cells in series must be used and at least one contactor must be installed to prevent the packs from runaway in the event of a cell failure.

Dramatically more engineering time must be invested for applications with multiple strings and is usually only done for hot-swap applications. It is also important to note that multiple parallel strings does not automatically increase the overall reliability. In most cases, paralleled strings will reduce the overall power and overall usable capacity of the pack.

Problems with paralleled strings

Paralleling strings present several challenges and issues:

1.) Cells will always have slightly different capacities. While it would seem that this configuration would result in a greater usable capacity, the differences in capacity are actually compounded by this configuration and a lower amount of overall energy is available.
2.) Cells will always have slightly different internal resistances. Differences in temperature from one portion of the battery pack to another lead to different currents flowing through each of the strings. Because of this, each string must be monitored separately and will have a different state of charge.
3.) Strings at different states of charge may have a significant current transfer when paralleled and not be able to be paralleled together until their state-of-charge has been balanced.
4.) Certain failures of a cell, such as reduced capacity or unbalance can lead to currents flowing from one string to another. This can lead to overcharging of a cell
5.) The total pack state of charge must be calculated from the individual string's state of charge. This is a less accurate than calculating state of charge for a single string
6.) The total pack power output calculation is significantly more complex and is almost always lower than the sum of all packs.

As a result:

1.) Both the usable capacity and usable power are almost always lower in the real world with this configuration than with a standard paralleled cell configuration.
2.) A weak cell will reduce the overall capacity and overall power from the pack more than would be the case with a standard paralleled cell configuration.
3.) Each string requires its own BMS, increasing the overall cost of managing the cells.
4.) One contactor per string is required to prevent one string from force-charging another string in a failure (or diodes may be used for some applications.)

Redundancy

Some applications require additional redundancy such that the power supply is not interrupted if there is a problem with a single string. While this is necessary for some specialized applications, paralleling strings requires additional complexity which may reduce the overall reliability. There is a trade-off between usable capacity and redundancy in this case.

Space Considerations

Many times system designers consider paralleling 2 strings because they are looking for ways to address space concerns. In almost all of these cases, a single string of cells split up throughout the chassis is preferable to two strings.