PARALLEL STRINGS – PARALLEL UNIVERSES

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ABSTRACT

Sometimes different parts of the battery community just don't seem to operate on the same level, and attitudes towards parallel battery strings are a prime example of this. Engineers at telephone company central offices are quite happy operating 20 or more parallel strings on the same dc bus, while many manufacturers warn against connecting more than four or five strings in parallel. To battery neophytes it must sometimes seem that the opposing viewpoints are coming from two different universes, and are not governed by the same laws of physics.

Experienced battery applications engineers speak darkly of 'circulating currents.' IEEE standards recommend that parallel strings be not just of the same capacity but of about the same age, and that circuit resistances for the strings be 'as similar as possible' to prevent imbalances. Yet two recent Intelec papers have clearly debunked these and other myths surrounding parallel strings. Another paper has even shown that completely different electrochemical systems can coexist peacefully in parallel on the same charger.

This paper lists some of the myths of parallel battery strings, and summarizes the evidence against them. Having established that multiple parallel strings are not detrimental to system operation, it goes on to discuss the pros and cons of such arrangements, from the point of view of applications engineering, system design, installation and maintenance. It will be demonstrated that multiple-string systems are beneficial in some applications, while in others their only real impact is to increase operating costs.

BACKGROUND

The first part or this paper will draw heavily from two papers published at Intelec in successive years. The first, from Intelec '98, was 'Operational Characteristics of VRLA Batteries Configured in Parallel Strings' by Cole *et al.*[1] The second was 'The Operation Of VRLA Lead Acid Batteries In Parallel Strings Of Dissimilar Capacity Or Can We Now Sin?' by Giess.[2]

THE MYTHS

Limit the number of strings

Cole *et al* tested up to four strings in parallel configurations. Careful monitoring of string currents on charge and discharge showed totally predictable behavior, with each string sharing the overall current in proportion to its capacity, relative to the total capacity. It is reasonable to extrapolate from this that there will be no magic number at which the system behavior will become unstable. Indeed, such an occurrence would require some adjustments to the laws of physics! The absence of any theoretical limitation to the number of parallel strings is borne out by the experience of telecom operators, and at least one battery manufacturer allows up to 16 parallel strings, depending on system voltage.[3]

Strings must be the same capacity and age

Both the Cole and Giess papers show that batteries of widely dissimilar capacities can coexist peacefully on the same dc bus. If, say, a 25Ah string can be operated in parallel with a 100Ah string, there is no logical reason why strings of the same battery type, but different ages, cannot also. Again, this is supported by the experience of telecom operators, who routinely replace individual strings as necessary in multiple-string configurations with no apparent problems.

The string circuit impedance must be identical for all strings

Cole *et al* tested a parallel arrangement consisting of a 265Ah and a 1000Ah string, using the combined 8-hour rates of the two strings. The first discharge used equal circuit impedances. The test was then repeated with double the circuit impedance for the smaller string, and again with quadruple the impedance. Yet again, the strings refused to disobey the laws of physics, and the differences in string behavior were well within the limits of experimental error.

Parallel strings will discharge into one another because of circulating currents

In float service, strings that are connected in parallel are maintained at the same voltage by the charger. If the voltage is the same, there can be no current flow between strings. On discharge, the voltages of the strings will remain equal; the variable is the amount of current supplied by each string, whether because of differences in age, rated capacity, or circuit impedance. Again, with no voltage differential there can be no current flow between strings. Even if a cell in one string is shorted, its effect on the overall string will be compensated for by a higher charge current through that string.

The only time that some strings may discharge into others is when left standing on open circuit. If one string contains a cell that is short-circuited, that cell will depress the inherent string voltage. Since the actual voltage cannot be lower, the parallel strings will compensate for this by discharging into the defective string. This discharge would continue until the defective cell reaches zero volts and all strings have stabilized at a lower open circuit voltage. Such a situation could also arise when discharging at a very low rate, but only if the self-discharge rate of a shorted cell exceeds the discharge rate of the system.

If a parallel-connected system is to be left on open circuit for a prolonged period, it is best to disconnect each of the strings from the dc bus. Before reconnecting the system, the string voltages should be checked to make sure there are no large discrepancies (see 'connecting new strings' below).

DESIGN ISSUES

So if paralleling is OK, should everyone do it? There is no simple answer to this question, since the advantages (and the disadvantages) vary from application to application. The reasons for adopting parallel battery arrangements also vary:

- The capacity required for the duty cycle may be larger than the largest available cell size.
- Multiple strings may be specified to achieve some level of redundancy
- For a large user, it may be desirable to adopt a single 'module' (string) size, and to install variable numbers of these modules for different loads.
- Cells or multicell units in single strings may exceed maximum weight limits for safe lifting by one person.

In many cases, a combination of these factors is at work. The following is a discussion of several design considerations. In many cases, there is considerable overlap between topics.

Cells or strings?

One of the first considerations is whether to connect individual cells in parallel, or complete strings. Although in theory the results should be the same, parallel cells are often discouraged from an operational point of view. The reason is that a problem in one cell may be masked by its parallel neighbor. For example, ohmic measurement devices can often detect internal defects, but these are more clearly visible when the measuring just the defective cell. Parallel cell arrangements introduce substantial errors (see Maintenance Considerations), making it more difficult to detect the early signs of a problem.

Parallel cell arrangements may be seen more frequently with some of the advanced technologies now under development, with which protective electronic devices may be deployed more effectively on groups of cells. However, for most of today's stationary batteries it is better to make parallel connections at the string level.

System voltage

One suggestion is to limit the number of strings in accordance with the system voltage, allowing more parallel strings at lower voltages. For example, the Dynasty Division of C&D recommends as many as 16 strings at 12V, but only 4 strings at 480V, on the grounds that system complexity (cabling considerations, connections to the dc bus, etc.) is a limiting factor at higher voltage[3]. (In the same document, it is acknowledged that there is no theoretical limit to the number of strings.)

Another view on this issue is that it may be more difficult to make accurate ohmic measurements in multiple low-voltage strings. This is discussed in greater detail under Maintenance Considerations.

Redundancy

Several methods exist for achieving redundancy in battery systems. Full redundancy is where one string or group of strings, capable of supporting the full specified load, is 'mirrored' by another, identical battery arrangement. In many large UPS installations, complete systems (charger, battery and inverter) are mirrored to achieve the desired redundancy. In modular systems such as those operated by telecom companies in their outside plant, it is possible to use 'n+1' redundancy, in which the deployed system comprises the number of battery modules required to support the specified load, plus one.

Many telecom operators have a policy of installing adequate capacity to support the system load (i.e. no redundancy), but using a minimum of two parallel strings. This is prudent system design for VRLA batteries, in which cells sometimes fail open or near-open, thus disabling a complete string. The principle is that if a 2-string system is designed to discharge over 8 hours a single string will achieve something close to 4 hours, which in most cases will be acceptable.

This philosophy is effective for low-rate discharges, but the same assumptions do not apply for high-rate operation. Consider a typical large lead-calcium vented battery with 33 positive plates, which we will call the XYZ33. The published performance is shown in Table 1.

First, we will assume that two parallel strings of this cell type are installed for an 8-hour application. Ignoring aging, temperature factors and design margins, we will assume that the system load is 580A, so that the two strings will carry this load for 8 hours when at 100% of their rated capability. If one string fails or is offline when a discharge begins, the remaining string will see the full 580A load, and will support this for better than 3 hours.

However, if the same arrangement is deployed for a system load of 3680A, or 15 minutes at full capability, the failure of one string will be catastrophic. The 1-minute rate of a single string is only 2240A, so the voltage would immediately collapse under a load that is 64% higher than this. Even when chosen for a 60-minute load with two strings (2336A), a single string would last for less than a minute, and possibly for only a couple of seconds if the coup de fouet, or initial voltage dip, causes system shutdown.

It can be seen, then, that splitting the system between parallel strings with no redundancy can be sound engineering practice for 8-hour loads, but the benefits are minimal to nonexistent for much shorter durations (at least in terms of redundancy).

Disconnect devices

One of the fundamental principles of designing systems with parallel strings is to use a separate disconnect device for each string. Depending on the circumstances, this may prevent a problem in one string from affecting the others, and at a minimum it allows for each string to be disconnected for maintenance purposes.

Many designers use circuit breakers for this purpose. If this is the case, it is important that the breakers be correctly rated to take into account all operational circumstances. For example, if one string in a two-string system is offline and a discharge is initiated, the disconnect device for the active string must be able to support the full system load, i.e. double the normal string load.

MAINTENANCE CONSIDERATIONS

One of the arguments against parallel string arrangements is that the man-hours required for maintenance are multiplied by the number of strings deployed. With the high cost of labor and pressures to cut costs in many operations, this can be a deciding factor against such arrangements.

Another consideration, particularly in low-voltage systems, is that internal ohmic measurements may become less accurate in paralleled systems. A parallel string represents an alternative current path or resistance to the cell or module being tested, thus introducing an error to the reading. The significance of that error increases as the string voltage decreases. Figure 1 shows a 48V system comprising 2 strings of 4 x 12V modules. When an ohmic measurement is taken on a 12V module in one of the strings, an alternative current path exists through the 7 other modules (the remaining 3 from the same string and the 4 from the parallel string) and the cabling between the strings. Ignoring module-to-module variability and the resistance of the cables, the alternative current path will have a resistance that is 7 times that of a single module. This will reduce the apparent resistance of the single module by 12.5%. In a 3-string arrangement, the apparent reduction would be 22.2%.

Table 1 – XYZ33 performance to 1.75 V/cell

	8hr	6hr	4hr	3hr	2hr	90m	60m	30m	25m	15m	1m
Rated current (A)	290	368	496	613	800	944	1168	1536	1616	1840	2240

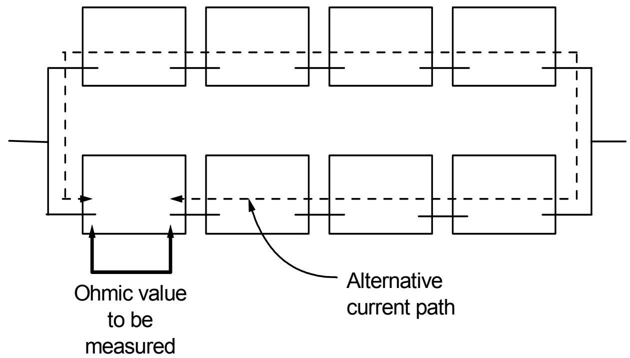

Figure 1 – Ohmic measurements in parallel strings

Of course, if a measurement was being made on a single cell, rather than a 12V module, the alternative current path would have 47 times the resistance (23 other cells in the same string, plus 24 in the parallel string), and the error would be insignificant. Likewise, higher voltage strings would not be subject to large measurement errors. The easy solution is to isolate the string being measured by opening its disconnect switch, but this might not be apparent to an untrained operator.

OPERATION OF PARALLEL STRINGS

The operation of parallel strings is quite predictable and is normally transparent to the user. However, there are a few special considerations that should be borne in mind.

Technology issues

Most stationary battery systems spend more than 99% of their lives on float charge, so the main operational consideration is that the recommended float voltage be the same for each string. This allows strings of differing technology, but similar float voltage, to be mixed with each other in the same system. Thus, for example, a high-rate VRLA battery string can be connected in parallel with a low-rate VRLA battery string, as long as their respective float voltages are similar. It should be noted, however, that the high-rate string will provide more capacity in the earlier stages of discharge (assuming the strings are of similar capacity), since its voltage would be higher in a single-string arrangement. As the discharge proceeds, the capacity of the high-rate string will be consumed more rapidly, and the low-rate string will start to assume a greater proportion of the overall current. At the end of the discharge, the low-rate string will assume the majority of the overall current.

This is not a problem for occasional discharges, or for more frequent discharges that are taken to completion. It can become an issue, however, for a system that is designed for long discharges, but is subjected to frequent shallow discharges. In this case, the high-rate battery will receive the brunt of the cycling duty, and may age prematurely as a result.

The mixing of technologies can be taken to extremes when strings of entirely different electrochemistry are operated in parallel. Vigerstol reported on a test system in which a nickel-cadmium test battery was installed in a telecom cabinet in parallel with two existing VRLA battery strings[4]. Although the strings had similar capacities, the Ni-Cd system has an inherently lower voltage through most of a single-string discharge. This would lead us to expect that the VRLA strings would carry most of the system load during the initial stages of a discharge. This is confirmed by the results of a capacity test on the Ni-Cd string and one of the VRLA strings, as shown in figure 2. The test was started with the normal system load of 17-18A for about an hour, then external load banks were brought into operation to avoid a prolonged test. This explains the variations in overall current during the test.

The figure records the currents supplied by the individual strings, and shows that the VRLA string supplies virtually all of the current for the first hour. When the load was increased, the Ni-Cd string gradually assumed an increasing portion of the load and by about 3.5 hours was supplying more current than the VRLA string. The overall capacity removed was the sum of the capacities of the two strings, indicating that they performed as expected despite the variation in loading during the test.

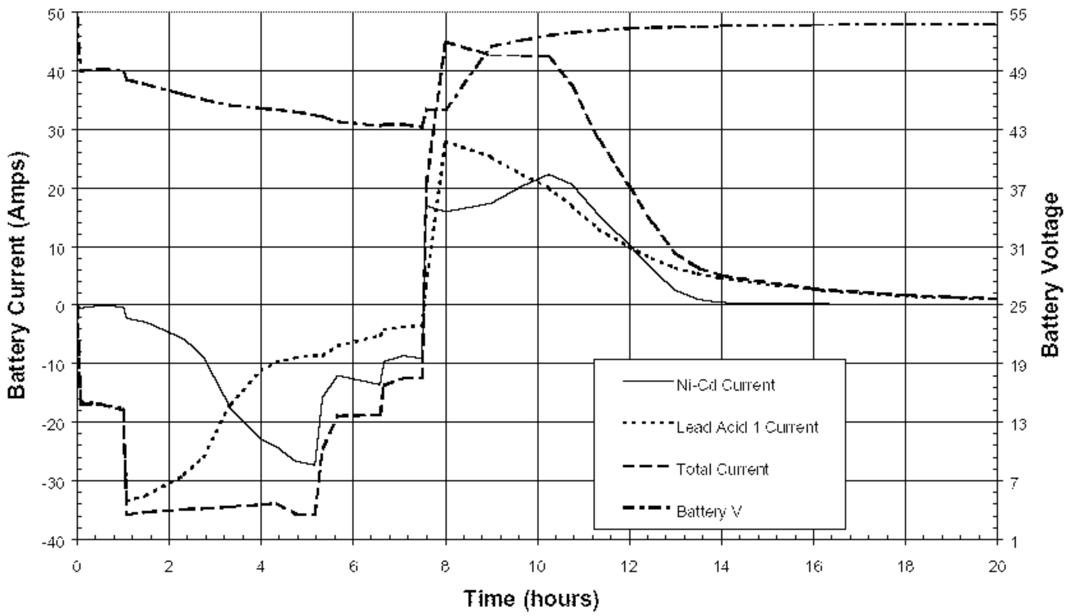

Figure 2 – Operation of Ni-Cd and VRLA strings in parallel

Testing

The above results demonstrate the importance of monitoring the individual string currents during capacity tests. If only the overall system load is monitored, there is no way to determine how much capacity each string is contributing. Ideally, if time permits and the system design allows, each string should be discharged separately to achieve the maximum accuracy. If this is done, however, care should be taken when restoring the system to normal operation. See 'connecting new strings' below.

Connecting new strings

In a single-string system, when a discharged battery is re-connected to the charger, the battery will usually accept the full charger output current until the battery approaches a full state of charge. Provided that the charger is correctly sized relative to the battery capacity, this is a normal situation and is not damaging. In an arrangement of parallel strings, however, complications may arise.

If all the strings are discharged together there is no problem. However, if a string at a lower state of charge is connected with fully charged strings, that string will receive not just the charger current, but also a potentially high current from the other strings until the voltages equalize. This is the situation when a new string is connected into a system with existing fully charged strings, or if a single string has been capacity tested. This may not be a problem in many cases, but it is possible that a VRLA string that is thermally unstable could be pushed into thermal runaway.

To avoid possible problems of this nature, the string to be connected should ideally be brought to the same voltage as the existing strings by a separate charging process. It might also be possible to achieve the same result by partially discharging the existing strings, but it would still be necessary to match the string voltages to minimize the current flow when connecting the new string.

CONCLUSIONS

There is a great deal of misinformation in the battery industry concerning parallel strings. For system designers and users, the best course of action is to treat any advice on this subject with a grain of salt, until it is reasonably certain that it complies with the laws of physics. Parallel strings can improve system reliability under the right circumstances, but it is important to know just what paralleling can do under the specific conditions of a given application.

REFERENCES

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