White Paper

# Maximizing Cell Site Reliability

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As wireless service is used for more essential services (such as First Responder support, etc.), cost-effective cell site reliability becomes ever more critical. The cell site backup battery system, a critical component for site reliability, is under increasing impact from the rising power demand of remote radio units (RRUs). With some LTE dual-band RRUs reaching a 1.5kW requirement, and even higher demands on the horizon, proactive measures are needed to ensure efficient delivery of power to the RRU and to minimize the impact on backup batteries. This paper explores this issue, demonstrating how it can be mitigated using the CommScope PowerShift™ dynamic power supply solution, and providing empirical test results of use cases defined by wireless carriers that quantify the reduced impact on backup batteries and the improvement in power delivery to the RRU.

## Introduction

A backup battery system provides direct current (DC) power for continued cell site operation when the primary power source at the site becomes unavailable. The RRU receives DC power over a significant length of copper cable, often referred to as a "trunk cable". As power flows through the trunk cable to the RRU, there is a voltage drop across the cable, typically referred to as "line drop". This voltage drop causes multiple problems. First, as the batteries discharge from their nominal float voltage down to a minimum voltage, excessive cable voltage drop will cause the RRU to be the first component to dropout of operation; this problem can be exacerbated by older batteries which may exhibit a brief voltage dip, further increasing the likelihood of RRU dropout. Second, excessive cable voltage drop is also associated with excessive power consumption in the cable (dissipated in the form of heat), which reduces the efficient use of battery power and decreases the battery runtime. The increasing power demand of RRUs exacerbates both problems and negatively impacts cell site reliability. The typical solution to reduce the cable voltage drop is to use larger diameter cables and/or to add additional battery capacity, both of which have significant cost impacts. The challenge then is to understand the details of these problems and apply a solution to mitigate them.

## Cell Site DC Power

The typical battery configuration at a macro cell site consists of one or more strings of batteries. Each string provides a nominal 48 Volts (note that positive voltages are used in this discussion for simplicity; most telecom sites use a negative DC power system), and multiple strings are used to increase total battery capacity in order to satisfy the aggregate demand of DC-powered equipment at the site. A key site design requirement is to size battery capacity such that all critical DC-powered equipment at the site is powered and can continue to operate on battery power for a desired time period (typically 8 hours). The amount of time the backup batteries can provide power for continued site operation is referred to as "battery runtime". Most cell site equipment is located close to the batteries (within a shelter or equipment cabinets), however the RRU is located at the top of the cell tower or building rooftop and thus power must be delivered over a long copper trunk cable. A diagram of this arrangement is shown in Figure 1, which depicts the loss of primary power and the resulting reliance on backup batteries. Ohm's Law states the voltage drop across the trunk cable ($V_C$) is equal to the current flowing through it ($I_L$) multiplied by the resistance in the cable. The total resistance of the cable is 2 x Rc (the trunk cable consists of two symmetric conductors) therefore the resulting equation is $\mathbf{V_C = 2 \times I_L \times R_C}$. This voltage drop across the trunk cable has two important impacts on the delivery of battery backup power to the RRU.

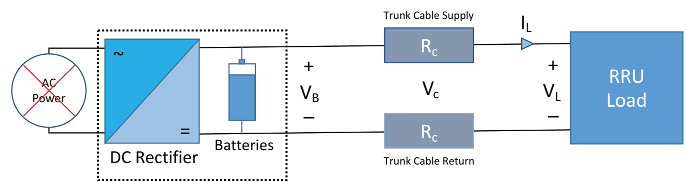



**Figure 1. Backup battery power delivery to the remote radio unit**

## Impacts of Cable Voltage Drop

The first impact of trunk cable voltage drop relates to the RRU input voltage level ($V_L$). Kirchhoff's Voltage Law states the algebraic sum of all the voltages in a closed loop circuit is equal to zero. Referencing the circuit in **Figure 1** and solving for the RRU load voltage yields $\mathbf{V_L = V_B - V_C}$. This equation expresses a straightforward concept that the voltage available to the RRU load is equal to the voltage output of the batteries minus the voltage drop across the cable. This has an important impact on the use of battery backup power. Like any DC-powered equipment, the RRU has a minimum operating voltage point below which the RRU will cease to operate (RRU dropout voltage). Add to this the fact that the battery output voltage decreases overtime as the batteries discharge and it becomes clear that the RRU dropout voltage is a critical factor that must be accounted for when the site is running on backup battery power. As an example, when a cell site is on backup power the batteries typically discharge down to a voltage level of 42 Volts. A typical RRU will have a dropout voltage around 38 Volts. Solving for $V_C$ in the above equation, $V_C$ = 42V – 38V = 4 Volts. This means the voltage drop across the trunk cable must be less than 4 Volts for the RRU to remain operational. A cable voltage drop greater than 4 Volts has the practical impact of reducing the "useable" battery runtime. For example, if the cable voltage drop is 6 Volts then 38V + 6V = 44V, which means when the battery voltage discharges below 44V the RRU will turn off. This is an important concept – excessive trunk cable voltage drop results in RRU "uptime" that is less than the battery runtime.

The second impact of the trunk cable voltage drop relates to efficient utilization of battery power. Watt's Power Law states power is equal to the voltage across a device multiplied by the current flowing through it; solving for voltage yields V=P/I. Substituting into the previous equation and solving for battery power yields $\mathbf{P_B = P_C + P_L}$. This equation expresses a straightforward concept that the power demand on the battery is equal to the power consumption in the cable ($P_C$) plus the power consumption of the RRU ($P_L$). Watt's Power Law also states that power consumption in the cable is equal to the square of the voltage drop across the cable divided by the cable resistance; referencing the circuit in Figure 1, $\mathbf{P_C = V_C^2/(2xR_C)}$. Therefore, an increase in trunk cable voltage drop results in increased cable power consumption, which in turn results in increased power demand from the battery. Every watt of battery power consumed by the cable is a watt of power not available to the RRU and the other DC-powered equipment at the cell site, resulting in an overall reduction in battery runtime.

In order to reduce cable power consumption, the challenge is to reduce voltage drop in the cable. As previously stated, the trunk cable voltage drop equation is $\mathbf{V_C = 2 \times I_L \times R_C}$. This indicates cable voltage drop can be reduced by lowering the load current ($I_L$) or lowering the cable resistance ($R_C$). The typical approach at a cell site is to lower cable resistance through use of larger diameter cable (the resistance of a conductor is inversely proportional to its cross-sectional area). But using heavier gauge cable is costly and has other negative impacts such as increased cable weight (e.g. increased tower weight load) and the cost to remove/replace existing cable for a cell site retrofit.

The optimal solution is the CommScope PowerShift product which compensates for the line drop, reducing the cable power consumption and eliminating the RRU dropout concern by regulating the RRU input voltage above its dropout threshold.

## Optimizing Battery Backup Power

The first challenge in optimizing the use of backup battery power is to address the RRU dropout voltage issue expressed in the equation $\mathbf{V_L = V_B - V_C}$. As shown in **Figure 2**, the PowerShift product is inserted between the battery plant and the trunk cable. The battery output is fed into PowerShift which adjusts its output voltage ($V_{PS}$) to compensate for the cable voltage drop ($V_C$), providing a regulated 56 Volts to the RRU input ($V_L$). The new equation is $\mathbf{V_L = V_{PS} - V_C}$. As the battery discharges down to 42 Volts, PowerShift continues to boost its output to maintain 56 Volts input to the RRU. This effectively eliminates the RRU dropout voltage as a major concern, ensuring full utilization of backup battery runtime by the RRU.

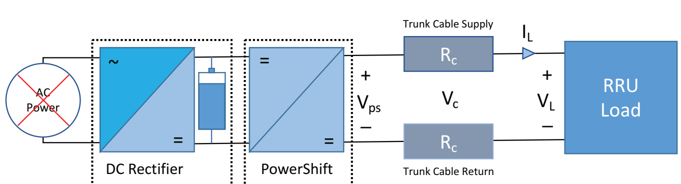



**Figure 2. Addition of PowerShift voltage booster**

The second challenge in optimizing the use of backup battery power is to address power consumption in the trunk cable. The previous equation $P_B = P_C + P_L$ established the power relationship between the battery, cable and RRU load. However, cable power consumption is also dependent on the battery voltage; as battery voltage decreases during discharge there is a resulting decrease in the RRU input voltage, which in turn causes the RRU to draw more current to maintain the same power level. A quadratic equation can be used to account for this; setting the previous equation equal to zero yields $P_B - P_C - P_L = 0$. Placing this equation into a quadratic form ($ax^2 + bx + c = 0$) yields: $-(\mathbf{I_L 2 \times 2R_C}) + (\mathbf{V_B \times I_L}) - (\mathbf{P_L}) = 0$. The cable resistance ($R_C$), battery voltage ($V_B$) and load power ($P_L$) can then be set as input conditions, and the quadratic equation used to calculate load current, cable voltage drop and cable power consumption. With the addition of PowerShift (**Figure 2**), the previous equation $P_B = P_C + P_L$ now becomes $\mathbf{P_B = P_{PS} + P_C + P_L}$, where $P_{PS}$ is PowerShift's parasitic loss (i.e., power consumed by PowerShift internal electronics). Because PowerShift provides a regulated 56 Volts to the RRU input, the load current ($I_L$) is no longer dependent on the battery voltage and can simply be calculated as the RRU power divided by the input voltage, $I_L = P_L/56V$; cable power consumption can also be easily calculated using the equation $P_C = I_L^2 \times 2R_C$. As will be shown, the result is that PowerShift reduces the load current and the cable power consumption.

Consider a cell site configuration that represents an actual use case defined by a Tier 1 wireless carrier. An 800-watt RRU is connected to the cell site power source over 8-AWG trunk cable with a length of 250 feet and a 12-AWG jumper cable with a length of 15 feet; the aggregate round-trip cable resistance is about 0.39 Ohms. The typical float voltage for a VRLA (valve-regulated lead-acid) battery string is 54 Volts, but once the primary rectifier power is lost the battery string will drop closer to its nominal 48 Volts and then discharge over time down to a minimum value of 42 Volts. The previously cited equations can then be used to calculate results for these battery maximum and minimum voltages. In **Table 1** the first two rows show the calculated results without PowerShift, and the last two rows show the calculated results with PowerShift. Note that the Net Power Loss column accounts for PowerShift's parasitic loss. The table clearly shows the advantage provided by PowerShift, a marked decrease in the load current, the cable voltage drop, and the cable power consumption. At the start of battery discharge the cable power consumption is 153 Watts without PowerShift, but only 105 Watts net loss with PowerShift, a reduction of 31.4%. When the batteries have discharged down to 42 Volts the cable power consumption without PowerShift has increased to 236 Watts, whereas the net loss with PowerShift is only 110 Watts, a 53.4% reduction. Furthermore, without PowerShift the RRU input voltage is only 32.4 Volts; a typical RRU will have already turned off due to the 38 Volt dropout voltage no longer being met; this is a direct example of the negative impact of trunk cable voltage drop on RRU uptime. In contrast, even with the batteries at 42 Volts, PowerShift continues to delivery 56 Volts input to the RRU.

These theoretical calculations clearly show an advantage with PowerShift, the final step is to confirm these calculations with empirical test results and to observe the resulting benefit to battery runtime and RRU uptime.

## TABLE 1. CALCULATED CABLE VOLTAGE DROP AND POWER LOSS (800W LOAD, 0.39 OHM CABLE RESISTANCE)

| Power Source | Battery Voltage (V) | PowerShift Output Voltage (V) | RRU Input Voltage (V) | Load Current (A) | Cable Voltage Drop (V) | Cable Power Loss (W) | PowerShift Parasitic Power Loss (W) | Net Power Loss (W) |
|---|---|---|---|---|---|---|---|---|
| Battery Only (starting) | 48 | N/A | 40.3 | 19.3 | 7.7 | 153 | N/A | 153 |
| Battery Only (discharged) | 42 | N/A | 32.4 | 24.7 | 9.6 | 236 | N/A | 236 |
| Battery with PowerShift (starting) | 48 | 61.5 | 56 | 14.3 | 5.5 | 78 | 27* | 105 (78+27) |
| Battery with PowerShift (discharged) | 42 | 61.5 | 56 | 14.3 | 5.5 | 78 | 32* | 110 (78+32) |

*PowerShift input/output efficiency is 97% with battery voltage of 48 Volts and 96.5% with battery voltage of 42 Volts

## Experimental Test Results

Experiments were conducted using a typical DC rectifier power shelf (GE CPS6000), a single string of new valve-regulated lead-acid (VRLA) batteries with a capacity of 170 Ampere-hours (Ah), a trunk cable resistance simulator (a wire-round resistor with variable tap points) and an electronic load configured for constant power (CP) mode to simulate an RRU load (it should be noted that an actual RRU will exhibit a dynamic load profile, however use of a constant power load provides a valid basis for comparing battery discharge tests with and without PowerShift). A data acquisition unit was used to record voltage and current in 1-minute intervals at multiple measurement points in the circuit. Two test configurations were used, based on actual use cases defined by two different Tier 1 wireless carriers. The first configuration consists of an 800W load and a cable resistance equivalent to 250-feet of 8-AWG trunk cable, plus 15-feet of 12-AWG jumper cable (aggregate resistance of ~0.39 Ohms). The second test configuration consists of a 1100W load and a cable resistance equivalent to 165-feet of 8-AWG trunk cable, plus 15-feet of 12-AWG jumper cable (aggregate resistance of ~0.27 Ohms). For each configuration two battery discharge tests were run, one with PowerShift in the circuit and the other without PowerShift in the circuit. Before every discharge test the batteries were run through a rigorous 5-day recovery procedure per the manufacturer's specification (consisting of recovery float charging, equalization boost charging, and adherence to maximum ampere charging limits), thereby ensuring the batteries began each test with the same state of charge. Each test was initiated using a manual battery discharge test feature available in the DC power shelf; the test is activated manually and exits automatically when the batteries have discharged to a specified voltage (the lowest allowable setting is 42 Volts, however in practice the power shelf exited at about 42.5 Volts). The testing was conducted in a lab environment with an ambient temperature of about 23C.

**Figure 3** shows the results for the 800W load test case, with PowerShift (green results) and without PowerShift (red results). Results are plotted with the x-axis showing battery runtime, and a dual y-axis; cable power consumption is at the bottom of chart with the y-axis on the right, battery output voltage (broken line) and load input voltage (solid line) are at the top of the chart with the y-axis on the left. Two reference lines are also added to show typical RRU dropout voltages of 38V and 36V. The results clearly show increased battery runtime with PowerShift. For the battery to discharge down to ~42.5 Volts the battery runtime was 509 minutes with PowerShift, and 481 minutes without PowerShift, an increase of 5.8%. But when the RRU dropout voltage is factored in the benefit of PowerShift are very significant, with a 46% increase in useable battery runtime when the RRU has a minimum operating voltage of 38 Volts. And even with an RRU dropout voltage of 36 Volts (which some RRU manufacturers are beginning to implement) PowerShift still provides an 18% increase in useable battery runtime.

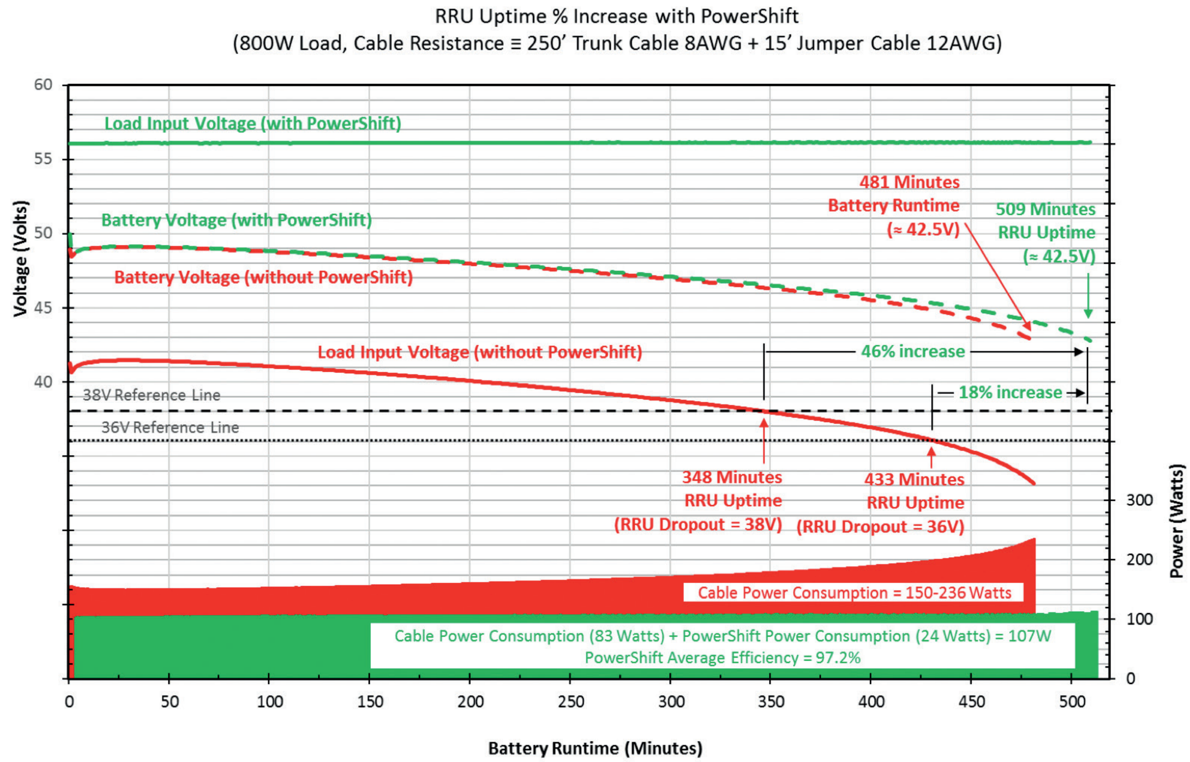



Figure 3. Battery Discharge Test Results for 800W Load

**Figure 4** shows the results for the 1100W load test case, using the same color scheme and dual y-axis as the previous figure. Again, the results clearly show improved battery runtime with PowerShift. For the battery to discharge down to ~42.5 Volts the battery runtime was 342 minutes with PowerShift, and 302 minutes without PowerShift, an increase of 13.2%. When the RRU dropout voltage is factored in the benefit of PowerShift are again very significant, with a 53% increase in useable battery runtime when the RRU has a minimum operating voltage of 38 Volts. With an RRU dropout of 36 Volts, PowerShift still provides a 26% increase in useable battery runtime.

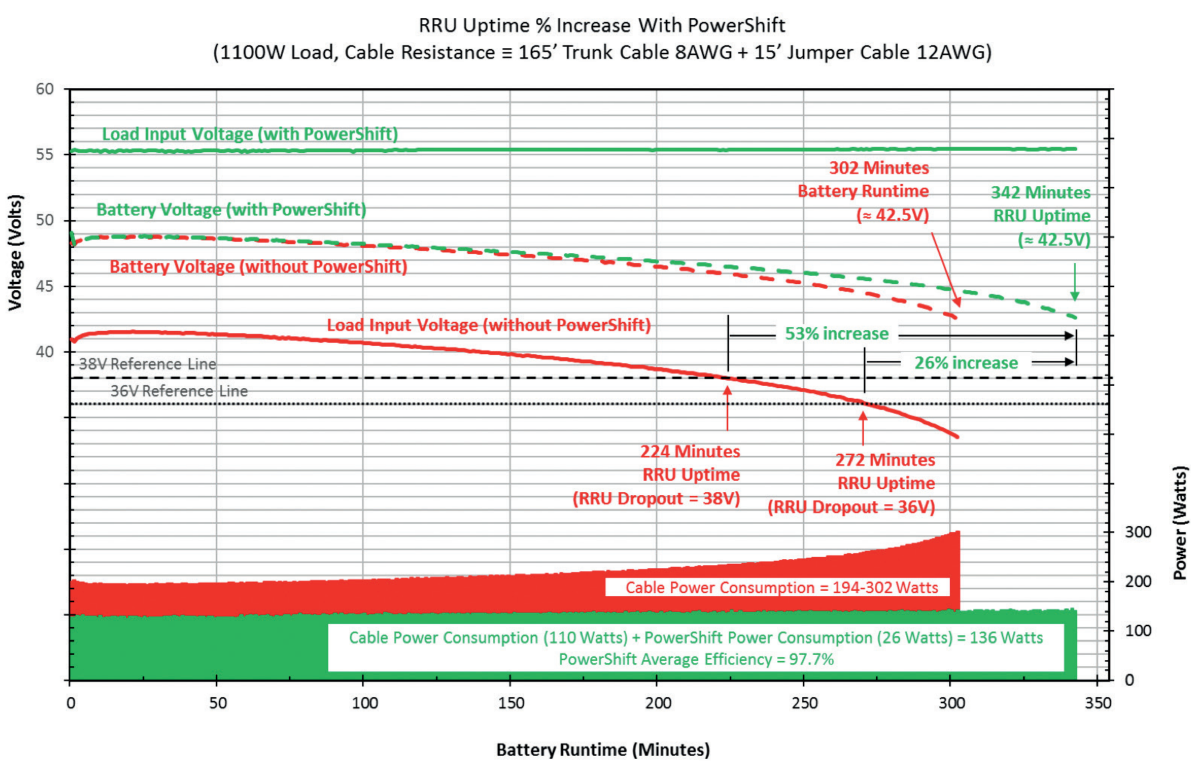
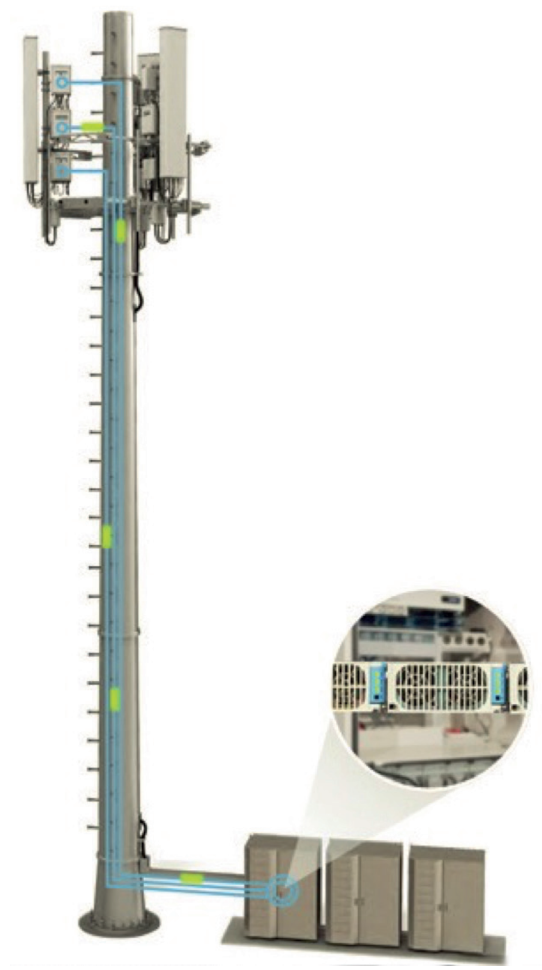



Figure 4. Battery Discharge Test Results for 1100W Load

# Conclusion

The ability of PowerShift to reduce the voltage drop across and power consumption in the trunk cable has been demonstrated. Empirical test results were provided for two different test configurations, based on actual use cases defined by Tier 1 wireless carriers, and the resulting positive impact on battery runtime and RRU uptime has been shown. The output voltage boost from PowerShift ensures delivery of optimal input voltage to the RRU, eliminating the risk of RRU dropout when batteries reach minimum voltage at full discharge and when older batteries suffer a momentary voltage dip. PowerShift also reduces power consumption in the trunk cable, resulting in increased battery runtime. The result is that PowerShift minimizes the cable gauge needed to support high-power RRUs, avoiding the need for larger diameter cables, enabling the reuse of existing cell site cables and eliminating the cost to tear out existing cables. By increasing battery runtime PowerShift minimizes the need for additional battery strings, and ensures the maximum utility and service life of older battery strings. The trend of increased power demand by remote radio units continues, with RRUs exceeding 1400 Watts already planned for availability in 2017 and even higher power radios are expected in the future. CommScope is expanding the capability of the PowerShift product line to keep pace with these demands and to continue maximizing cell site reliability.



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