BATTERY PROTECTION METHODS – IMPORTANT VARIABLES TO CONSIDER

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ABSTRACT

Telecommunication battery plant design requires compromises constrained by future upgradability, present and future capacity, and present costs of hardware. Initial designs may overlook the flexibility available in today's battery plant configurations. Systems today allow rectifiers and/or larger battery system additions to serve increased loads with minimal infrastructure modifications. Balancing cost-efficient initial designs in relation to the maximum desired plant capabilities and capacity is a prominent factor during DC battery plant design. Battery circuit breaker coordination is critical where 200 ampere to 2400-ampere DC plants will provide increased DC load through the addition of batteries or rectifiers.

The term 'protection device' referenced in this paper is limited to the use of a circuit breaker that combines overload, short circuit, and disconnect capability. This paper defines the term 'short circuit' as "an often unintended low resistance path through which current flows around, rather than through, a component or circuit."[1]

This paper presents recommended battery protection practices to accurately protect the battery and associated DC plant, operations, and personnel while considering economic investment. Subjects discussed include: battery protection device selections, DC current protection variables, short-circuit battery potential, and DC plant illustrations.

INTRODUCTION

Telecommunication DC plant configuration choices available today for designers are numerous, resulting in a vast mix of systems. Industry deregulation is promoting plant design variations complemented by the recent advancement of battery and charger technology. The capability to expand the battery plant as DC loads increase or reliability demands change is an inherent part of present design practices. The designer may specify an initial battery sized to serve immediate loads while maintaining flexibility for future increased capacity requirements with minimal plant modifications. A common practice today is to select multiple battery strings and connect them in parallel. Each battery string could have a dedicated battery protection device. A single protective device to protect the parallel battery plant is an option.

Rectifier or charging equipment choices available for maintaining normal DC load while recharging the battery in a post outage scenario have also advanced. New technology now makes available compact switch mode rectifiers. Switch mode rectifiers provide increasingly higher capacity in smaller packages. Where the addition or replacement of rectifiers without downtime or minimum labor costs is mandatory, designers appreciate the flexibility of these systems. Due to the ease of rectifier upgradability, the designer must protect for maximum capacity.

There have been many batteries available to the designers of battery-standby systems. Size, weight, and discharge capacity have generally improved as new materials and methods to use them have found their way into the battery mix. Historically, flooded (wet), single-cell lead acid battery strings have been installed. Advancements in the state of the art have given way to a predominance of valve regulated batteries, due to advantages in smaller size, higher power density, and perceived lower cost maintenance. Monoblock or multi-cell battery designs, with less exposed intercell connectors, provide reduced installation and maintenance costs. Monoblock batteries also allow for a reduced footprint that directly translates into real estate availability and thus resultant cost savings.

Whichever package the designer chooses, one of his primary concerns should be sound fire and safety practice. The availability and mix of components may result in the designer inadvertently compromising the protection of maintenance or emergency personnel. In addition, good short circuit coordination results in limited damage and achieves corporate goals such as system reliability, performance, long term costs reduction, and safety. This paper expands on the short circuit coordination issue by briefly discussing DC short circuit protection scenarios and the subsequent application and selection of battery protection devices, including downstream circuit breaker coordination.

BATTERY CONTRIBUTION TO A SHORT CIRCUIT

Batteries designed today provide power for short, medium, or long duration discharges. Whichever battery the designer selects, an enormous amount of energy is available during a bolted short circuit. Worst-case short circuit analysis is a battery at equalize voltage without external cell-to-cell resistances resulting in conservative sizing of protection devices.

The following expression describes the short circuit current for an open circuit battery.[2,3]

$$I_{sc} = \frac{OCV}{R_c + R_{sc}}$$

Where: Isc = Short Circuit Current
OCV = Open Circuit Voltage (Specific Gravity and Temperature Specific)
Rc = Internal cell resistance
Rsc = External (post to post) measured resistance

The cell resistance can be calculated by consulting the battery manufacturer's discharge tables or fan curves to determine the tested discharge currents at two points related to their corresponding voltage.

$$R_c = \frac{\Delta E}{\Delta I} \quad or \quad Rc = \frac{(E_1 - E_2)}{(I_1 - I_2)}$$

Example: Calcium 9 plate cell

$$R_c = \frac{(1.75 - 1.50)}{(536 - 288)} = \frac{0.25}{248} = 0.001008\Omega \Rightarrow R_c = 0.001008\Omega$$

$$\frac{2.06V}{0.001008\Omega} = 2043.6\,Amps$$

Table 1 lists predicted short circuit currents using published discharge tables and/or the above equations. The data assumes an electrolyte temperature of 77 °F (25 °C) and battery open circuit voltage.

Type Cell/Unit	**Capacity: 8 or 20 Hr**	**Wet or VRLA**	**Short Circuit Amps**
9 Plate	8 HR Rate 200AH	Wet	**2043**
3 Plate	8 HR Rate 50AH	Wet	**535**
45 Plate	8 HR Rate 3900AH	Wet	**20893**
11 Plate	Short Duration Design	Wet	**7315**
17 Plate	8 HR Rate 680AH	VRLA	**5316**
21 Plate	8 HR Rate 750AH	VRLA	**6164**
17 Plate	8 HR Rate 720AH	VRLA	**6203**
12-50	20 HR Rate 50 AH	VRLA Monoblock	**2500**
12-370	20 HR Rate 100 AH	VRLA Monoblock	**5200**
12-90	20 HR Rate 100 AH	VRLA Monoblock	**3600**
12-180	20 HR Rate 200 AH	VRLA Monoblock	**4650**
12-100	8 HR Rate 100 AH	VRLA Monoblock	**2545**
6-125	8 HR Rate 125 AH	VRLA Monoblock	**3180**
6-200	8 HR Rate 200 AH	VRLA Monoblock	**5089**
1280	8 HR Rate 82.4 AH	VRLA Monoblock	**3366**
12170	8 HR Rate 170.4 AH	VR Monoblock	**7976**

Table 1: Sample Battery Short Circuit Data

Battery short circuit current is an important variable to the designer and is required to evaluate short circuit scenarios and the battery protection device.

BATTERY PROTECTION DEVICE SELECTION

Using a circuit breaker as both a disconnect device and an overcurrent device is very common. The selection process should consider system upgradability, capacity, and cost. Several core parameters, such as maximum system DC voltage, discharge currents, rectifier charging current, short circuit current, and downstream protection device information are required to provide a successful design. This paper assumes that the designer has made the decision to install a battery circuit breaker that provides both disconnect and protection capabilities.

The current rating is determined by calculating the worst-case discharge rate of the load and the worst-case battery charge rate. This determines the minimum protection device and bus conductor's size.

The worst-case discharge rate of the load depends on the type of load. The two types of load commonly found in the telecommunication industry are constant-power loads and constant-current loads. Constant-power loads are at their worst value while operating at the lowest possible supply voltage. For instance, during battery discharge, and before low voltage disconnect occurs, the bus voltage is the lowest value. Applying Ohms Law,[4] the current is calculated I=P/E. Constant-current loads are at their worst-case continuously, since they draw the same current value within their voltage range.

The worst-case battery charge rate occurs with the load offline and a fully discharged battery. This situation causes the rectifiers to be in current limit and supplying their full output to the battery. Note that this is not a normal occurrence. However, the designer should be aware of and address this possibility. The normal operating mode is the rectifier supplying dedicated load and battery float current. This can be determined quite easily, based upon the current limit settings of the rectifiers, which is usually no more than one to ten percent of their full output ratings.

Selection of the protection device is based upon worst-case current to or from the battery. Industry documentation suggests increasing this value by 25%, based on the charger rating.[5,6,7] The analysis completed above is a worst case situation, and the designer may want to reconsider the 125% overrating of the protection device, based upon the calculations they made above and the time response curve of the breaker. Many breaker designs will not trip unless the current exceeds 125% of nameplate rating for a substantial time duration. Individual applications will vary. Consult your vendor for actual ratings.

The designer must verify that the correct conductor size for noncontinuous and continuous currents installed on the battery plant based upon this information. An excellent reference is Article 220-3 (with examples) in the 1999 National Electric Code Handbook. Summarizing this article, the conductor ampacity rating for continuous current is increased by 125% of the noncontinuous load. In addition, the overcurrent device rating cannot exceed the final ampacity of the circuit conductors after the designer applies all temperature derating or correction factors.

Designers often overlook the maximum interrupt rating of the circuit breaker. The maximum interrupt rating, also industry referred to as AIC for Asymmetrical Interruption Current,[8] is the highest current the device can break consistently. If the breaker tries to break a current higher than the AIC rating, the breaker may successfully interrupt the current, weld closed, open without extinguishing the arc, or open but not be able to dissipate the arc energy. The latter three outcomes may result in damage to equipment or injury to personnel.

Circuit breakers that do not have an AIC rating, or breakers for alternating current (AC) only, may not function during a DC short circuit event. Standard AC service breakers derated for DC overcurrent applications lack the basic arc-extinguishing features of a DC certified breaker. The AC rated breakers depend on the gap distance and the zero-phase crossing of an AC waveform to extinguish the arc. With the higher short circuit currents developed in battery plants, these devices may or may not be capable of interrupting the short circuit.

To determine the required AIC, designers should refer to present battery specifications. Consideration of the battery external resistance can be included, especially if the final AIC value is near the common AIC step limit provided by the breaker manufacturer. Each battery string should have a short circuit current rating that you can use to determine the AIC required. If the battery table does not have this information, it is in the best interest of the designer to contact the battery manufacturer to assist in determining this value. Without this information, the designer cannot properly select the protection device, since battery short circuit current values vary dramatically.

Trip-time curves provide the “adjustability” a breaker has to determine how quickly it opens on an overload or short circuit event. Standard trip-time curves consist of three areas: long time region, transition region, and instantaneous region. IEEE 1375-1998 details these breaker regions. The resultant curve made up of these three regions is a map of how the breaker responds to the current flowing through it. Most breaker manufacturers will have three trip-time curves available for each circuit breaker model. The manufacturers usually refer to trip curves as short time delay, medium time delay, and long time delay.[9] The different trip-time delays adjust the width of the transition region that pushes out the instantaneous region in trip time.

PROTECTION DEVICE COORDINATION

Breaker coordination is the comparison of device ratings between source and load to ensure proper operation of all protection devices. The method to conduct breaker coordination is not well defined, but applying the DC plant information outlined above, the designer can determine a reasonable compromise for plant design. Conductor, current, and interrupt coordination are the important factors to examine.

The purpose of a protection device is to prevent conductor insulation failure by overloads or short circuits.[9] Correct conductor sizing should be matched to the circuit breaker rating for safe operation. Wire and busbar current ratings at specific ambient temperatures and tray fills are available from ANSI and cable manufacturers.

For proper current rating coordination, the designer needs to make sure the battery disconnect breaker is sized according to the battery, rectifier, interconnect wiring, and short-circuit events. Once that is established, the designer examines the distribution panel to determine individual circuit feeds. These individual circuit feeds are usually rated at 125% of the full load current per the National Electrical Code. The sum of all the distribution breakers is usually much more then 125% of the entire normal output of the DC plant or the battery disconnect breaker. The reason this occurs is because the individual breakers are added based upon the short circuit and overload requirements of the load instead of the source. The source cabling is protected to the distribution panel for designated loads according to the battery disconnect rating. Once it is at the distribution panel, the source rating is ignored, and the load is used to determine the proper breaker to install. This is the correct way to design the system, as long as the actual load does not exceed the battery disconnect rating.[6]

Coordination of AIC ratings is not quite as simple. The short circuit can occur at the output of the distribution protection device, and the designer must verify that, when the short circuit occurs, the distribution protection device will not try to break the high current arc faster than the battery protection device, unless it has an AIC rating that can handle the short circuit current. If the distribution protection device does trip faster than the battery protection device, or any intermediate protection devices, then it may either successfully interrupt the current, weld closed, open without extinguishing the arc, or open but not be able to dissipate the arc energy until the main breaker trips. The latter three outcomes may result in damage to equipment or injury to personnel.

DC PLANT SHORT CIRCUIT SCENARIOS

DC plant design directly affects where the highest short circuit risks occur and/or the short circuit current magnitude. A DC power plant design typically consists of single or paralleled battery strings with multiple chargers and distributed loads. Illustrated in Figure 1 are four sample short circuit scenarios.

The first short circuit is possible by a conductive object, such as a tool, crossing the minus 48v and positive 48v return bus. The short circuit could occur anywhere along a parallel path consisting of the bus conductors, rectifier, battery, and distribution hardware.

The second short circuit likewise occurs along a path described above, but has a higher probability of occurring due to numerous ground references. This is due to the purposeful grounding of the equipment rack.

The third short circuit example, similar to Figure 1, occurs between the discharge bus (input to the –48v load protection device) and the + 48v return bus. Generally, the only difference between the two examples is the additional bus impedance. This short circuit also has a high probability of occurring, due to the typical longer conductor lengths of the minus 48v-discharge bus feeding the load protection devices.

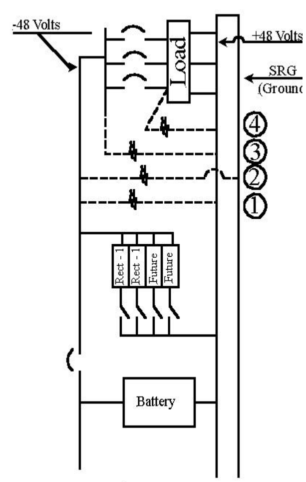

Figure 1

The fourth short circuit example occurs between the output of the minus 48v-load protection device and the positive 48v return bus. The distribution conductors to the load are located in close proximity to one another, lending themselves to inadvertent short circuit during installation and removal processes.

APPLICATION CASE EXAMPLES

This section applies variables previously discussed as they apply to two situations the designer may encounter. All data is theoretical and may not be available as defined.

Case 1, illustrated in Figure 1, describes a plant load of 40 amperes with two 50 amp rectifiers (four rectifiers total capability) that provide an n+1 redundancy. The design calls for a battery backup capability of four hours. We select a 6-200 battery as defined by Table 1. This 200 Ah battery, at the eight-hour rate, delivers 46 amps at 77 °F (25 °C) for 4 hours, to an end voltage of 1.75 vpc. Table 1 lists the available battery short circuit current at 5089 amps. The maximum charge current available to the battery is 200 amperes after the future rectifier installation.

The suitable current rating for the battery protection device is 250 amps (125% of maximum installed charger rating), with an AIC rating greater than 5089 amps. DC distribution branch circuit breakers have ratings between 5 amps and 30 amps. However, the AIC rating of these breakers is typically less than 5000 amps. On occasion, installation of breakers with unknown AIC ratings occurs. Verify that the AIC is equal to or greater to the battery short current. All conductors between the battery and the discharge bus are rated for 250 amps minimum at 77 °F (25 °C), and conductors on the load side of the distribution breakers match the breaker current rating

Case 2, illustrated in Figure 2, describes a plant designed for future expansion. The future plan includes an additional rectifier shelf, a third battery string, and individual battery disconnect devices. The DC plant has a load of 170 amperes that requires four 50 amp rectifiers (a second shelf provides a capability of eight maximum) to provide an n+1 redundancy. The design calls for a battery backup capability of eight hours. We select three 17-plate VRLA batteries as defined in Table 1. Each 680 Ah battery string, at the eight hour rate, delivers 85 amps at 77 °F (25 °C) for 8 hours, to an end voltage of 1.75 vpc. Table 1 lists the available battery short circuit current at 5316 amps. The maximum charge current available to the battery is initially 200 amperes, and 400 amps with a maximum upgrade.

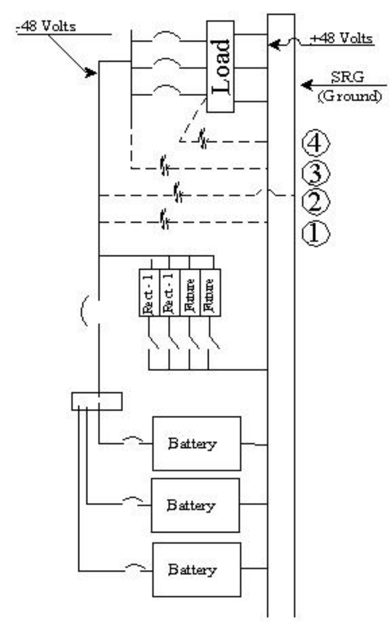

Figure 2

A suitable main battery protection device has a current rating of 500 amps and an AIC rating greater than 15948 amps. Individual battery disconnect devices require the same current rating of the main device. This requirement is due to two batteries being off line. The remaining battery still provides full system current to the load, even if it is for finite time duration. Disconnect devices are not designed to break short circuit current and, therefore, do not have AIC ratings. There are three reasons that individual battery protection device are not necessarily recommended for this application. First, coordination issues exist between individual and main battery protection devices. Secondly, physical size limitations prevent efficient use of space and future expandability. Lastly, protection devices cost more than disconnect devices.

DC distribution branch circuit breaker current and AIC ratings are identical to Case 1. All conductors between the each battery and the discharge bus will be rated for 500 amps minimum at 77 °F (25 °C), and conductors on the load side of the distribution breakers match their breaker current rating.

SUMMARY

When the designer considers the DC plant, accounting for future growth based on the criteria outlined in this paper, the initial and final designs will operate in accordance with good engineering practices. Conversely, when the DC battery plant is installed with a minimum capacity because the designer has not provided for maximum future growth, the final plant will have safety and protection issues. This paper omits advanced and controversial subjects to maintain an informative paper presentation.

The practical selection of an initial physical plant that meets future upgrade requirements, including overload and short circuit parameters, is challenging. The ability to upgrade fixed, in-place conductor, increased protection device frame sizes, and maintaining equal or less battery short circuit values may be unobtainable in an undersized physical plant. Often, equipment upgrades, including construction costs, far exceed planning for and installing a DC plant that meets the “best guess” future load profiles. Selecting the battery protective device, based on the initial plant continuous and short circuit current availability, may limit the designer's ability to upgrade later. A single battery string will attempt to provide total load when parallel strings are not available to contribute their share. The default of parallel multiple battery strings output current requires the conductor emanating from any one string to be capable of conducting the entire load during an abnormal event.

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