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Simplified Restoration: Extending Battery Life During Station Outages

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SUMMARY

When substations lose their auxiliary AC power during unexpected faults or planned outages, DC loads, such as protective relays, communication equipment, and circuit breakers, are powered by substation batteries. In this way, batteries ensure customers are in-service and the station can still be monitored and operated safely. Typical industry practice involves sizing these batteries for an 8-hour window of relay operation and ensures that battery-powered equipment can operate for at least one occurrence of the worst-case momentary (most power intensive) demand while accounting for an aging coefficient. This paper proposes a new way to achieve the goal of extended battery performance during complete station outages. Projections indicate these changes could extend a 50 Amp-Hour battery bank currently sized for 8 hours of performance to almost 7 days by making minor modifications to controls and DC auxiliary configuration. As a result, substations with this system could endure several days without an auxiliary source, saving manpower and equipment during challenging situations such as a major weather-related event.

KEYWORDS

Battery, Battery Sizing, Battery Extension, Station Outage

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BACKGROUND

Relays and circuit breaker tripping and closing are powered by a direct current system in a typical substation. During normal operation, this DC is powered by battery chargers, which receive their power from the station's auxiliary AC supply. When this AC supply (and DC chargers) are lost, the DC is provided by a battery. These batteries also provide the high momentary currents, associated with breaker tripping and closing, that exceed the amount of current that chargers can provide. These batteries are usually Lead-Selenium or Lead-Calcium variations of the Vented Lead Acid type (also known as "wet" or "flooded"). The arrangement of this DC system is shown below:

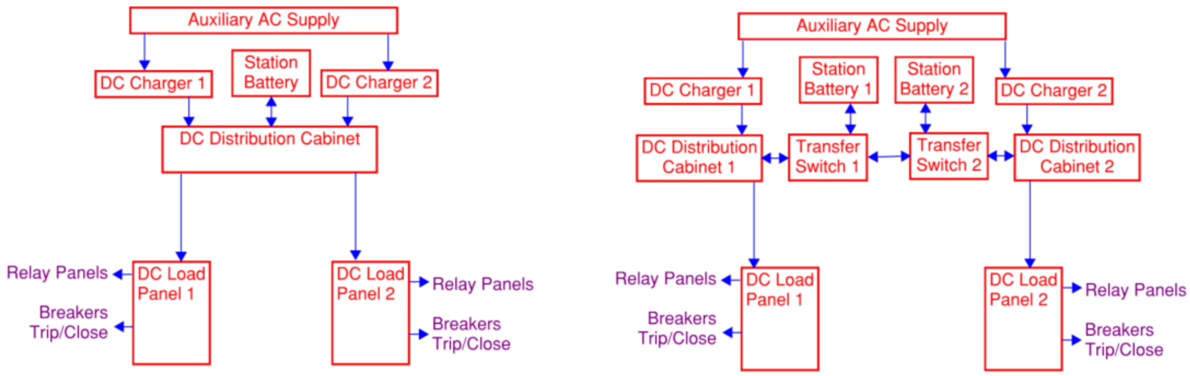

Figure I: On the left, a typical configuration of a one battery, two charger system for substation DC supply. On the right, a typical configuration of a two battery, two charger system for substation DC supply.

These batteries are typically sized to handle the entire continuous DC load of the substation, including relays, station computers, and telecommunications equipment, for 8 hours, along with at least one occurrence of the worst momentary current, consisting of breakers tripping or closing. Relays still operate off the battery even if they are not needed, such as would occur if all lines into a substation were dead, and thus no portion of the substation was energized and there is nothing for the relays to protect.

Current substation owner practice is to bring in an alternative source of power for an outage of a substation's direct current chargers that will last more than the (typically) 8 hours for which the batteries are sized to back up the station. This alternative source of power is usually a mobile generator or battery truck. During events, like extreme weather, that take many substations completely offline, the need for such alternative sources of power can stretch both the availability of equipment and manpower. If a substation was able to detect that it was completely offline, shut down most of its unnecessary relaying, it would drastically increase the time it could operate off its battery, and could avoid the need for an alternate power source at a time when the equipment and manpower are in short supply.

PROPOSED SOLUTION

This paper proposes such a system that will remove the DC supply from all other loads in the station, such as relays, breakers, and telecom equipment, when the station is completely offline, and therefore the relaying systems it powers are not needed. This will extend the time for which a battery can back up the station, without an alternative source of power, from the typical time of 8 hours to multiple days.

The system consists of a latching DC contactor located to isolate the battery and charger from DC load panels, digital control circuitry to activate the contactor, and a connection to the station's DC supply located between the battery and contactor to power this digital circuitry. The system is shown below:

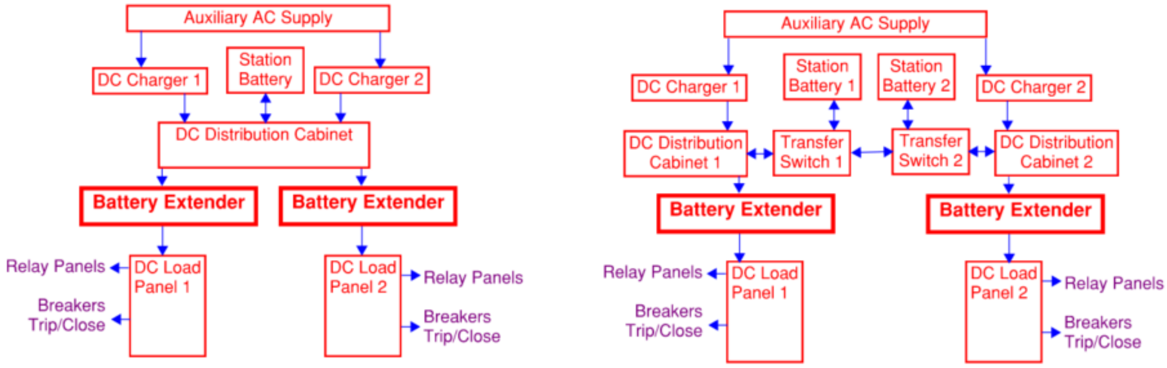

Figure II: Location of the battery extender within a typical substation's auxiliary power system. Note that the battery extender also isolates load from charger, because a substation should never be operated with its charger only. Single and dual battery systems are shown.

The system works by inserting a latching DC contactor in series between the station's DC supply (both the battery and charger) and DC load cabinet. The contactor is positioned to isolate the DC load cabinet from both the DC charger and battery because a substation should never be operated with a battery charger as its only DC supply. This is because virtually no chargers are sized to provide the high momentary currents needed for relay tripping (which can be more than 10 times the steady state value), which are supplied by the station's battery. Therefore, a substation whose only DC supply is its charger will likely be unable to trip or close its breakers. Although the chargers would be unavailable when this system operates, since their AC supply is not available, isolating them is a fail-safety measure which prevents this system from allowing the substation to operate with its charger only if the latching contactor fails to close when it should.

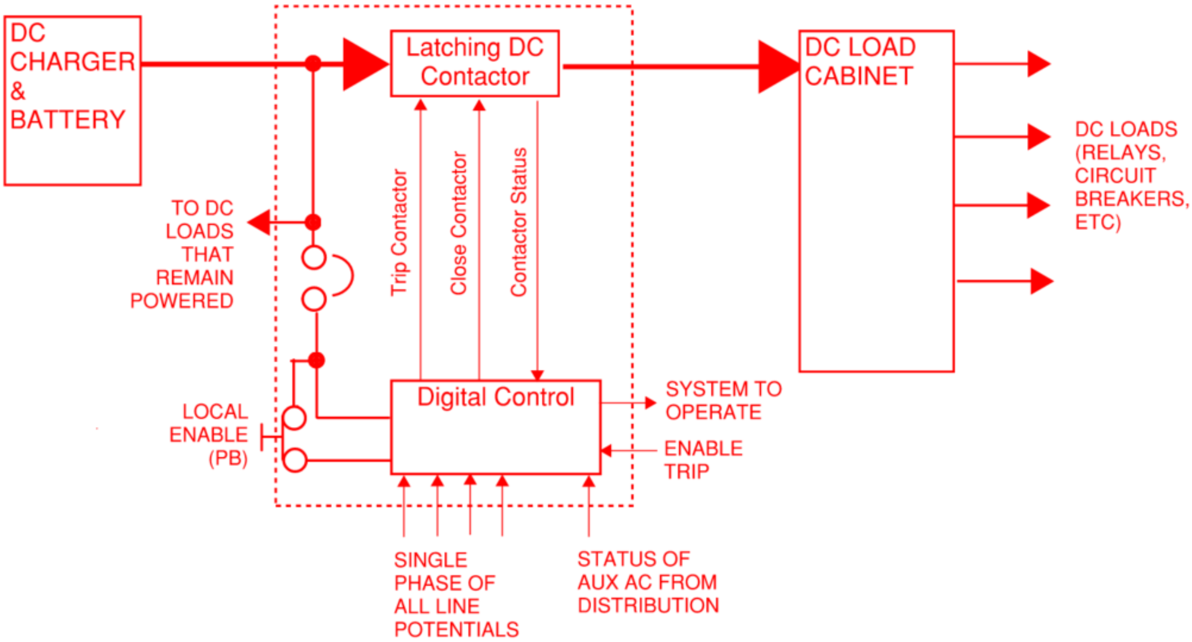

Figure III: Hardware layout of the battery extender.

It is important that the contactor is of the latching variety. In a latching contactor, a momentary signal to trip or close is sent to the contactor, which then holds its position even after the signal is removed. Latching contactors come in the single coil variety, in which the polarity of the voltage differentiates between a signal to open and close, or in a dual coil variety, in which a voltage is applied to separate trip and close coils to activate (much like a high voltage circuit breaker on an electrical power grid). A non-latching contactor would require a constant signal to hold it either opened or closed, which would cause wear on the coil and much more quickly drain the station battery.

Use of a normally open, non-latching contactor is an unacceptable solution. Even though it would not require power from the battery during operation of the battery extender, its failure would remove DC power from critical loads during normal substation operation. The battery extender is designed to ensure that it fails in a manner that does not remove DC power from loads that need it.

A digital system operates this contactor that monitors a single phase of voltage of all supply lines into the station to establish whether the station is alive or dead. If all supply lines (and AC auxiliary power if provided from an external connection to local distribution) are dead, then the station is dead and therefore all loads in the DC Load Cabinet are unnecessary. When it is determined that the DC loads are no longer needed, the latching contactor trips, thus removing the cabinet and its connected loads. A DC connection supplies this digital system located between the latching contactor and battery. Therefore, it remains energized while all other loads are disconnected. When it senses that one of the supply lines into the station is alive, it closes the latching contactor, thus restoring relaying, telecom, and breaker trip/close functions. Contactor open/close status feeds back to the system to determine whether to open or close the contactor. A "local enable" signal allows the user to activate or deactivate this system. A "system to operate" alert can be routed to other systems in the substation indicating that the battery extender is going to disconnect the DC load. Finally, an "enable trip" signal is provided to allow external controls in the substation to give permission for the system to trip, and they are combined with a timer that delays dropout since any external input will lose power and automatically drop to zero once the contactor opens. The combination of "system to operate" alert and "enable trip" can provide a substation's SCADA system the option to trip all breakers in the station when the battery extender is about to operate, and to prevent the battery system from operating unless all breakers trip. This functionality of this check was not built directly into the battery extender because doing so would require too much additional wiring. This system does not require operator intervention to either activate or deactivate.

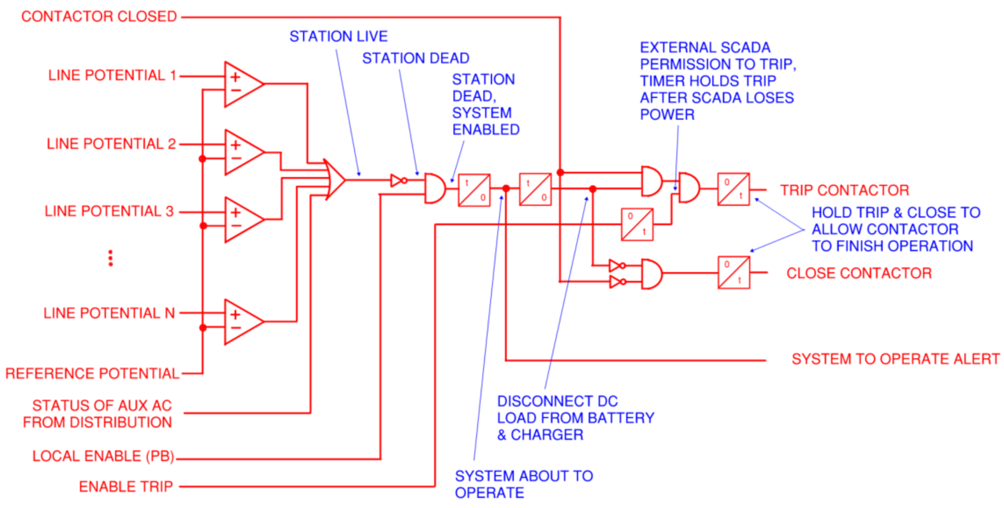

Figure IV: Logic diagram of the digital system controlling the latching contactor in the battery extender. The system shown above is for a dual coil latching contactor.

It should be noted that the system is positioned to remove power to all DC loads connected to the main DC load panel. This may include emergency lighting, as some utilities power it off of the main batteries (though many utilities use emergency lighting systems with their own batteries). The utility may wish to supply this and other loads even when the battery extender removes power to the main DC load panel. Therefore, an output is provided on the battery extender to wire these loads to. The need to power these loads would reduce the increase in battery duration that the battery extender could provide.

BATTERY CALCULATIONS

Calculations and assumptions were needed to predict how long a substation battery could last with this reduced load mode. The following assumptions were made:

- It was assumed that the load of the battery extender would be 15W, which is the power demand of an SEL-2411, that can execute this function (though a cheaper, lower power PLC can likely perform this program as well).
- It was assumed that this system will operate on a 125V DC system with a 50 Amp-Hour (for an 8-hour discharge) vented lead acid (VLA) battery. 50 Amp-Hours represents the smallest size of a battery typically found in most substations. 100-200 Amp-Hours is a much more typical size for a substation's batteries.
- It was assumed that the battery's Amp-Hour capacity was 80% of its original due to aging. VLA batteries lose capacity over time, and this loss increases rapidly when they reach 80% of their rated capacity, so IEEE Standard 485, *Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications*, calls for lead acid batteries to be replaced before they decline to 80% of their original capacity.
- It was assumed that the battery should only be discharged to a depth of discharge of 50%. Depth of discharge refers to the percentage of the rated Amp-Hour capacity that is used for a given battery. Completely discharging the entire capacity of any battery

will damage it. For both VRLA and vented lead acid batteries, it is generally accepted that depth of discharge should be limited to 50% to avoid a decrease in life [3].

- The effects of Peukert's Law were ignored in this paper's analysis. Peukert's Law consists of a mathematical formula that describes how the effective energy storage capacity of a lead acid battery will increase as its current is drained more slowly. While the effect of Peukert's Law will improve the duration for which the station outage battery extender system can last, the mathematical relationship does not hold at a reduction as substantial as that from typical steady state relay demand (a few Amps) to the 120mA demand of the 15W PLC assumed for this system.
- Self-discharge is ignored because it is not a significant phenomenon in lead acid batteries, which typically self-discharge about 5% of their stored charge in a month [1].

Using these conservative assumptions, when a 50 Amp-Hour battery is assumed to have degraded to 80% of its original capacity, and when depth of discharge is limited to 50%, this provides an effective capacity of 20 Amp-Hours to supply to the load. If the battery extender consumes 15W, which equates to 120mA at 125Vdc, it can be supplied by this battery for 166.7 hours, which equates to almost 7 days. When the station comes back online, the breakers that have tripped can be closed using the remaining capacity in the battery. This will not be a significant enough drain to damage a battery even at 50% depth of discharge.

CONCLUSIONS

This paper presented a system that can extend the life of a 50 Amp-Hour substation battery from the 8 hours that it is typically sized for to almost 7 days during a complete station outage. This system works by sensing that all lines and sources of power into the station are dead, and then removes all other DC loads (which are no longer needed) from the battery, leaving only itself. It monitors the incoming voltages, and when any source of power into the station comes back on, it returns DC power to the other loads, restoring normal relaying. This system does not require operator intervention to either activate or de-activate.

BIBLIOGRAPHY

[1] Battery University "What Does Elevated Self-Discharge Do" https://batteryuniversity.com/article/bu-802b-what-does-elevated-self-discharge-do

[2] Institute of Electrical & Electronics Engineers, (2020) IEEE Recommended Practices for Sizing Lead-Acid Batteries for Stationary Applications (IEEE 485), Retrieved from https://standards.ieee.org/ieee/485/6726/

[3] ECO SOCH https://www.ecosoch.com/lead-acid-batter