ADVANCED SYSTEM MANAGEMENT FOR STATIONARY STANDBY BATTERIES

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ABSTRACT

Between scheduled capacity tests, we accept the proposition that a battery maintains its advertised and tested capacity. In actuality, we have little choice but to accept this premise. In some cases, but not all, we periodically check battery capacity with a complete discharge test to determine if it can deliver the power and energy required to support our critical loads. These tests are both time consuming and expensive but are considered essential to maintaining our confidence level that indeed, the batteries can deliver their rated capacity when called upon during a power outage. But then, although the system passed the last capacity test, when it is called upon during an unscheduled power outage, we are surprised (and disappointed) when the battery fails to meet backup power demands.

Monitoring and periodic capacity tests are currently the most widely accepted methods for battery system management. But, even the best monitoring systems cannot reliably predict that a battery will deliver rated capacity. Recent research at Sandia National Laboratories has resulted in the development of a battery management and control methodology that can routinely report actual battery capacity in real time. Using this methodology, periodic capacity testing is unnecessary as the capacity is continuously monitored under actual operating conditions and is routinely reported. In addition, the battery is always in standby while the methodology is being applied, ready to deliver full rated capacity in the event it is called upon during a power outage. This paper will describe the methodology applied in this revolutionary approach to stationary standby battery management and control.

INTRODUCTION

Many industries and applications have a critical need to be assured that power sources will be able to supply critical loads in the event of a power failure. Such industries include, but are not limited to, telecommunications, power utilities, information technologies industries (for example, banking, stock brokerage, and insurance applications), and critical care medical facilities. Countless examples exist of power sources failing to operate as needed when required. These examples include events resulting in millions of dollars of losses, and events creating public hazards (including air traffic control system failures).

A standby power supply is generally a requirement of the power systems for these applications. A standby power supply can alternatively be called an uninterruptible power supply (UPS) or a back-up power supply, or other descriptors, having slightly different designs but each being used to provide a continuous supply of electricity to critical equipment in the event of an electric utility outage. Such standby power supply systems generally include power conversion equipment, batteries, and controls to enable appropriate discharging and recharging of the batteries. Standby power systems are put into use only rarely, as utility outages are themselves rare. Because accurate testing of the standby power supplies is generally performed manually at discrete intervals, it is expensive and time consuming. Such testing is therefore not done frequently and there are sometimes problems with the standby power system failing to perform when required. Additionally, during the time period during which the testing is performed, the standby system is not available in the event of a power failure unless provisions are made for a temporary backup system, another expensive item.

Consequently, a standby power system is required that can reliably provide sufficient power for a critical load in the event of a power failure and, at the same time, does not require frequent and expensive manual testing to ensure the reliability of the standby power. To meet this requirement, a new battery management and control methodology is needed that will accurately and reliability report the condition of a UPS in real time.

THE METHODOLOGY

A New Paradigm

At Sandia National Laboratories, a new methodology has been developed which is based on a power management system that constantly tests and monitors a battery in a continuous and highly controlled way so that at any given time, the state of health of the battery is always known. One of two requirements must be met for a battery system that can utilize this methodology:

1. The battery system must have a minimum of at least two independent parallel battery strings, each of which must have the available capacity to support the critical loads.

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2. In a battery system with more than two independent parallel battery strings, the battery system must be designed in such a way that the critical loads can be supported with one of the strings off-line at any given time.

System Functionality

The control module, as illustrated in Figure 1, consists of both hardware and software that independently tests, monitors, and manages each of the strings in the battery system. The control module also retains past history data so that each time a test is performed, trend analysis can also be performed. While a single string is undergoing independent testing, all the remaining strings remain in standby, ready to support loss of primary power in the event of a utility power outage. At least two battery strings are required, but the actual number of battery strings used will depend on the power requirements of the system and design and cost requirements. The control module also functions to supply standby power from the battery to the load in the event of a detected power failure, determining which strings of batteries can reliably provide the standby power.

The control module not only provides for switching the battery strings into a test mode, but also provides hardware and software for measuring and then recording the performance characteristics of the tested battery strings. Data is then evaluated to determine the performance response and trends of the string and, as required, the control module will issue instructions for manual maintenance or repair of a particular string or power supply element making up the string. The test module functions to test each of the battery strings according to a predetermined schedule or algorithm. The testing can include the entire battery or individual strings or combination of individual strings as commanded by the control module. Based on data analyzed during a discharge test, the test module recharges the string returning the energy used during the discharge and whatever makeup charge is needed to return the string to a full state of charge. Equalization charging can also be performed in the event the control module determines that equalization is needed. The testing can be comprised of a variety of tests including a short duration test discharge of a battery string to detect possible increases in resistance. Other tests may be executed to develop data sequences for trend analysis where voltage, current, temperature and other parameters can be monitored as a function of time so that string performance or degradation can be evaluated.

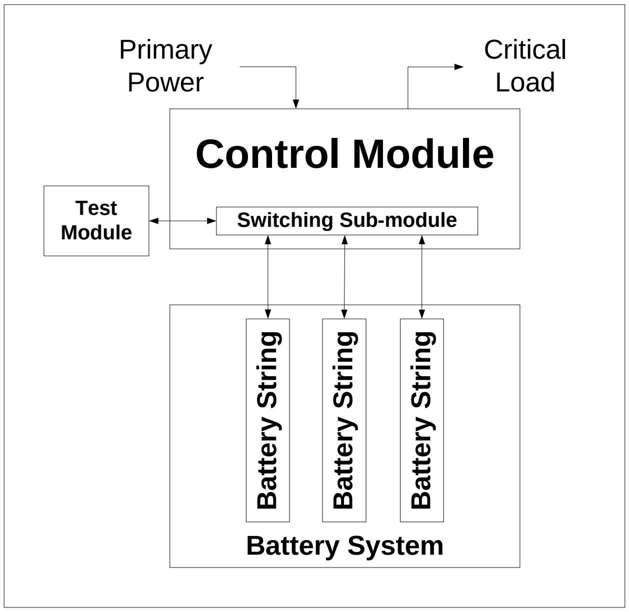

Figure 1. UPS System Diagram with Control Module

Overview of System Architecture

As shown in Figure 2, the system consists of a control module, a switching sub-module, and a test module. The control module is the heart and brains of the system containing the control software program, analysis algorithms, performance history data, and status call-out capability. The switching sub-module, commanded by the control module, switches the various battery strings to the configuration required for the performance of the various tests. The test module consists of the necessary hardware, software and data acquisition components to measure and record the performance characteristics of each individual battery string. The test module provides the means for performing the discharge test and the capacity test. In the general discharge test, a battery string is discharged by an integral load at an appropriate rate and to a defined depth of discharge to validate the string's (or string subset's) state of readiness to perform its intended function. The string can then be fully recharged and conditioned as necessary before being switched back into the backup power supply circuit.

How does the system work?

As shown in Figure 2, two battery strings are included in the example design. Each string is capable of supporting the critical load. Two each, two-way switches are employed, one in String A and one in String B. Shunts are also present in each string for the purpose of measuring individual string currents. One pole on each switch is connected to the DC bus, the other pole is connected to a third switch that controls the functionality of the test module. The switches are remotely operated by the control module and could be electromechanical relays or semiconductor devices that can perform the switching functions.

During normal operation, each of the switches is positioned so as to connect the corresponding battery string to the main direct current (DC) bus, as shown in the Figure 2. Thus each parallel string can be float charged from the DC bus as is the standard practice in such UPS equipment. Under control of the control module, based on the frequency that is selected for testing for the particular function that is to be performed, switches are reconfigured so that one of the strings is connected to the test load. Following completion of the test being conducted, the string undergoing testing is connected to the auxiliary charger in the test module. According to the schedule specified in setting up the test algorithm in the control module, each of the strings will be disconnected from the main DC bus and connected to the test load and then to the auxiliary charger in a pre-determine sequence. The time interval between testing events is such that there is always adequate power and energy available to supply the critical load in the event of a power failure.

When one of the strings is connected to the test load, that string is discharged. The voltage and current and other performance parameters for each string are analyzed and archived to determine the reliability of the batteries in the string and of the interconnections between the batteries and between the strings and the main DC buses. After the discharge, the string that has been tested is recharged with the auxiliary charger until measurement of voltage and current indicate that the string is fully recharged and ready to be returned to service.

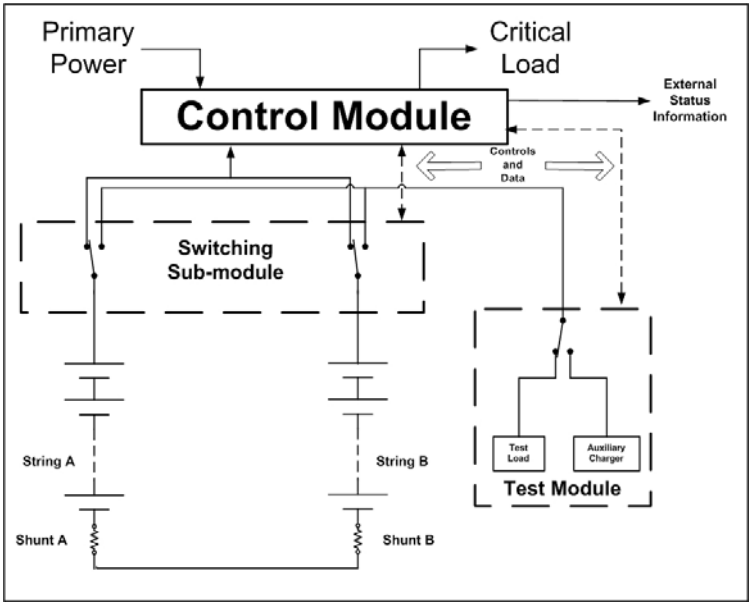

Figure 2. System Drawing

If, during the test, it is determined by the control module software that the string is not likely to perform as required during a power failure, then a signal is sent via the external status information link to an external maintenance facility, human agency, or other facility to alert personnel that a repair is required. Thus, the system does not require maintenance until automatic testing and analysis determines that maintenance is needed, allowing more efficient use of personnel. Additionally, the control module can provide a record of the performance characteristics of the string requiring maintenance to maintenance personnel so that more efficient problem diagnosis and repair can be made.

Tests Applied by the System

Specific discharge tests measure impedance values through the application of a high rate test load for a short period of time to determine if impedance values have increased, thereby indicating degradation in performance. The control module controls the test module which in turn provides the means for putting a test load on the battery string and measuring impedance values. For capacity testing, the control module commands the discharge of individual battery strings at a specified rate to a specified end voltage and tracks and records overall performance.

Unique to the power system being described, all tests are performed while the system is still on-line and capable of supplying back-up power in case of a power failure of the primary power system. One or more battery strings can be tested simultaneously, as long as the remaining battery strings are capable of supporting the critical load in the event of a primary power loss. For example, if the system battery consists of more than two parallel battery strings, one or more of these strings can be tested, as predetermined by the testing algorithm in the control module. In the event that the stand-by power supply system is called upon to discharge while one of the strings is in the test mode, then the string(s) undergoing testing can automatically be brought back into service at an appropriate time during the outage event.

Another test of performance characteristics is trend analysis which uses established algorithms and historical data archived in the control module in conjunction with the most recently measured data on current, voltage, resistance or other measured electrical characteristics, to predict the future performance of a battery string. This analysis can be used to predict time to failure or significant performance degradation even though significant performance degradation has not yet occurred. Consequently, preventative maintenance can be recommended if necessary or a battery replacement strategy can be developed.

Major Functions Performed by the Control Module

One function performed by the control module is to schedule and initiate periodic switching of battery strings to the testing module on an individual basis. The control module provides for automatic testing of the battery strings and elements thereof so that human intervention need only occur when the control module detects a failure or a potential failure in the backup battery. The control module controls all testing and analysis functions. The control module also controls monitoring of electrical performance characteristics, such as current, voltage, resistance, and temperature of the backup battery system. These monitoring activities provide the data necessary for the device to determine failures or potential failures and manage trend analysis functions. The control module also controls monitoring of the primary power supply to detect power failure as well as controlling subsequent switching of the standby power to the critical load as needed. As predetermined from design requirements, the control module controls float charging of power supply strings using a pre-determined or pre-programmed algorithm to perform continuous or semi-continuous float charging of any or all of the battery strings to maintain the performance capabilities of the battery.

Test Protocol

Figure 3 illustrates the testing protocol. The frequency of testing and the application of the various test procedures are determined by the user or as recommended by the backup system installer or battery manufacturer. Under the control of the control module, the battery strings are switched individually in a pre-determined sequence from a ready-to-be-used standby mode, into a test mode. The i^{th} battery string, where i goes from 1 to N (the total number of strings that make up the backup power system), is switched to the test mode where the test module evaluates the performance of that string. The performance is evaluated according to pre-determined protocol as previously described, and can include discharge tests, capacity tests and performance trend analysis where test results include voltage values, current values, temperature values and impedance values over time. The performance of the entire string can be evaluated as well as the performance of individual elements of the string or some subset thereof. If pre-determined performance specifications are met, the battery string is switched back into standby mode, the value of i is incremented to the next string until the final string is tested, at which time the counter i is reset to the first string and the testing process repeats, with the control module switching the next battery string into the test mode. If the performance specifications of the battery string are not met, then an external signal is sent to initiate repairs or maintenance of the string.

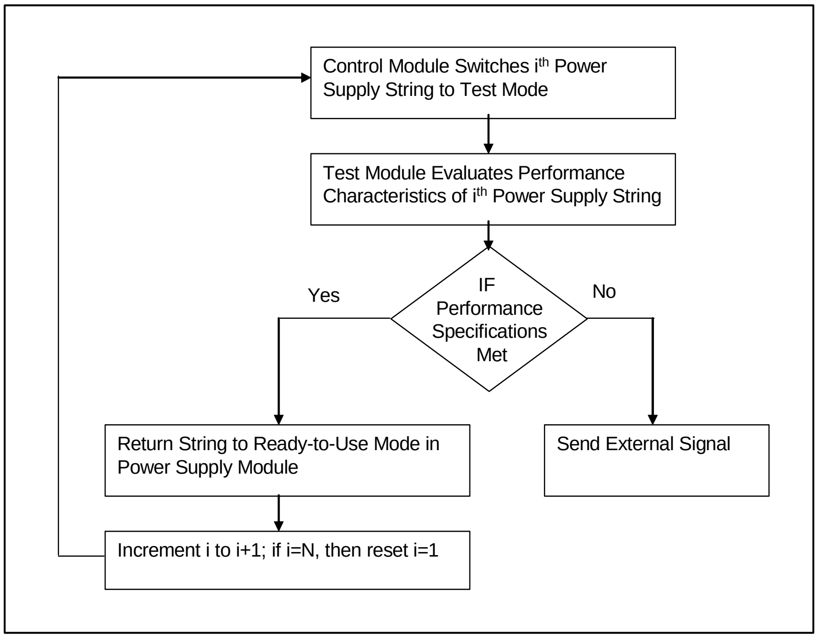

Figure 3. Testing Control Logic

Additionally, by monitoring trends in string current and voltage while the battery is in a standby mode and not undergoing active testing, the performance of the battery strings can continue to be evaluated. Similar to the test mode, the voltage, current, impedance and temperature can be monitored and analyzed to evaluate the performance characteristics of each battery string even though specific performance tests (such as the discharge test) are not performed. These values can be measured at pre-determined intervals while the system is in a stand-by mode and can also be measured if the UPS is called into service in the event of a power failure of the primary power supply. Using performance trend analysis or other analysis to compare the performance characteristics of the power supply strings in the ready-to-be-used mode compared to the performance during the power failure, the battery system performance can also be evaluated.

CONCLUSIONS

The methodology developed at Sandia National Laboratories solves one of the primary problems in battery system monitoring in that the system can be tested proactively on a periodic basis and monitored continuously to detect trends in degradation in real time, not just when special capacity testing or periodic maintenance is performed. A primary benefit of the testing system is its ability to perform all tests in such a way that the backup power system is always available in the event of a primary power failure. In addition, the condition of the battery is always known. The downside of implementing this backup power system configuration is the necessity to have excess capacity in order to be able to withdraw selected battery strings from standby service for discharge testing to verify battery string capacity and collect data for trend analysis. The upside is that the system is continuously monitored, both actively and passively, so that trends are analyzed and reported long before the battery is in a compromised state. No more surprises and an even more tangible benefit, reduced maintenance costs.