Some advances in control for telecommunications DC power systems

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ABSTRACT

This paper discusses a new control concept that uses the information contained in monitored data to modify telecommunications DC power system operation in a beneficial manner. The application of this concept to common functions of low-voltage battery disconnection, battery condition testing, and recharge current limiting is presented. The control concept can also be applied to the less commonly used intermittent charging technique.

INTRODUCTION

Improving power system design and practices, and individual components, has been a focus activity for INTELEC since its inception. In contrast, power system control has not enjoyed many prominent advances over the last 10-20 years. Advances in digital techniques have seen microprocessors, memory, and digital transmission supplant discrete analog logic and manual maintenance processes; as well as augment alarm processes. However, digital techniques have not significantly added to the functionality of control, or its impact on system reliability.

In critical *telco* standby plant infrastructure, power system functionality has always been coupled to some sort of status measure. In historical terms, rudimentary hard-wired alarms based on discrete set-point decisions provided local information about the operational status and condition of the power system. The basic electrical information was sometimes augmented by physical information collected by local on-site manual maintenance activities. In recent years we have seen the emergence of automated monitoring to assist with alarming and diagnostics related to the operation of DC power systems. Automated and centralised monitoring has generally provided improved data and, indeed measurement of the power system reliability. It has also provided real-time information to allow intervention action to address potential loss of system functionality. The value of this real-time information in contributing to improved system functionality, is however, directly affected by practical operations and maintenance practices. Notably, the monitored information itself can not and does not, *by itself*, contribute to system functionality or reliability. That is, the monitored status and diagnostic information is valueless unless it is used effectively. Increasingly, the wealth of passive information that is provided by these automated systems is starting to be used to pro-actively maintain component failure and component end-of-life, and hence does directly contribute to system reliability. For example, service life condition of the storage battery in standby DC plant can directly affect system functionality. In the particular case of lead-acid batteries, control of the operating conditions of the batteries and system can directly affect the service life. Manipulation of the control of the operating conditions requires sufficiently discriminated information about the operational status of the batteries. On-line monitoring, at the individual cell level can now provide a suitable information set to make intelligent informed control decisions which will lead to improved overall system reliability.

The general thesis which extends from this specific example is effective coupling of monitored and system control and a knowledge-based approach to the modification of "whole-of-system” operation in a beneficial manner.

SYSTEM CONTROL

Standby DC power plant can be simply described as a connectivity between energy storage devices (batteries), power converter devices (rectifiers) and distribution devices (HODs, LODs, protection gear, cabling, bussing, etc). While protection gear might be remotely controllable, in practical terms, it is really only the rectifiers in a typical power system that are "controlled". Individual rectifier units incorporate simple voltage and current limit regulation, and are normally under the control of an external rectifier system monitor-controller. The system controller allows more adaptive control functions to be implemented. These can range from the simple to the complex: from simple float voltage temperature-compensation, where the output (function) of the rectifier is modified due to temperature (*i.e.* a local condition); to current limiting after discharge, where one of the primary output functions of the rectifier is conditionally modified depending on some previous state of the system; to even more

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complicated tasks such as periodic battery condition monitoring, where the entire functional purpose of the rectifier is suspended, and the ability of the storage batteries to support the load is tested. Some other system components incorporate simple control functionality through protective mechanisms, such as over-current protection (*e.g.* circuit breakers) and under-voltage protection (*e.g.* low-voltage disconnect - LVD).

NEW CONTROL CONCEPT

The main limitation of existing control systems for telecom DC power is not micro-processor capability, but rather the lack of valuable information with which to make intelligent control decisions. Intelligent control decisions in relation to the "whole-of-system" function required a knowledge-based approach to arbitrating the relationships between local assessment of status and the desired functional condition. On-line monitoring of individual battery cell voltage and impedance is deemed to be the most advanced means to acquire sufficient information to assist system control in both a knowledgable and beneficial manner. Individual cell monitoring can be augmented by monitoring cell interconnect impedance, cell temperatures and string current (down to float current level). This level of battery information can then be used to make more informed control decisions from a functional "whole-of -system" perspective.

In simple form, the proposed concept is to monitor individual component operations within a system, and use component-level data, rather than aggregated data, to make control decisions. The concept has particular beneficial in power systems comprising a number of individual elements, each with a reportable status. For instance, in the case of a DC power system, which contains strings of battery cells, where historically, only string voltage is typically available.

Implementation of this new type of scheme involves coupling both monitoring and control elements. Concepts of data collection in battery and power systems are well developed. The generic characteristics of battery monitoring systems have been widely described. However, it must be said that the interpretive and diagnostic ability of commercially available devices varies widely. The recent trend has been to consider the integration of the operational status of the power conversion and distribution components as well as the energy storage components into a "whole-of-system" functional monitoring [1-4]. The scope of interaction of power system components is potentially broad, and the complexity of functional monitoring depends on the degree of system information and control required by the application. Integration of functional monitoring into the management of operational DC powering infrastructure has been proposed [5]. The addition of a local operational control element to the role of functional monitoring is an extension of the versatility and usefulness of those previously considered approaches.

In a co-operative, interactive, component system, the quality of the overall output function may be continuously assessed. In all systems involving some form of feedback, functional assessment is a core role of the control function. When conditions occur which represent a risk to the function of the system, the assessed risk may be self-handled by the system as part of a self-regulation and control process. Additionally, the risk may be reported as an element of control to a supervisory platform or as management information to an external system.

A necessary requirement for intelligent self-regulation and exception reporting is a means or process to order and prioritize the various contributions to the determination of risk to function. This demands a degree of self-diagnostic assessment capability. The degree of local "intelligence" must be sufficient to determine optimal and abnormal operational and performance conditions. Rule-book approaches are typically used when prioritised decisions (and actions) are required. Rule-book approaches require identification of all the elements which contribute to the functional output. Thus, as shown in Fig 1, functional monitoring requires a local process to logically determine the true status of the power system with respect to risk to the output functionality.

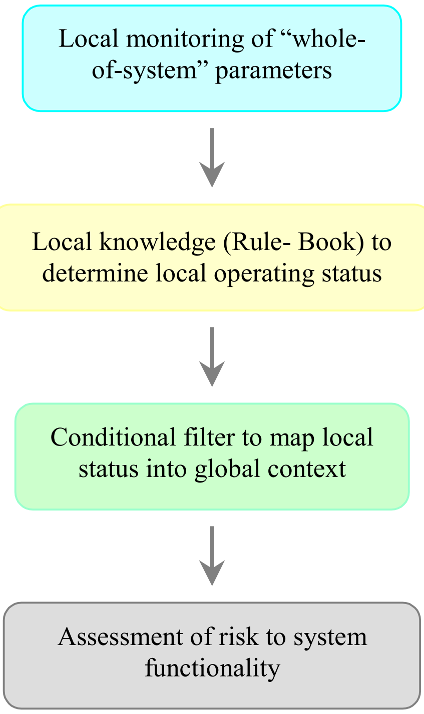

Fig 1. Local influence of output functionality

These ideas associated with this control concept can be best seen in discussion of three specific applications: low-voltage disconnection of a failed battery (*i.e.* the low-voltage disconnect, or LVD), battery condition testing, (*i.e.* generic BCM feature), and recharge current limiting.

APPLICATION #1 – LOW VOLTAGE DISCONNECT (LVD)

In common use is the LVD function, which automatically disconnects the battery from the DC bus when the battery string voltage decreases to below a preset voltage level. The benefit of this function is to inhibit the battery from sustaining damage for instances such as during failure of the AC power source when the battery discharges into the load. However, the generic LVD has the major disadvantage that it only senses the battery string voltage.

Generally, the weakest cell limits the performance of a battery string, and so a battery string containing cells having significant capacity variation may have a direct impact on system autonomy. LVD's operate on an set-point being an aggregate representation of cell terminal potential. At best, the use of a string voltage set point is only a design approximation of the capacity of the battery string, and does not necessarily indicate the existence of a weak cell with an abnormally low capacity. The LVD may not actuate prior to a weak cell becoming fully capacity depleted, and a over-discharged cell might subsequently become a risk to the system. An LVD may also actuate prior to the battery reaching an acceptable level of capacity depletion, thereby degrading system autonomy. The monitoring of a suitable information set providing sufficient data to allow an assessment of the status of individual cells during a discharge event will allow more appropriate control decisions to be made for the actuation of an LVD.

The interruption to system operation is another disadvantage of the LVD. Typically the entire load is disabled by disconnection of the battery, and there is no option to shed portions of the load. Some telecommunications equipment has the ability to operate with a lower level of redundancy, or in a reduced functional capacity, when portions of the load are not powered. The ability to shed non-essential load is therefore a means of realising the power system's full autonomy time. Monitoring of key parameters, such as string current, individual cell voltage and impedance, and real-time assessment of battery capacity and run-time, allows appropriate control decisions to be made in effecting load-shedding. That is, the availability of real-time component performance and status data allows for dynamic and flexible control options.

Transient currents can occur upon re-connection of the battery, due to discharged capacitance in the load equipment. The magnitude of transient current experienced during re-connection can be large enough to operate over-current limiting devices, such as fuses and circuit-breakers within the DC distribution network. In many installations that suffer these types of trips it is common practise to recharge deeply discharged batteries separately (off-line). Appropriate automatic control of the re-connection of an LVD to minimus bus perturbation can be achieved by utilising monitored data of the string voltage of current.

APPLICATION #2 – BATTERY CONDITION TESTING

The battery condition monitoring (BCM) function is also a common, if not popular form of "advanced rectifier feature". In general, the BCM function is offered as an automated test of the ability of the storage battery to support the load. There is a tendency to interpret the result as a rated capacity test. While a discussion of the meaningfulness of BCM is outside the scope of this paper, the test is at least a short-term test of the conduction integrity of the battery system at the load demand current density. In this context, the test is useful. As it is commonly implemented, the rectifiers are automatically and periodically disabled for a preset period of time, during which time the battery supports the load. At the end of the preset period of time the rectifiers are automatically returned to normal operation. During the time the battery supports the load, if the battery string voltage decreases to below a preset voltage level then the BCM function is normally configured to generate an alarm, and to terminate the test.

However, the generic BCM has the major disadvantage that it only senses the battery string voltage. At best, a string voltage set point can only provide an approximate relationship to the capacity of a battery, and the BCM test does not necessarily indicate the existence of a weak cell with an abnormally low capacity. The monitoring of string current, and individual cell voltage and impedance, and the real-time assessment of cell capacity during a discharge, is seen to be an effective way to improve BCM performance. Monitoring string current will automatically accommodate for particular power system configurations, as well as accommodate for changes in load current for a particular power system resulting from changes of load equipment configuration over the life of the power system. Monitoring of individual cell voltage and impedance, as well as interconnect impedance, will contain enhanced information relating to the ability of the battery string to support load.

The BCM is sometimes used to predict remaining run-time during a discharge. However, battery string voltage, or the change in voltage during the discharge period, may not achieve accurate prediction of the remaining run-time of the battery. The monitoring of string current, and individual cell voltage and impedance, and the real-time assessment of cell capacity, achieves a substantial improvement in prediction accuracy for the remaining run-time of the battery during a discharge.

APPLICATION #3 – RECHARGE CURRENT LIMITING

In many telecommunications DC power systems, the voltage, current and power operating characteristics of the rectifier apparatus typically control the battery charge current. The battery charge current subsequent to a discharge event is normally only constrained by the maximum current limit of the rectifiers, minus the current drawn by the load.

In some recharge situations, a battery can experience cell, or monoblock, voltage or current levels that exceed specified limits. Operation of battery cells, or monoblocks, at excessive voltage or current levels can degrade battery life, can lead to an increased requirement for maintenance, and can void battery warranty. The monitoring of individual cell voltage during a discharge, and the ability to control rectifier voltage and current, is seen to be a most appropriate method to eliminating the chance of exceeding specified battery voltage limits. Likewise, battery temperature is another important battery parameter requiring management during recharge.

For the situation where a battery is deeply or over-discharged, then permanent capacity loss due to corrosion can result from subjecting the battery to too high a charge current density whilst it is in a deeply discharged state. The monitoring of string current, and individual cell voltage and impedance during a discharge, coupled with the real-time assessment of individual cell capacity and the ability to control rectifier voltage and current, allows appropriate control decisions at the rectifier to help eliminate unwanted operating conditions which are not beneficial to the battery.

INTERMITTENT CHARGING

In most telecommunications standby power systems, lead-acid batteries are deployed in a manner where the battery spends the majority of time operating in a float condition. In a float condition, a small current passes through the battery that effectively replaces capacity lost due to self-discharge and maintains the battery at full capacity. The battery experiences both electrochemical and chemical modes of degradation, and these degradation modes predominantly determine the service life of the battery. The float current supplied by the rectifier is the result of a simple aggregate process, which assumes a nominal and equivalent condition of all the cells connected to the rectifier. This approach is effectively detrimental to the batteries.

In an open-circuit condition, with no current passing through the battery, the battery experiences only chemical modes of degradation and can exhibit a comparatively longer service life. The literature [6-10] has generally coined the term "intermittent charging" to refer to methods of charging the battery, whereby the battery does not receive a continuous charging current, and operates for a substantial period of time in an open circuit condition. Three references [6-8] show that batteries operated under open-circuit conditions, compared to batteries operated under float conditions, can exhibit up to a 100-200% improvement in service life.

Important control requirements for implementing intermittent charging are to gauge cell capacity as it falls due to self-discharge, to monitor battery connectivity, and to control recharge periods for maintenance of system autonomy. The monitoring of individual cell voltage and impedance and interconnect impedance, and the real-time assessment of individual cell capacity, allows appropriate control decisions to be made with intermittent charging. Monitoring technology with sufficient interpretive and diagnostic ability is now available [2, 11, 12]. Moreover, the generic software characteristics and constructs to support knowledge-based processing for flexible and adaptive control algorithms have already been proposed [5].

The advantages of this intermittent charging scheme are not only increased service life for float applications, but also the alleviation of thermal-runaway affects, and the ability to include recharge current limit at the string level.

CONCLUSION

This paper has proposed that advances in the performance of high reliability DC power systems can be achieved by coupling highly specific and resolved data, monitoring the status of the components of the system, with a knowledge-based approach to the control and operation of the system.

Information is not useful knowledge until it is utilised. Monitoring methods are relatively low cost and the collection of appropriate information sets is now rather trivial. It appears common sense to collect and use component-level data, rather than aggregated data, to make control decisions for an "whole-of-system" beneficial outcome. The concept has particular benefit in power systems containing strings of battery cells, where historically only string voltage monitoring has been typically available. When implemented with appropriate controlling devices, the concept can significantly alleviate many of the operational problems experienced with batteries, such as irreversible damage during recharge and discharge, thermal runaway, and unreliable determination of battery health at the cell level. This new control concept is the subject of a patent application [13].

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