Reduced Control Voltage Testing of Low and Medium Voltage Circuit Breakers

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REPORT SUMMARY

This report provides nuclear electric utilities with some basic information and insight into the use, benefits, and limitations of reduced control voltage testing of low and medium voltage circuit breakers.

Background

The nuclear power industry's circuit breaker users groups, under the sponsorship of EPRI-NMAC, are involved in the development of circuit breaker maintenance guidance documents for industry use. Over the course of developing guidance, it was apparent that it would be beneficial for the groups to collectively address reduced control voltage testing. By collectively addressing this test, the industry could attempt to establish a position on the use, benefits, and limitations of reduced control voltage testing. This effort was designed to develop a technical basis for the use of reduced control voltage testing in proper maintenance, such that utilities could enhance and justify their specific site procedures.

By providing guidance on reduced control voltage testing of low and medium voltage circuit breakers, utilities can establish a platform from which the entire industry can justify and improve maintenance programs for these circuit breakers.

Objectives

- To provide nuclear electric utilities with some basic information and insight into the use, benefits, and limitations of reduced control voltage testing of low and medium voltage circuit breakers.
- To provide a consensus between utility personnel, considering the manufacturers' recommendations and the unique application of these circuit breakers within our industry.

Approach

This document was developed by a utility working group, under the management of EPRI-NMAC. The utility working group (1) reviewed utility procedures and vendor manuals, and (2) obtained input from utility personnel, manufacturers, and other

organizations. After initial development, the draft was provided to a larger working group and to manufacturers for review and comment. GE, ABB, and Westinghouse NSD representatives reviewed the document and were offered opportunities to make comments. Laboratory testing of circuit breakers was not performed, as this was not deemed necessary to accomplish the objectives of this effort.

This guidance is applicable to both low (480/600 volt) and medium voltage (4160/15,000 volt) circuit breakers.

Results

This guidance defines reduced control voltage testing, presents the information obtained from this type of testing, provides a utility consensus with respect to the regulator, presents factors that should be taken into consideration when calculating minimum control voltage, and provides the industry's current position on trending and predictive maintenance.

The general consensus within the industry is that testing with reduced control voltage is a good engineering practice. Trending of data is not generally performed and is not recommended. Reduced control voltage testing is generally considered a pass or fail (go/no-go) test.

EPRI Perspective

This effort is a collaborative industry effort with numerous utility and non-utility personnel providing their experience and knowledge. By documenting a consensus opinion of the industry, EPRI-NMAC hopes to elevate the collective knowledge of the industry with respect to circuit breaker maintenance programs, while simultaneously providing guidance on prudent and cost-effective maintenance practices.

This is considered a living document. The nuclear industry's circuit breaker users groups, along with EPRI-NMAC, are tasked with providing an annual forum or mechanism to incorporate additions or changes to this guidance. It is expected that plant personnel and the circuit breaker users groups will periodically review the contents. This document was designed to complement the circuit breaker maintenance guide series (EPRI NP-7410).

Keywords

Circuit breaker
Electrical distribution
Switchgear
Maintenance

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CONTENTS

LIST OF FIGURES

1

INTRODUCTION

1.1 Purpose

The purpose of this paper is to provide information and insights into the use, benefits, and limitations of reduced control voltage testing of low and medium voltage circuit breakers, such that utilities can enhance and justify their specific site procedures. This guidance represents a consensus between utility personnel, considering manufacturers' recommendations and the unique application of these circuit breakers within the nuclear power industry. By providing guidance that contains the collective experience of the industry's circuit breaker users groups, utilities can establish a platform from which the entire industry can justify and improve their circuit breaker maintenance programs.

1.2 Conclusions

Following are the significant conclusions of this document.

- Reduced control voltage testing is considered good engineering practice and is a quick and easy test to perform.
- There is no explicit regulatory requirement to perform reduced control voltage testing to verify design basis.
- If reduced control voltage testing is performed, it is not necessary to test below the licensing design basis voltage (or minimum calculated voltage at the coil).
- If desired, testing below the licensing design basis calculation can be used to demonstrate additional margin.
- Reduced voltage testing is considered a pass or fail (go / no-go) test to verify that the breaker will perform its function to open or close. There is no empirical data that supports the use of this testing as a predictive maintenance tool.
- Reduced control voltage testing provides information only on the operation of the open and close coils (solenoids) and their interaction with their respective trip and close components (latches, bushings, rollers, linkages, and so on).

2

DEFINING REDUCED CONTROL VOLTAGE TESTING

Testing of a circuit breaker with reduced control voltage involves the application of a control voltage that is less than the nominal station voltage, and subsequent verification of proper breaker operation. To perform a reduced voltage test, a minimum operating control voltage is determined and then applied to the circuit breaker's close and trip control circuitry. The circuit breaker is then cycled open and closed and the breaker's operation is verified.

It is possible to calculate the minimum control voltage at the circuit breaker's close and trip coils, considering all design basis events and a "station blackout" event. If a circuit breaker is tested at this calculated minimum control voltage, then there is reasonable assurance that the breaker will perform its design function when required. Indeed, the purpose of reduced control voltage testing is to conservatively demonstrate that a circuit breaker will perform its function (to open and close) with a reduced control voltage for all design basis events, including a "station blackout" event.

3

INFORMATION PROVIDED BY REDUCED VOLTAGE TESTING

Reduced control voltage testing is performed to provide assurance that the breaker will perform its function at a reduced control voltage. For circuit breaker functionality, the question is—did or would the circuit breaker perform its intended design function (trip open or close) at a reduced control voltage?

Reduced control voltage testing provides information only on the operation of the open and close coils (solenoids) and their interaction with their respective trip and close components (latches, bushings, rollers, linkages, and so on). Reduced control voltage testing does not provide information on the condition of the remaining components within the operating mechanism or other components within a circuit breaker.

Reduced control voltage testing, used in combination with visual inspections and mechanical and electrical testing, can provide a good indication of overall breaker condition. However, satisfactory results from reduced control voltage testing alone will not ensure reliable operation.

4

WHEN SHOULD REDUCED VOLTAGE TESTING BE PERFORMED?

4.1 Routine Preventive Maintenance

Since reduced control voltage testing is considered good engineering practice and is a quick and easy test to perform, this type of testing can be performed at any time during routine preventive maintenance. Current guidance documents, developed by the industry's circuit breaker users groups, suggest performing this test during routine preventive maintenance.

Reduced control voltage testing can be performed prior to maintenance, as an "as-found" test, to determine if corrective maintenance is necessary prior to checking mechanical adjustments. In addition, this test can be performed as an "as-left" (post-maintenance) test to verify that the maintenance activity did not introduce a problem into the circuit breaker.

4.2 Overhaul

Manufacturers and utility personnel agree that reduced control voltage testing should be performed after any circuit breaker overhaul or maintenance work affecting the trip or close coils (solenoids).

5

REDUCED CONTROL VOLTAGE CALCULATIONS

Minimum expected control voltage varies from plant to plant, from one electrical bus to another, and possibly from one circuit breaker to another.

5.1 Considerations for Calculating Minimum Control Voltage

The following should be considered when calculating the minimum control voltage.

- Completeness and accuracy of the calculations.
- The minimum calculated control voltage should be the voltage available to the trip and close coils at the circuit breaker.
- Minimum battery terminal voltage based on a worst case voltage for the battery discharge event.
  - DC battery voltages for the duration of design basis accidents
  - DC battery voltages for the duration of a station blackout event
  - Other expected loads on the batteries during design basis events
  - Battery design margins
  - Battery aging margins
  - Temperature correction factors
- Cable losses or voltage drops.
  - Cable length and resistances (path of greatest resistance)
  - Load on the cable (worst case expected loads on at one time)

- Conservative assumptions.
  - — Conductor temperature
  - — Charging motor inrush

5.2 Reduced Control Voltages and Manufacturers' Specified Minimum Voltage

Plant electrical system designers should have designed each system such that the minimum control voltage is greater than the manufacturers' specified minimum control voltage. This is true in most cases, and the minimum calculated control voltage at the circuit breaker is higher than the manufacturers' specified minimum control voltages (typically 70 Vdc to trip (open) and 90/100 Vdc to close, reference ANSI/IEEE C37.16-1997). (see Figure 5-1)

If this is not the case, further investigation should be considered. It is possible that the minimum control voltage calculations might be too conservative and, if so, might need to be revised.

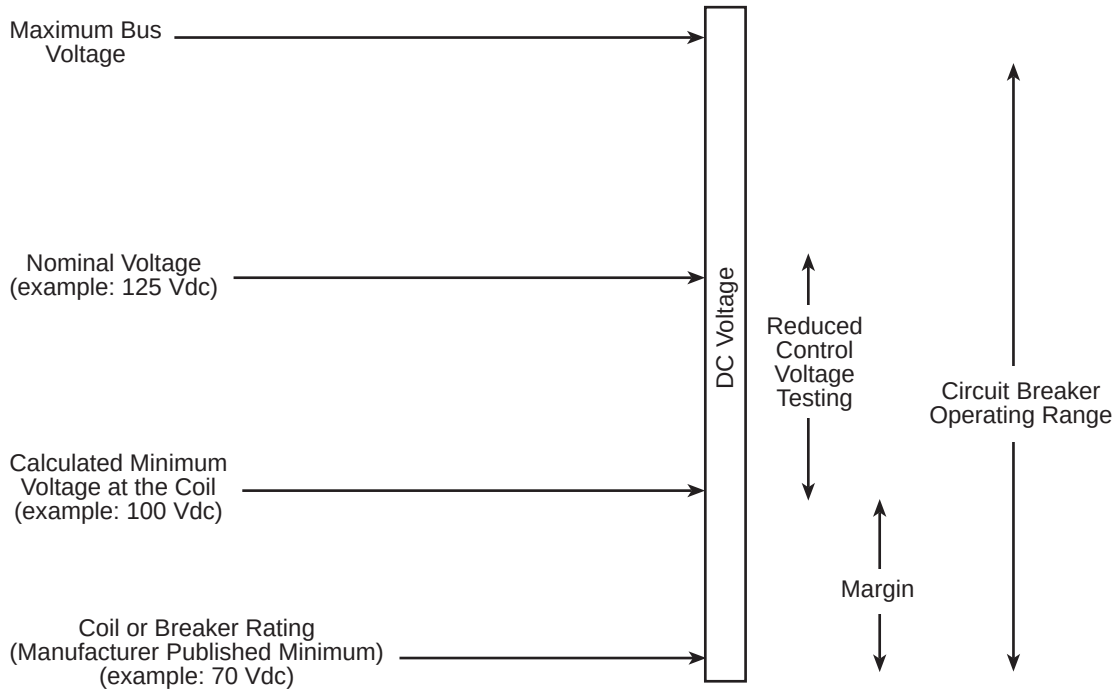

Figure 5-1
Circuit Breaker Control Voltage Operating Range

6

TRENDING/PREDICTIVE MAINTENANCE

6.1 Trending

At the present time, there is no empirical data that provides a basis for trending of reduced control voltage testing data. Consequently, it is the consensus of utility personnel that trending should not be performed on circuit breaker reduced control voltage testing data. Reduced control voltage testing should be treated as a pass or fail test (go / no-go test).

6.2 Predictive Maintenance

In addition, there is no empirical data that provides a basis to justify the use of reduced control voltage testing as a predictive maintenance tool. Trending of reduced control voltage testing data is not generally performed.

It is possible to determine at what point the circuit breaker operates (pick up point) by successive tests and through progressively increasing control voltage steps (for example, 5-volt intervals). It has been suggested that the results of such testing might be trendable and used as a diagnostic tool. In the collective knowledge of industry personnel, there is no engineering analysis or test data that demonstrates this type of testing can be trended or is either beneficial or cost-effective.

Consequently, reduced control voltage testing is not considered a predictive maintenance test. As stated above, the purpose of reduced voltage testing is to demonstrate that the circuit breaker will perform its function, to open and close, with the minimum expected control voltage for all design basis events, including station blackout. It is generally considered a pass or fail (go / no-go) test.

7

REGULATORY CONCERNS

Industry representatives of the various circuit breaker users groups and the Nuclear Energy Institute's (NEI) Circuit Breaker Task Force have discussed reduced control voltage testing with NRC staff members. Conclusions from these discussions have been summarized below.

- Reduced control voltage testing is considered good engineering practice and is a quick and easy test to perform. As discussed in numerous industry users group meetings, industry personnel agree that reduced control voltage testing is a prudent action and does not significantly increase the cost of maintenance programs. Consequently, industry circuit breaker users groups are recommending this testing.

- There is no explicit regulatory requirement to perform reduced control voltage testing to verify design basis.

- If reduced control voltage testing is performed, it is not necessary to test below the licensing design basis voltage (minimum calculated voltage at the coil).

- If desired, testing below the licensing design basis calculation can be used to demonstrate additional margin.

It should be noted that the NRC's Inspection Manual, Temporary Instruction 2515/135, Section 3, Item "E", states: *Verify that the breaker operation is assured at minimum operating voltage as specified in the vendor's manual or minimum calculated voltage, whichever is the lowest. The breaker response time should be trended.*

In discussions regarding TI-2515/135, NRC staff stated they did not intend to suggest that trending be performed at reduced voltage.

8

THE CHARGING MOTOR

Design basis and station blackout events at each plant vary. Consequently, plant maintenance/engineering personnel might wish to perform a detailed review of their own requirements for circuit breaker operation and charging motor requirements during design basis events and station blackout events. Each plant should address their design basis commitments and modify their testing accordingly.

If performing a review of requirements for circuit breaker operation during design basis events and station blackout, plant personnel should consider:

- The sequence in which the charging motor is called to operate within the circuit breaker's cycling (open and close) process
- The electrical load shedding sequence and process
- The diesel generator breakers
- Is the circuit breaker open or closed at the time of the event?
- Design basis events
- Station blackout events

Typically, the circuit breaker's charging motor does not need to be tested at a reduced voltage, as it is not required to function until the breaker is closed again. Consequently, reduced voltage testing typically does not encompass testing of the charging motor. However, depending upon a plant's design basis events and station blackout, the charging motor might be called upon to perform during a plant event. One example scenario is a loss-of-coolant accident followed by a loss of off-site power. Other scenarios might also be possible.

Consider the following worst-case scenario:

A station blackout occurs at the same time a design basis accident happens for a unit with one diesel generator per train (no backup diesel). The safety-related medium voltage breaker operation scenario would be as follows:

Breakers that would be closed at the time of the event would open as a result of a load shed. The charging motor would not function because the closing springs were charged when the breaker closed. When the diesel generator was started, those breakers that were load-sequenced on to the diesel generator would be closed at the appropriate time and the charging motor would charge the springs.

If the diesel remained energized, the charging motor would not be required. However, some design scenarios have the diesel getting through either part or all of the sequence, only to fail. In this case, the charging motor would be required again. If a plant does have a multiple start scenario, the charging motor might have to function at the minimum voltage criteria, even with the battery charger energized in the first sequence. This is the case if the battery charger has a current limiting design. If so, the current limit feature will act to drive the voltage on the charger down to the voltage of the batteries at the time the charger is turned on. Therefore, the charging motor would have to function at the battery minimum reduced voltage.

9

EFFECTS OF REDUCED VOLTAGE TESTING ON CIRCUIT BREAKERS

The following should be considered when testing at reduced control voltages.

- The effect of reduced voltage on the open and close coils.
- The effect of reduced voltage on the charging motor.

If the appropriate measures are not taken to ensure the dissipation of heat from the coils, reduced voltage testing might degrade the coils and / or the charging motor. Heat will degrade the coil insulation and, each time the coil is operated, the temperature will rise.