Meeting Minutes
Task Force To Study Shunt Reactor Switching Endurance for HVCB
October 11, 2017 Portland, ME

Introduction of members and guests

33 attendees present
21 members
12 guests

Discussion

1. Reviewed concerns on switching endurance which was the basis for forming this TF. Shunt reactors typically fail around 500-1000 operations and there is no electrical endurance requirement only M2 is specified.
2. Shunt reactor switching a unique duty. It's not possible to cover every application with a simple set of tests. The IEC 62271 -110 tests are not intended to prove reactor switching capability per se, but rather to provide baseline data that can be used to estimate reactor switching endurance for specific applications.
3. Even so, the predicted endurance is often not met in practice by a factor of 5 or so
4. Shunt reactor switching devices include both HV >100kV and MV (Tertiary reactor)
5. HV shunt reactor switching current is generally <300A and for MV it is anywhere between 1000 - 3000A continuous current.
6. Statistical no of switching operations performed in the lab don't represent real life. Also, test parameters are different than the actual application circuit parameters.
7. Reviewed available IEC info for extending 80 shot shunt reactor test data to the user's particular Reactor and installation Parameters
8. Use of RC snubbers brought up as a mitigation method for multiple reignitions.
9. The TF will focus on the circuit breaker only however by protecting the breaker by limiting overvoltages /recovery voltages & mitigating reignitions indirectly the shunt reactor internal windings are being protected.
10. The TF output could be PES Technical Report or lead to recommendations for breaker / or reactor testing.
11. Victor Hermosillo Volunteered to write a condensed guide on how the test results can be used to predict suitability and endurance for specific applications, including chopping number, reignition "free" window, etc.
12. It was decided that a user and manufacturer survey would be useful for attaining failure data, a list of criteria used for specifying reactor switching breakers, and numbers of various size/ Voltage ratings of reactor switching devices/ shunt reactors sold etc.
13. Following participants volunteered to develop survey questions to capture data from users as well as manufacturer. The survey can be discussed at the Spring 2018 meeting. (expect to be available 3/1/2018). Volunteers- Mike Skidmore, Carl Schuetz, Jan Weisker, Dave Lemmerman & David Caverly.

Action Items

1. Literature survey.
2. Victor to write a short guide on the use of test results for predicting suitability for the specific application.
3. Design User & Manufacturer survey questions by Mike Skidmore, Carl Schuetz, Jan Weisker, Dave Lemmerman & David Caverly.
4. Create list of breaker contacts for different utility area wise for better coordination of the survey

Attendance:

Sr. No.	First Name	Last Name	Company	Role	10/11/2017
1	Roy	Alexander	RWA Engineering	Secretary	X
2	Arben	Bufi	HITACHI HVB, INC.	Member	X
3	David	Caverly	Trench Limited	Member	X
4	Andrew	Chovanec	GE	Member	X
5	Chih	Chow	PEPCO	Member	X
6	Denis	Dufournet	Alstom Grid	Member	X
7	John	Hall	Tennessee Valley Authority	Guest	X
8	Helmut	Heiermeier	ABB	Member	X
9	Jeremy	Hensberger	MEPPI	Guest	X
10	Victor	Hermosillo	Alstom Grid	Member	X
11	Amir	Khosarvi	BC Hydro	Guest	X
12	David	Lemmerman	PECO/Exelon	Member	X
13	Hua Ying	Liu	Southern California Edison	Member	X
14	Peter	Meyer	S&C Electric Company	Guest	X
15	Alan	Peterson	Utility Services Corp	Guest	X
16	Brian	Roberts	Southern States LLC	Member	X
17	Jon	Rogers	Siemens Energy, Inc	Member	X
18	Carl	Schuetz	American Transmission Company (ATC)	Member	X
19	Moin	Shaikh	Siemens	Guest	X
20	Devki	Sharma	Consultant	Member	X
21	Sushil	Shinde	ABB Inc.	Chair	X
22	Michael	Skidmore	AEP	Member	X
23	Robert	Smith	Eaton Corporation	Member	X
24	Vernon	Toups	Siemens	Guest	X
25	Jan	Weisker	Siemens AG	Member	X
26	Richard	York	MEPPI	Member	X
27	Will	Zhang	HITACHI HVB, INC.	Member	X
28	Chris	Slattery	First Energy	Guest	X
29	Jordon	Tsvetanoff	First Energy	Guest	X
30	Thomas	Kohhler	Ameren	Guest	X
31	Andy	Keels	Salt River Project	Guest	X
32	Bob	Behl	ABB	Member	X
33	Gustavo	Leal	Dominion Energy	Guest	X

Task Force To Study Shunt Reactor Switching Endurance

Sushil Shinde

October 11, 2017 / Portland, ME

Agenda

- Welcome and Introductions
- Objective of TF
- Excerpts from Existing IEC/IEEE Standards
- Next steps

Objective of TF

- Document submitted by Roy (see attachment).
- Roy discussed some concerns in existing standards where testing practices for shunt reactor switching may be lacking.
- A motion was pasted to create a TF to study electrical endurance of shunt reactor switching.

Objective of TF

Explained by Roy Alexander at HVCB meeting (4-26-17):

Roy Discussion

There are 2 flaws in IEC 62271-110

1) There is nothing to determine switching endurance. 40 or 80 shots do not ensure endurance. Many are failing or failing the reactors after say 500 operations.

2) The reignition requirements are hokey at best. Presently, one is allowed any number and magnitude of reignitions in one half cycle but none in subsequent half cycles. This is crazy. There should be limits on the number of big reignitions. What difference does it make if small reignitions occur on subsequent half cycles?

TF could possibly review and study a new standard or modifications to parts of existing documents (such as IEC) with a new number to be determined.

Motion: Form a TF to study shunt reactor switching endurance.

Moved: Mike Skidmore

Second: John Webb

Vote (only members)

Unanimous approval

Shunt Reactor Switching

- The phenomena likely to generate overvoltages upon low inductive current breaking are well known.
- There are two types as follows:
  - premature current interruption, commonly termed “current chopping”;
  - successive re-ignitions.
- These two phenomena can in fact take place successively during the same operation

Shunt Reactor Switching

- The overvoltage level depends on numerous parameters such as:
  - the natural frequency of the load-side circuit;
  - the point on current wave of contact separation;
  - the rate of rise of dielectric strength across contacts;
  - the characteristics of the high-frequency current oscillation

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Overvoltage Limitation

Overvoltage limitation method	How does the method work?	Advantage	Disadvantage
Opening resistor	Resistor causes phase shift of current with respect to voltage resulting in current interruption by resistor switch at lower point on voltage halfwave thus reducing k_a and consequently k_{rv} significantly.	Very effective on circuit-breakers with very high chopping numbers, i.e. air-blast and dual pressure SF_6 circuit-breakers.	Adds significantly to mechanical complexity and maintenance requirements of the circuit-breaker; not viable – technically or economically – on single pressure SF_6 circuit-breakers; re-ignitions can still occur.
Surge arresters to earth at shunt reactor	Limits overvoltage to earth (k_a) at shunt reactor.	Passive.	Effective only for circuit-breakers producing suppression peak overvoltages in excess of the surge arrester protective level; re-ignition overvoltages still occur at up to twice the protective level of the surge arrester with no reduction in the re-ignition overvoltage excursion frequency.

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Overvoltage Limitation

Overvoltage limitation method	How does the method work?	Advantage	Disadvantage
Metal oxide varistor (MOV) across circuit-breaker [34]	Limits the recovery voltage (k_{rv}) across the circuit-breaker to the protective level of the varistor and subsequent re-ignition overvoltages to maximum $1+\beta k_{arv}$ where k_{arv} is the protective level of the arrester in p.u. of V_o.	Passive; effective for all circuit-breaker types; particularly suitable for use on circuit-breakers at ≤ 52 kV; magnitude and probability of re-ignitions significantly reduced; energy absorbed by surge arrester is minimal.	Adds to complexity of circuit-breaker; surge arresters must be able to withstand forces associated with circuit-breaker operation; some re-ignitions will still occur albeit at low voltage levels.
Surge capacitor	Decreases frequency and thereby rate of rise of the load side oscillation; decreases frequency of re-ignition overvoltage excursion.	May reduce probability of re-ignitions; reduces frequency of the voltage excursion imposed on the shunt reactor winding; may reduce value of k_a for vacuum breakers where chopping current is dependent mainly on contact material.	Does not influence k_a for circuit-breakers other than vacuum type; leads to increased chopping current but not necessarily increased suppression peak overvoltages; does not eliminate re-ignitions; may have the effect of reducing the minimum arcing time such that probability of re-ignitions is unchanged; require space.
Controlled switching	Ensures contact parting with respect to current wave such that interruption occurs at the first subsequent current zero.	Eliminates re-ignitions.	Suitable only for mechanically consistent circuit-breakers with appropriate minimum arcing times; requires independent pole operation.

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Circuit Breaker Specification

- dielectric withstand requirements;
- rated short-time and peak withstand currents (assumes no fault clearing);
- shunt reactor rating;
- shunt reactor current;
- load side characteristics: Inductance *L* of the shunt reactor and *C*L the total effective capacitance of the load side circuit including the shunt reactor and all connected equipment;

Circuit Breaker Specification

- overvoltage limitation: The suppression peak overvoltage (*k*a) should be stated; a *k*a value of 2 p.u. is recommended for applications at or above 72,5 kV and 2,5 p.u. for applications at ≤ 52 kV. Note that no limitation for re-ignition overvoltages should be stated since these overvoltages are very circuit dependent;
- earthing arrangement whether solidly earthed, non-effectively earthed or neutral reactor earthed. In the latter case, the inductance of the neutral reactor should be stated;
- mechanical endurance: Shunt reactor circuit-breakers are usually subject to frequent operation and class M2 should be specified.

Testing

- EHV and HV circuit-breaker shunt reactor switching tests are normally unit tests in single phase circuits.
- The representation of the shunt reactor side circuit is of the essence.
- The test should be carried out using a directly connected HV shunt reactor and not a transformer coupled shunt reactor. This ensures that the load side oscillation is single frequency (as it should be), that the load side effective capacitance (*C*L) can be exactly defined and that the proper interaction between the circuit-breaker and the circuit occurs.
- The exact definition of the load side effective capacitance, which includes the stray capacitances in the circuit and the circuit-breaker grading capacitance, is mandatory in order to determine the true chopping member of the circuit-breaker.

Testing

- The purpose of the testing is not so much to demonstrate interrupting capability – the current is after all forced to a premature zero – but rather to establish that the circuit-breaker meets certain performance criteria and to derive its chopping current and chopping number characteristics.
- These characteristics are dependent on arcing time for most circuit-breaker types and a large number of test shots are required in order to provide confidence in the results.
- In a typical test, the required number of test shots are applied over the expected range of arcing time and the suppression peak overvoltages are measured.

Testing

- Equation is used to calculate *chopping current* and chopping number λ .
- A regression analysis is required to derive the chopping number characteristic and, once derived, the characteristic can be used to predict actual performance in the field
- it would be impossible for any laboratory to carry the range of reactor sizes required for the purpose.
- To be judged as suitable for shunt reactor switching, a circuit-breaker must meet the following two performance criteria:
  - the circuit-breaker shall interrupt the current with at most one re-ignition leading to conduction of another loop of power frequency current. This criterion applies to all three circuit-breaker poles in three-phase tests;
  - all re-ignitions should occur between the arcing contacts.

Testing

- The reactor switching tests shall consist of two three-phase test duties or three single-phase test duties using the supply circuit detailed in 6.115.4 and the load circuits detailed in 6.115.6.2 and 6.115.6.3 of IEC 62271-110.
- Twenty breaking operations shall be made with each load circuit with the initiation of the tripping impulse distributed at intervals of approximately 9 electrical degrees for three-phase tests and of 18 electrical degrees for single-phase tests.

Testing

For single-phase tests,

- the third test duty consisting of 18 breaking operations shall be performed with load circuit 2 around the arc duration at which the re-ignitions occurred in the previous test series with load circuit 2.
- Six breaking operations shall be made with the initiation of the tripping impulse at the point that gave the highest breakdown voltage *u*w,
- Six breaking operations with the initiation of the tripping impulse retarded by 9 electrical degrees and 6 breaking operations with the initiation of the tripping impulse advanced by 9 electrical degrees.

Testing

If no re-ignition occurs in the test duty with load circuit 2,

- the third test duty shall consist of 6 breaking operations with the initiation of the tripping impulse at the point that gave the shortest arcing time,
- 6 break tests with the initiation of the tripping impulse retarded by 9 electrical degrees and
- 6 break tests with the initiation of the tripping impulse retarded by a further 9 electrical degrees.

Testing

- Test duty 4 shall be performed at the minimum pressure for interruption, insulation and operation using load circuit 2 only.
- For three-phase tests, 10 breaking operations shall be made with the initiation of the tripping impulse distributed at intervals of approximately 18 electrical degrees.
- For single-phase tests, 10 breaking operations shall be made with the initiation of the tripping impulse distributed at intervals of 36 electrical degrees.

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Test Duty Summary

Table 5 – Test duties for reactor current switching tests

Test duty	Number of breaking operations		Test current determined by
	Three-phase	Single-phase	
1	20	20	Load circuit 1 (6.115.6.2)
2	20	20	Load circuit 2 (6.115.6.3)
3	–	18	Load circuit 2 (6.115.6.3)
4	10	10	Load circuit 2 (6.115.6.3)

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Testing

The criteria for successful testing:

- the circuit-breaker shall consistently interrupt the current with re-ignitions at one current zero crossing only. Voltage tests shall be performed in accordance with 6.2.11 of IEC 62271-100; (NOTE If no re-ignitions occur during the test, visual inspection is sufficient and the voltage test may be omitted.)
- re-ignitions shall always occur between the arcing contacts.

System and Station Characteristics

- The system characteristics which impact on reactor switching are the source inductance and the source side capacitance.
- The source inductance can be derived from the prevailing short circuit level at the station.
- The source side capacitance is in general very much greater than the load side capacitance. For circuit-breaker type testing purposes, the former capacitance is assumed to be at least 10 times greater than the latter.
- The station characteristics which are of relevance are the inductance of the connecting busbar or line and any capacitances in addition to that of the reactor.

Application Of Laboratory Test Results To Actual Shunt Reactor Installations

- Chopping number of one interrupter
  - The chopping number is an inherent characteristic of the circuit-breaker and is usually independent of the circuit.
  - The chopping number can therefore be used to estimate the behaviour of the circuit-breaker in other circuits than the test circuit
- Estimation of chopping overvoltages in shunt reactor installations
- Estimation of re-ignition overvoltages in shunt reactor installations
- Evaluation of recovery voltage stress across circuit-breaker

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Next Steps

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Questions?