VACUUM INTERRUPTER IMPULSE VOLTAGE TESTING PROCEDURES SHOULD RECOGNIZE INITIAL BREAKDOWNS AS RECONDITIONING EVENTS

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SUMMARY

It is well known that the ability of a gap in vacuum to withstand high voltages is a property enhanced by conditioning with high voltage[1]. Moreover, the conditioning effect is actually produced by small spark discharges that occur while this high voltage is applied. These spark discharges, or disruptive discharges in the language of test standards, are therefore required to produce the desired conditioning effect in the vacuum interrupter. In addition, the few disruptive discharges that sometimes occur during the process of performing impulse voltage testing in a completed circuit breaker are normal. Although observing such discharges is not new to those active in vacuum technology, they have only recently become an issue in performing impulse voltage certification testing as design voltages have increased to 36 and 38 kV and as the demand for ever smaller interrupters has led to higher stressed designs. The procedure for performing impulse voltage tests must therefore allow for a few disruptive discharges in a way that does not erroneously consider them as evidence of failure in the test.

1.0 INTRODUCTION

Withstanding high voltages across its open contacts is one of the primary duties of the interrupter in a circuit breaker. The ability to withstand high voltages is provided in balance with the other primary duties which are to carry currents when the contacts are closed and to switch off currents when the contacts open. Currents that must be switched range from small values at low loads, to moderate values at normal load currents and high values under fault conditions. Switching currents, especially high fault currents, normally takes precedence in design since this task is the key to providing circuit protection against faults. In recognition of this, isolating switches with even higher voltage withstand abilities are normally used to isolate the circuit breaker from the system during prolonged periods when an open circuit is desired. This is especially true during maintenance on the circuit as a precaution for the safety of maintenance personnel.

The interrupter is designed to operate at one of the normal system voltage levels listed as preferred in the applicable standards. Additional voltage withstand requirements are also included in the standards in terms of:
- a Rated AC Power Frequency Withstand Voltage, and
- a Rated Impulse Withstand Voltage.

These ratings establish a safety margin in the design to provide for an ability to withstand occasional overvoltages that can occur in a power system from normal switching operations or from more abnormal natural causes such as lightning. These ratings do not ensure that any possible overvoltage will be withstood, but the requirements do provide that most typical overvoltages that occur in service will be withstood. The values listed in the standards for the 2 withstand voltages are chosen such that the withstand levels for the various kinds of equipment found in a power systems are coordinated and consistent with what experience has shown are typically observed overvoltages.

For circuit breakers, the most important reasons to withstand voltage are to prevent:
- phase -to-ground breakdowns,
- phase-to-phase breakdowns, and
- line-to-load breakdowns.

Phase-to-ground and phase-to-phase breakdowns represent outright failures to support voltage and the design objective should be to avoid these as much as possible within the required rating of the circuit breaker. Line-to-load breakdowns must be viewed in terms of the resulting current that flows through the interrupter. A breakdown followed by an uninterrupted flow of current represents a failure of the circuit breaker to maintain the open status of the power circuit. However, if a very short passage of current occurs that is quickly interrupted, the circuit breaker can then be considered to have essentially preserved the open status of the power circuit.

So the importance of the ability of the open interrupter to withstand high voltages, such as a lightning impulse, must be viewed along with the ability to interrupt the power frequency current that could follow a breakdown through the open interrupter. Many interrupters in use today rely on contact motion to interrupt the current. An SF6 puffer interrupter is one example in which contact motion is required to allow an attached piston to compress gas that can then flow over the arc and provide interruption. So the power frequency current that could follow a breakdown of the open interrupter has almost no chance of being interrupted by an open SF6 puffer interrupter. Thus, the ability to maintain the open status of the circuit is lost if a breakdown occurs and current follows.

Vacuum interrupters are rather unique in being able to interrupt current, even when the contacts are in the full open position. Arc interruption in vacuum is not dependent on the motion of the contacts. The arc is controlled by the geometry of the contact structure. In addition, the last remaining conducting charge carriers are quickly dissipated in the vacuum after current zero arrives. So in vacuum interrupters, even if a breakdown does occur and results in a power frequency current, the vacuum interrupter will clear the circuit at the next current zero. This behavior is rather unique to vacuum and is not seen in other techniques such as minimum oil, air magnetic or SF6 puffer interrupters. Therefore, the ability to of an open interrupter to withstand high transient voltages such as lightning surges is not as crucial for vacuum interrupters since aside from a possible brief half cycle of current, the open status of the circuit is maintained by the open vacuum interrupter.

The ability of a vacuum interrupter to withstand high voltages is strongly related to the condition of the contact surfaces. Vacuum interrupters are very compact with small gaps between the open contacts. Gaps of from 8 to 25 mm are typical for interrupters for medium voltages of 3.6 to 38 kV. Moreover, the very low pressures inside a vacuum interrupter mean that the electrode surface condition is of much higher relative importance compared to the gaseous material between the contacts than is the case in a pressurized gas interrupter. Contact condition is constantly changed by mechanical action of making and breaking and by the action of the arc during current switching. So we find as Greenwood[1] describes “that from a breakdown point of view, the behavior of a vacuum interrupter is likely to be more statistical and less deterministic than, say, a gas blast circuit breaker”.

It is within this context that we approach the subject of performing certification tests on vacuum interrupters for the statistically defined lightning impulse voltage withstand requirement while recognizing that an occasional disruptive discharge can occur in the preliminary trials at less that rated voltage. For 12 and 15 kV vacuum interrupters where the impulse withstand rating is 95 kV, the actual ability of the interrupter to withstand impulse voltages is normally much higher. In fact, the same designs with a slightly larger contact gap can be applied at 24 kV with a 125 kV impulse rating. So the occasional disruptive discharge at a voltage that is less that the actual interrupter capability is probably at a voltage greater than the 95kV rating, and hence is practically never observed when performing certification tests. As designs for 36 to 38 kV have become more commonplace, and the demands for compact designs more insistent, the design ability of the interrupter and the rating are now much closer together. As a result, the fact that an occasional disruptive discharge can occur at less that rated voltage has become more widely known. This paper describes these discharges and proposes that preliminary trials at lower that rated voltage be used as a normal part test procedure. In addition, the paper presents the explanation for considering the observation of an occasional disruptive discharge at trials at less that rated voltage as the reconditioning event that it is and not as an indication of a failure to meet the required impulse withstand rating.

2.0 CONDITIONING AND DECONDITIONING OF VACUUM INTERRUPTER CONTACTS

Conditioning at high voltage is a normal part of the manufacturing process for every vacuum interrupter. The contacts of the interrupter are opened to form a gap and the interrupter is then subjected to a high voltage from a high impedance source for many minutes. A great many discharges involving small currents from the high impedance source happen with decreasing frequency during the conditioning time as microscopic sharp spots on the contact surfaces are smoothed over by the discharge currents. As a confirmation of the conditioning result, an impulse voltage test is then performed on the interrupter while the contacts still in the open position used for the conditioning procedure. The test voltage is chosen to be at least 5 kV greater than the rating.

Deconditioning of the voltage withstand ability of the contacts is also a normal occurrence.[2] Deconditioning takes place when the contacts are allowed to touch and especially when the vacuum interrupter is installed in a circuit breaker and operated mechanically. The mechanical touching of the contacts reintroduces some rough spots on the contact surfaces. These rough spots may sometimes result in 1 or more breakdowns at a voltage less than the design rating of the interrupter. Therefore, before certification testing is done to demonstrate the impulse voltage withstand ability of the circuit breaker, it is typical to apply some high voltage to the open vacuum interrupters in order to recondition the contacts thus restoring their ability to withstand impulse voltages.

3.0 RECONDITIONING VACUUM INTERRUPTERS WITH BREAKDOWNS AT LESS THAN THE RATED IMPULSE WITHSTAND VOLTAGE

High voltages and low current discharges can be used to recondition a vacuum interrupter and restore its ability to withstand impulse voltages. The most straight forward method is to combine the reconditioning process with the impulse voltage test procedure. This is done by applying impulse voltages to the interrupter starting at voltages less than the rated voltage and increasing to the rated impulse voltage as described below.

Preliminary impulse tests are performed on each interrupter by applying both positive and negative impulse voltages with two purposes in mind:

A. Reconditioning the interrupter’s ability to withstand impulse voltages, and

B. Reversing the trapped charge on the internal floating shield whenever the polarity is changed.

The preliminary voltage tests consist of several impulse voltage applications performed at each voltage magnitude level before increasing the stress to the next level. If a disruptive discharge occurs on a given impulse test, and if this is the only discharge that is observed in 6 impulses, then the voltage is increased to the next level until preliminary tests through 90% of the rated voltage have been withstood. If more than one breakdown is observed, then repeated impulse voltages can be applied at the same voltage crest level until about 3 to 5 impulse voltages in a row have been withstood. This process further reconditions the contacts. However, this additional reconditioning is rarely needed or done. At this point, the certification tests at 100% of the rated voltage can begin by using for example the IEC method of applying 15 impulse voltages during which only 2 disruptive discharges are permitted.

This method of using preliminary impulse voltage tests to recondition a vacuum interrupter normally results in at most only 1 or 2 tests at lower voltages where a breakdown occurs. This is shown in TABLE 4 at the end of this paper in which some experience at the Horseheads Power Test Lab is summarized for some 36/38 kV interrupters with a rated impulse voltage withstand of 170 kV Crest. Of the 12 interrupter samples described in this TABLE 4, five experienced 1 or more breakdowns at an impulse voltage less than the maximum withstood by that sample. Seven of the 12 had no such breakdowns at lower voltages. So 2 things are clear from this experience:

A. Preliminary tests sometimes result in breakdowns at lower than the maximum impulse voltage withstood by an interrupter sample.
B. Breakdowns during preliminary tests are very successful in reconditioning the interrupter's ability to withstand its rated impulse voltage.

This data then demonstrates the effectiveness of the using preliminary tests to recondition vacuum interrupters and that a breakdown at a lower than rated voltage is not a sign that the interrupter will fail to withstand its rated voltage according to the standard test method.

Occasionally an interrupter may require more than 1 or 2 breakdowns to provide the necessary reconditioning. In this case, repeated impulse voltages are applied at the same voltage crest level until about 3 to 5 impulse voltages in a row have been withstood. Then the voltage is increased to the next level. Such cases are not often encountered. Far more typical are the cases where breakdowns at lower voltages than rated either do not occur at all or occur only once or twice as discussed above and shown in TABLE 4.

The AC withstand test should always be done first before impulse tests are performed as a means for checking that the interrupters and the complete circuit breaker insulation system are in good condition. The AC withstand test can will identify any interrupters that may have been damaged during the assembly and initial mechanical operations of the circuit breaker to the point of producing a leak in the vacuum tight braze joints. So performing the AC withstand test first is a prudent step which requires little time to perform. It is suggested that the AC Withstand Test be applied at 80% of the rated power frequency withstand voltage for 1 to 3 minutes, and then 100% of the rated power frequency withstand voltage for 1 minute. The duration of the test at 100% of the rated power frequency withstand voltage test should be limited to 1 minute since other circuit breaker insulation paths are subjected to this same voltage.

A small amount of reconditioning of the vacuum interrupter may occur during the AC power frequency withstand test, but this is very unlikely. The voltage magnitudes used in the AC power frequency withstand test are much lower than those used in the manufacturing conditioning operation. The various rated voltages and production test voltages are shown below for a typical rated voltage of 36kV. The peak voltage of 99 kV applied during the AC power frequency withstand voltage test is only 58% of the 170 kV impulse withstand. The reconditioning provided with this voltage is therefore expected to be minimal. In fact, from TABLE 4, we see that no breakdowns were observed at such a low level. The application of a higher AC voltage in an effort to achieve more conditioning is not recommended when the interrupters are installed in a circuit breaker. This same higher AC voltage would be applied to the other insulation paths in the circuit breaker and may exceed their capability causing a flashover and possible damage to the insulation.

The AC power frequency withstand test should still be performed before the impulse voltage tests even though little if any reconditioning is expected. Since the AC power frequency withstand voltage test has to be performed anyway, it is prudent to perform this test first and gain any reconditioning the AC voltage may provide.

TABLE 1
– Rated Production Tests Voltages for 36 kV Interrupters

Voltage	**Value**	**Units**
Rated Operating Voltage	36	kV, rms
Rated Power Frequency Withstand Voltage	70 99	kV, rms kV, peak
Rated Impulse Withstand Voltage	170	kV, crest
Typical Production Impulse Test Voltage	175	kV, crest

4.0 USING LOWER THAN RATED IMPULSE VOLTAGE WHEN REVERSING THE POLARTY OF THE IMPULSE

Impulse test voltages with a crest that is less than the rated value are also required whenever changing from one polarity to the opposite polarity. This is mentioned in IEC 694 in Note 3 of Clause 6.1.6 entitled "Lightning and switching impulse voltage tests"[3]. These lower than rated test voltages will act to remove and reverse the charge that builds up on the floating shield inside the vacuum interrupter during the testing at one polarity. This charge, if not removed, can result in higher than normal stress on some of the internal dielectric gaps and this stress can also show-up as a breakdown at a lower level than the interrupter is known to be able to withstand. Moreover, the higher than normal stress from the trapped charge would be found at locations other than between the contacts. So breakdowns in these locations could produce unwanted internal damage instead of producing reconditioning of the contacts. Therefore, the preliminary trails at less than the rated impulse voltage will also serve to remove any opposite polarity trapped charge on the shield and then reverse the charge in the new direction to result in properly located stresses in the interrupter.

5.0 TEST PROCEDURE TO DEMONSTRATE THE RATED WITHSTAND VOLTAGE OF VACUUM INTERRUPTERS IN A CIRCUIT BREAKER

5.1 AC POWER FREQUENCY VOLTAGE TESTS

Apply an AC voltage to each interrupter in the circuit breaker at the following levels and times:

TABLE 2 – Recommended AC Test Voltages and Times

Applied Voltage	Time Duration of Test
80% of Rated	1 to 3 minutes
100% of Rated	1 minute

This test demonstrates the ability of the interrupter to withstand the rated AC power frequency withstand voltage. In addition, some reconditioning of the vacuum interrupter contacts may be provided. In additional, this step also tests of the ability of all insulating paths of the circuit breaker to withstand the rated AC power frequency withstand voltage.

5.2 IMPULSE VOLTAGE TESTS ON THE VACUUM INTERRUPTERS IN A CIRCUIT BREAKER

Each interrupter in a vacuum circuit breaker should be tested in the following manner. As discussed above, preliminary tests are performed starting at a fraction of the rated impulse withstand voltage. These preliminary tests provide some reconditioning of vacuum interrupter to smooth sharp spots produced by mechanical touching of the contacts. In addition, the preliminary tests are especially important whenever changing from one polarity to the opposite to remove and reverse the charge that builds up on the floating shield during the testing at one polarity. Any disruptive discharges that occur in the preliminary trials at less that rated voltage are not counted in the statistics for pass/fail determination at the rated impulse voltage.

The sequence of tests in TABLE 3 is recommended. This sequence is based on the ANSI/IEEE and IEC impulse voltage test methods described in the relevant switchgear standards. ANSI/IEEE has used a method called the 3x3 method (pronounced “3 by 3”) for many years while IEC has used a 2x15 method. A compromise method called the 3x9 method is now the standard method in new revisions of ANSI/IEEE standards and is an acceptable alternative method in IEC standards. These test methods are explained below.

3 x 3 Impulse Voltage Test Method[4]:

Step 1 Apply 3 impulses of a desired crest voltage.

- If all 3 impulses are withstood, then the device has passed the test.
- If two disruptive discharges are observed on a test, then the device has failed the test.
- If one disruptive discharge is observed on a test, then perform 3 more tests in step 2 at the same crest voltage.

Step 2 Apply 3 impulses of the same crest voltage.

- If all 3 additional impulses are withstood for a total of 1 breakdown in 6 tests, then the device has passed the test.
- If a second disruptive discharge is observed, then the device has failed the test.

3 x 9 Impulse Voltage Test Method:

The 3x9 method is the same as the 3x3 except for 2 changes:

- the number of additional trials to perform is 9 if there is one disruptive discharge in the first 3 trials, and
- If all 9 additional impulses are withstood for a total of 1 breakdown in 12 tests, then the device has passed.

2x15 Impulse Voltage Test Method[3]

Apply 15 impulses of a desired crest voltage:

- If no more than 2 disruptive discharges are observed for a total of 2 breakdowns in 15 trials, then the device has passed the test.

TABLE 3 – Recommended Voltage Steps for Impulse Testing

Test Condition	Voltage Polarity	Test Voltage Applied	Number of Trials
Initial	**Polarity**	**% of Rated**	
Preliminary	Positive	50%	3 Note 1
	Positive	75%	3 Note 1
	Positive	90%	3 Note 1
Certification	Positive	100%	N Note 2
Reverse	**Polarity**		
Preliminary	Negative	50%	3 Note 1
	Negative	75%	3 Note 1
	Negative	90%	3 Note 1
Certification	Negative	100%	N Note 2

Notes to TABLE 3

Note 1
If a disruptive discharge occurs in one of these trials, then use the 3x3 method at this voltage or, for more conditioning, perform additional trials at the same voltage until 3 to 5 impulses are withstood in a row.

Note 2
The number of trials performed at the rated impulse withstand voltage depends on the standard used.
- For IEC tests to IEC standard 56 and 694 and 60: N=15 and Pass ≤ 2 breakdowns in 15 trials
- For ANSI tests to C37.09 and IEEE Standard 4: N=3 or 6 and Pass ≤ 1 breakdowns in 6 trials
- For both ANSI and IEC standards, recent revisions: N=3 or 12 and Pass ≤ 1 breakdowns in 12 trials

6.0 EXAMPLE OF TEST RESULTS

Some typical test results are shown in TABLE 4. The interrupters tested are all the same size and with similar arc chambers and are rated for 36/38 kV 3 phase systems with a 170 kV Impulse Withstand Voltage Rating.

The impulse voltage tests on these VIs were performed in a manner similar to the above described procedure. The tests at all voltages were performed with the 3 x 3 test method. So at any voltage, observing 2 or more disruptive discharges in 6 trials was considered a failure to pass the impulse voltage withstand test. The highest voltage passed was considered to be the highest voltage at which no disruptive discharges in 3 trials or only 1 disruptive discharge in 6 trials was observed. So there was no attempt make to use the impulse test as a means to do any extensive reconditioning beyond that which 1 or 2 breakdowns can provide.

TABLE 4 - Examples of Reconditioning Vacuum Interrupters with Impulse Voltages

VIs: Rated System Voltage = 36 / 38 kV
Rated Impulse Withstand Voltage = 170 kV

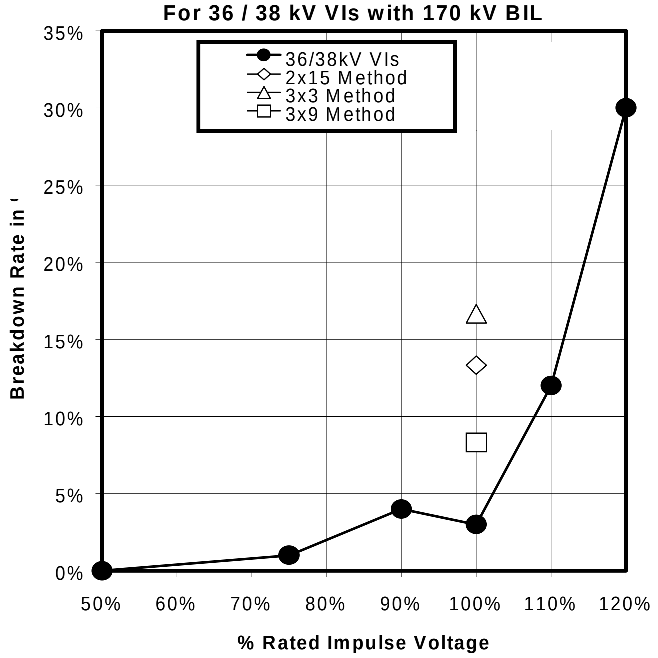
Impulse Voltage Test Method = ANSI/IEEE 3x3
Pass if the # of Breakdowns is < or = 1 in 6 trials

Sample No.	Test Voltage	Breakdowns at < max Impulse passed			max Impulse passed	
	Polarity	% of Rating	kV crest	# of Brkdns	% of Rating	kV crest
1	pos			0	110	187
	neg			0	110	187
2	pos			0	130	221
	neg			0	110	187
3	pos			0	110	187
	neg			0	110	187
4	pos	120	204	1	130	221
	neg	90	153	1	130	221
5	pos	100	170	1	110	187
	neg	90	153	1	130	221
6	pos			0	110	187
	neg			0	110	187
7	pos	75	128	1	120	204
	neg	110	187	1	120	204
8	pos				110	187
	neg	110	187	1		
	neg	120	204	1	140	238
9	pos			0	120	204
	neg			0	130	221
10	pos			0	120	204
	neg			0	100	170
11	pos	90	153	1	130	221
	neg			0	130	221
12	pos			0	100	170
	neg			0	100	170

The results of TABLE 4 can be summarized as follows:
- 12 VIs were tested
  - 7 VIs had no breakdowns at a voltage lower than the maximum passed which was ≥ the rated voltage
  - 5 VIs experienced 1 or 2 breakdowns at some lower voltage than the maximum passed, and of these:
    - 1 VI had only one breakdown
    - 4 VIs had 2 breakdowns, of which:
      - 3 VIs had 1 breakdown on polarity, and
      - 1VI had 2 breakdowns on the negative polarity.

So the overall incidence of observing 1 or 2 breakdowns at some lower voltage than the maximum is actually very small. The impulse tests were plotted as a rate of breakdowns in the trials performed in percent as a function of the test voltage in percent of the rated impulse withstand voltage of 170kV and is shown in FGURE 1. And at 100% of rated impulse voltage the rate of breakdowns was 3% which is much less than the breakdown rates of 8% to 17% permitted by the standards at the rated impulse voltage. At 50%, 75% and 90% of rated impulse voltage, the rates of breakdowns observed were respectively 0%, 1% and 4%, or 2% overall for all preliminary tests below the rated impulse voltage. So breakdowns at less than the rated impulse voltage do happen, but they are quite infrequent.

FIGURE 1 - Breakdown Rate in % vs % of Rated Impulse Voltage For 36 / 38 kV VIs with 170 kV BIL



7.0 VACUUM INTERRUPTERS IN SERIVCE

The fact that a vacuum interrupter occasionally can breakdown on the application of a impulse voltage that is lower than the rated value presents no problem for vacuum circuit breakers in service on power distribution systems. There are 3 main reasons that this feature of vacuum interrupters does not cause problems in the field.

A surge protection keeps impulse voltages low,
B breakdown is statistically rare, and
C vacuum interrupters can interrupt the power follow current even when sitting open.

These factors suggest that impulse voltage breakdowns at less than the rated value do not cause problems in service.

Few high impulse voltages as high as the rated value actually reach most circuit breakers or reclosers. Systems are designed using insulation coordination techniques to avoid overstressing individual pieces of equipment. In addition, protective devices are used, such as arresters, ground wires above lines, ground masts around substations and spark gaps at various locations to limit the impulse voltages that reach the location of circuit breakers or reclosers. Moreover, most circuit breakers and reclosers spend most of their lives in the closed position carrying current to feed loads. During lightning storms, the closed circuit breakers and reclosers are there to open if phase-to-ground or phase-to-phase faults are caused by lightning induced breakdown of system insulation or by water, ice or wind blown actions. When open for extended periods, circuit breakers and reclosers are usually isolated with disconnect switches, especially during line repair work. So the application of impulse voltages to open vacuum interrupters is limited in magnitude and very infrequent.

A breakdown of a vacuum interrupter occurring from an impulse voltage within the equipment rating is also a statistically rare event. The certification pass criteria for impulse voltage withstand tests provides that no more than 1 of 6 (17%), or 1 of 12 (8%) or 2 of 15 (13%) breakdowns should occur at the rated voltage. And the occurrence of breakdowns at less than rated is also infrequent. Moreover, often the opening of a breaker or recloser is performed to switch-off a current. The arcing that accompanies current interruption tends to clean-up the contacts and results in similar reconditioning of the voltage withstand ability of the vacuum interrupter. So the application of high impulse voltages to an open interrupter is infrequent and the occurrence of a subsequent breakdown is also infrequent.

However, even if a breakdown does occur and results in a power frequency current, the vacuum interrupter will clear the circuit at the next current zero. Assuming that there are no faults on the system, the follow current is likely to be rather small and easily switched off by the vacuum interrupter. In ungrounded systems, it would take breakdowns in 2 interrupters simultaneously to result in a power frequency current, and this is an unlikely event. More typical in such systems would be a breakdown in only one phase followed by a high frequency current which is also easily interrupted by vacuum interrupters. Many such incidents have probably occurred over the years and not been noted since circuit isolation is quickly restored by the vacuum interrupters and the effects on the system most likely not significant.

These factors combine to suggest that impulse voltage breakdowns at less than the rated value do not occur very often and do not cause problems in actual service. In fact, vacuum circuit breakers made with millions of interrupter units have now been in service in power systems for over 3 decades with no history of problems that have been related to the occasional breakdown on an impulse voltage that is lower than the rated value.

8.0 CONCLUSIONS

Conditioning at high voltage is a normal part of the manufacturing process for every vacuum interrupter. Deconditioning of the voltage withstand ability of the contacts is also a normal occurrence. Deconditioning takes place when the contacts are allowed to touch and especially when the vacuum interrupter is installed in a circuit breaker and operated mechanically. The mechanical touching of the contacts reintroduces some rough spots on the contact surfaces. These rough spots may then result in 1 or more breakdowns at a voltage less than the design rating of the interrupter. Therefore, before certification testing is done to demonstrate the impulse voltage withstand ability of the circuit breaker, it is typical to apply some high voltage to the open vacuum interrupters in order to recondition the contacts thus restoring their ability to withstand impulse voltages. High voltages and low current discharges can be used to recondition a vacuum interrupter and restore its ability to withstand impulse voltages. The most straight forward method is to combine the reconditioning process with the impulse voltage test procedure. The procedure for performing impulse voltage tests must therefore allow for a few disruptive discharges in a way that does not erroneously consider them as evidence of failure in the test.

Preliminary impulse tests at less that the rated voltage provide the means to handle this reconditioning in a logical manner. Moreover, the preliminary tests also handle the need apply some voltage to reverse the charge trapped on the floating vapor shield inside the interrupter whenever the polarity is changed. Therefore, it is recommended that these preliminary tests be performed and that the 1 or 2 breakdowns that occasionally occur be disregarded for the purposes of the withstand statistics used to determine pass or fail performance of the circuit breaker.

9.0 REFERENCES:

[1] Greenwood, Alan, *Vacuum Switchgear*, IEE Power Series Volume 18, IEE, London, UK 1994, Section 3.3 “Electrode Effects”, pp. 55-58

[2] Farrall, G. A., “Electrical Breakdown in Vacuum” in *Vacuum Arcs: theory and application*, ed. J. M. Lafferty (John Wiley and sons, N.Y.), pp. 69-74

[3] IEC publication 694, 1980 Edition, *Common clauses for high-voltage switchgear and controlgear standards*, Clause 6.1.6, “Lightning and switching impulse voltage tests”, Note 3

[4] ANSI/IEEE Standard C37.09-1979, Test Procedures for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis