Survey results: PD in bushings during factory acceptance testing

Changes to the Rev2 version of this document are highlighted in yellow.

A survey was sent to the members and guests of the Dielectric Test Subcommittee on September 23, 2019. Since a number of notable responses were received, the survey and a summary of initial responses were then sent on March 10, 2020 to a broader group consisting of the Dielectric Test Subcommittee, Bushing Subcommittee, and the Task Force on Continuous Revision to Low Frequency Dielectric Tests.

The follow text restates the survey proposal, provides a summary table of responses from the initial survey, and lists comments received back from the survey responders.

Proposal: Add the following text to standard C57.12.90 Section 10.8.5:

"If the partial discharge is observed during the induced testing of the transformer and appears to be generated within an OIP bushing(s), it is permissible to "vent" the bushing(s) to the atmosphere using the bushing manufacturer's instructions to allow for the dissipation of gas bubbles in the oil. Gas bubbles sometimes form following a temperature rise test during cool down or may be present for other reasons. Reestablishment of the bushing gas space blanket and resealing of the bushing must also be performed in accordance with the bushing manufacturer's instructions following completion of the induced test."

Summary of 9/23/2019 Survey Responses

	Number	%	Comments
Ballots	929		
Returned	132	14.2%	
Abstain	11		1
Responses	121		
Approve	105	86.8%	10
Reject	16	13.2%	16

Summary of Comments:

- Two problems exist with PD in bushings during factory testing due to non-steady state, non-equilibrium conditions in bushing following the transformer temperature rise test.
    1. Partial vacuum in the gas space which can result in low dielectric strength.
    2. Bubble formation in the core caused by supersaturation of gasses in the oil.
- It is necessary to understand where the PD is occurring (i.e. core or gas space) to accept that venting is a corrective step.

- Bubble formation in bushings is a problem.
- Gas bubbles in the oil/condenser core will not dissipate quickly.
- Concern that the same condition can occur in service.
- Concern if bushing is vented (and PD goes away), there may still be a problem with the bushing.
- Venting bushings during factory testing is a relatively common practice.
- Not all bushings have the problem of PD during transformer induced voltage test.
- Some disagree with responsibility being placed on the transformer manufacturer. Should bushing manufacturers perform similar testing (i.e. heating followed by induced voltage), change designs?
- Venting and reestablishing gas space should be performed in accordance with bushing manufacturers' instructions.
- Inadequate venting instructions provided by bushing manufacturers. Detailed bushing specific instructions should be provided and used (i.e. oil type for refilling if necessary, how to replenish gas space).
- Bushing manufacturers should specify acceptable heating and cool down rates.
- Venting may not be acceptable to some bushing manufacturers.
- Venting may not be acceptable for some bushings (type, ratings).
- Repeat the induced voltage test in entirety after venting.
- Venting a bushing may compromise the bushing insulation: pressure, oxygen, moisture.
- It was discussed at the last meeting that the factory dielectric test voltage levels are higher in comparison to service voltage levels.
- Approval from the transformer purchaser and bushing manufacturer should be required before venting bushings.
- Venting of bushings should be documented in test report.

Comments to Reject:

1. REJECT: I cannot understand we allow gas bubbles in oil in any product and to change conditions of a product during FAT is a no go for me. I heard only one supplier has issues with gas bubbles in an OIP bushing during heat run test. Erich Buchgeher

2. REJECT: In my opinion it is a technological problem from the bushing manufacturing process, which cannot affect the standards. For some technologies/manufactures this issue does not exist. - Everton Luis De Oliveira

3. REJECT: We as ABB Bushing manufacturer have to REJECT your proposal as a generic solution for all bushing types, since we do not recommend this for larger bushings. Larger OIP bushings have an overpressure when delivered from the factory. If the bushing is vented during or after temp rise test this overpressure will become a lower pressure inside the bushing when cooled down. This lower pressure can cause PD activity and subsequently failure at low ambient temperatures in service. We recommend that the OEMs wait until the bushing has cooled down before any venting. This is due to the gas content during heating must reach equilibrium in oil before venting. However this can be applied on small bushings, typically GSU types. – Niklas Gustavsson

4. REJECT: The text below suggests that OIP bushings can be vented to the atmosphere according to the bushing manufacturer's instructions if partial discharge is observed during the induced test. But the PD test is the last test which follows the impulse tests, therefore it happened that we damaged bushings during the impulse test because there were gas bubbles already in the bushing which weakened the insulation. This has led to considerable time delays and cost. I did not see any manufacturer's instruction which identified clearly all bushing types which can produce partial discharge in the dielectric tests after a heating cycle and they also do not specify the admissible heating cycle for each type of bushing. Therefore all the responsibility to identify which bushing shall be vented is transferred to the byer of the bushing, which is not acceptable. Also there is no instruction available from the bushing manufacturers on how to avoid oil spill when the venting cap of the bushing is removed. Oil can be spilled during the heat run of the transformer when the oil in the bushing is heated and expands and the oil level is higher than the level of the opened venting plug. The oil is spilled to the transformer and to the floor of the test room and can lead to considerable health and safety risks which are not acceptable. The bushing manufacturers do also not specify in their instructions the type of oil which shall be used to refill the bushings if the mentioned oil spill happens. Filling the bushing with an oil chosen by the transformer manufacturer can compromise the integrity of the bushing. Therefore I propose that we work out clear instructions to avoid all the risks mentioned above. – Egon Kirchenmayer

5. REJECT: It would see this clause as shift of responsibility from product supplier in the direction of the manufacturer – Kurt Kaineder

6. REJECT: I thought we agreed on "it is permissible to "vent" the bushing(s) to the atmosphere ***if the bushing manufacturer is contacted and they provide specific instructions***" to allow for the dissipation of gas bubbles in the oil. – Mario Locarno

7. REJECT: The presence of gas in the bushing and subsequent venting should require the test that caused the bubbles is repeated. This may also indicate the bushing was not properly processed during manufacturing and the subsequent PD tests on the bushing. Just venting does not assure the final user this activity will be resolved when the bushing is subjected to load at the users location. Bad idea and we have always disallowed this practice. – Thomas Lundquist

   (2^{nd} response, Lundquist) I still reject such allowance. These gas bubbles that some time are caused during a temperature rise test are an indication the bushing was not processed properly or has been damaged. The main reason to reject is that the bushing may simply have the same problem, when the user loads the transformer within acceptable loads or over loads. As was pointed out by numerous rejections the bushing has been compromised with such venting. The bushings are part of the transformer and if PD is detected and it is found to be the bushing the transformer failed the test and the bushing should be replaced not "vented" to get a defective bushing through tests. This is an unacceptable practice and should not be allowed. I will vote negative if this appears in the revised standard. IEEE should not allow a compromised bushing to sneak thru test by such venting. It should be rejected and returned to the manufacturer for analysis. I believe you have sufficient rejects from knowledgeable engineers to delete this and replace it with a bushing rejection clause.

8. REJECT: Background is that venting of OIP bushing if it fails during FAT because of bubble formation seems not acceptable since it should have been stable = moisture free during manufacturing. Just my comment as an end user. If we would be venting it to equalize pressure between atmosphere and bushing (which is under vacuum) then there is a possibility of moisture ingress (if surrounding atmosphere has high humidity). – Darrell Mangubat

9. REJECT: This is a technology problem which cannot be transferred to the standards. Bushing manufacturers should solve this issue. By the way, a kind of temperature rise test followed by PD test shouldn´t be part of the bushing standards? – Juliano Montanha

10. REJECT: I think that the condition that appear during testing could also appear in service. – Sylvain Plante

11. REJECT: The reason of my negative vote is if the bubble formation is also occurring in service, this will possibly lead soon or later to a bushing failure. We shall be very careful, mainly for EHV bushings that are very sensitive to the impact of gas bubbles. Perhaps, this allowance can be limited to less than 245 kV. – Pierre Riffon

12. REJECT: If I look on the short ABB manual i.e. for the OIP bushings I can find: "Our default recommendation is not to open a bushing because this can compromise the integrity of the bushing's internal environment. Opening the bushing adds the risk of contamination and the possibility of failure to reseal the bushing properly. However, we recognize that there are circumstances which mandate breaking the bushing seal. Venting is done on a relatively frequent basis by transformer manufacturers and bushing users without unsatisfactory results." So we need probably add some more information in the sentence. – Janusz Szczechowski

13. REJECT: The last sentence states "Reestablishment of the bushing gas space blanket" however, many bushings do not have any gas blanket over the oil. Can be accepted if this portion of the statement is deleted. – Vinay Mehrotra

14. REJECT: Proposal is acceptable to me if "Reestablishment of the bushing gas space blanket and resealing of the bushing must also be performed in accordance with the bushing manufacturer's instructions following completion of the induced test" is replaced by "Venting/resealing of the bushing(s) shall be performed in accordance with the bushing manufacturer's recommendation." Reasoning – Not all bushing types have a blanket. – Ajith Varghese

15. REJECT: I reject the wording of the proposed statement. If gas bubbles appear in a bushing during the transformer induced test, damage may have occurred in the bushing during said induced test. I would be satisfied if the bushing were vented to atmosphere or nitrogen, whatever gas is supposed to be in the expansion cap, as suggested, and an induced test at the bushing's appropriate voltage level is then placed on the bushing by itself. This should also include before and after power factor/capacitance tests and partial discharge tests during it induced test.– Loren Wagenaar

16. REJECT: If this practice is to be allowed, parameters of when to perform the practice should be included so as to require other diagnostic methods and only subjecting the bushing to air as a last resort. – Kris Zibert

17. REJECT: I cannot support the inclusion of the proposed text in any form. There are credible instances where bubbles can be evolved in bushings as the result of rapidly cycling load. This is an issue with the application of the bushing, as such bubbling would be damaging to the bushing insulation and should not be tolerated under any scenarios that may occur in service. The heat run test is intended to replicate conditions in service (for the most part). Therefore, if bubble evolution occurs within the bushing during a heat run, there is certainly the potential for it to occur in service. This is an issue that needs to be resolved between the transformer manufacturer and the bushing supplier. Venting the bushing is only a temporary fix to get the transformer through test. – Timothy Raymond

18. REJECT: I have experienced this problem during the overload tests on several transformers. I have never experienced it during the normal temperature rise test. As the overload requirements may occur during emergency conditions in service, there is a potential that gas bubbles may evolve during this occurrence. I do not like the instructions given by the 2 main North American bushing manufacturers. I think the bushings should be designed and rated for the maximum overload conditions that are in the standards. If some utilities have more sever requirements, the bushing should be designed for that requirement. There may be various solutions which the bushing manufacture needs to propose. Thus I reject the proposal as it is written. – Dennis Marlow

19. REJECT: I would also vote to reject the wording. In my view, the induced test must be repeated as there could be an internal problem with the bushing. – Brad Staley

20. REJECT: The text covers draw-leads-type of bushings, in our experience. These bushings are used for the smaller type of transformers and use the transformer oil as insulation. There, by natural expansion, it is quite possible to have gas bubbles at the top of the bushings at the end of any temperature change. Venting of this kind of bushings is safe and common practice during the installation of the bushing on the transformer. But we should never use the proposed method on sealed bushings without consent of the bushing manufacturer. In such bushings the sealed insulation media is very sensitive. Any disturbance may destroy the bushing. Also it will relieve the responsibility of the technical quality of the bushing from the manufacturer. The proposed text is not specific enough to mention the type of bushings for which it is applicable. – Shankar Subramany

21. ACCEPT (with changes): "If partial discharges above the limit are measured during the induced test, and appears to be generated within an OIP bushing, it is permissible to relieve the gas in the bushing to the atmosphere using the bushing manufacturer's instructions to allow for the dissipation of gas bubbles in the liquid. Gas bubbles sometimes form during cool down following a temperature rise test, or may be present for other reasons. Reestablishment of the bushing gas blanket and resealing of the bushing must be performed in accordance with the bushing manufacturer's instructions following completion of all the tests." - Juan Castellanos

22. ACCEPT (with changes): I tend to agree with adding a statement, as proposed, to this standard regarding the allowance of venting bushings if PD measurements are above criteria and it is suspected that gas bubbles within the bushing may be the cause. However, I think it should be stated that the purchaser must approve of such action. My concerns when presented with this during a FAT is that the bushing manufacturer agrees to the venting and will still honor the performance and warranty of the bushing(s) after the venting and re-sealing of the bushing. I think we should make it

explicitly clear that approval from the purchaser and bushing manufacturer must be obtained in order to perform this venting. One thing transformer manufacturers can do to speed up the process is ask for generic approval from bushing manufacturers on a bushing type, rating, voltage, etc. basis that they can refer to when the situation arises. – Tony Franchitti

23. <u>ACCEPT</u>: The assumption is made that gas bubbles may have formed in the bushing as a result of the temperature rise test, which is legitimate - but not a proven conclusion. My concern is that there could be other factors playing a role – but hopefully this would show up in subsequent testing. Another concern is that the gassing in the bushing may have been caused because of a problem with the bushing, and venting the gas from the bushing without further investigation could potentially mask a problem that could cause a bushing failure later on, but that may not be detected during the testing. – Alwyn VanderWalt

24. <u>ACCEPT</u>: The topic of having to vent Bushings is a concern in our industry and there should be better solutions. However it is a good first step to include such a procedure in the standards clarifying how to deal with it. – Arnaud Martig

25. <u>ACCEPT</u>: This proposal is pretty good. I remind you that unless things have changed, ABB does not support relieving the gas. Their comment was that it will void the warrantee on the bushing. You may want to follow up on that. In cases that venting is used on the test floor to resolve the issue of high PD, the only comment I would suggest adding is: "make sure that the induced test is fully repeated after the venting." – Joe Melanson

26. <u>ACCEPT</u> (with changes): "If the partial discharge is observed during the induced testing of the transformer and appears to be generated within an OIP bushing(s), it is permissible to "vent" the bushing(s) to the atmosphere using the bushing manufacturer's instructions to allow for the dissipation of gas bubbles in the oil. This venting procedure must be approved by the purchaser and documented in the transformer test report. Gas bubbles sometimes form following a temperature rise test during cool down or may be present for other reasons. Reestablishment of the bushing gas space blanket and resealing of the bushing must also be performed in accordance with the bushing manufacturer's instructions following completion of the induced test. – Art Del Rio

27. <u>ACCEPT</u> (offered changes): If the partial discharge is observed during the induced testing of the transformer and appears to be generated within an OIP bushing(s), it is permissible to "vent" the bushing(s) to the atmosphere ~~using the bushing manufacturer's instructions~~ to allow for the dissipation of gas bubbles in the oil. Gas bubbles sometimes form following a temperature rise test during cool down or may be present for other reasons. ~~Reestablishment of the bushing gas space blanket and resealing of the bushing must also be performed in accordance with the bushing manufacturer's instructions following~~

~~completion of the induced test."~~ Venting of the bushing(s) shall be performed in accordance with the bushing manufacturer's instructions." - John Foschia

28. ABSTAIN: I infer from the text that purpose for venting the bushings is to remove trapped gas bubbles from the bushing insulation. Venting must be done in a dry atmosphere as hot core can easily absorb air humidity. One of the common failure of OIP bushings is moisture ingress. Therefore, I'm not sure if a bushing manufacturer will agree to guarantee a bushing performance when user vents it. I have no experience in this and so, I chose to Abstain. – Raja Kuppuswamy

29. COMMENT: I saw some really great comments and think it's going to make for a great discussion, but my response is to address the seemingly common misunderstanding of the scope/context of the survey and more specifically, the term "blanket" by many responders. Multiple responders claim there are many bushing types which do not have "blankets". Perhaps they're referring to oil-less bushings or maybe some porcelain, bulk-type bushings which share oil with the transformer, but the context of the survey is clearly and specifically in regards to OIP type bushings and I cannot think of an OIP bushing that exists that does not also have its own self-contained oil supply. There is not an OIP bushing that exists (at least for very for long) that does not have some form of a "blanket" or perhaps more appropriately termed "cushion" of gas/air. The point is, some other, more compressible insulating medium than oil, which will allow the bushing's self-contained oil supply to expand and contract with changes in temperature without resulting in excessive pressure, explosion, nor exposure of the paper condenser to the gas/air medium for excessive periods of time. – J D Brafa

    (2nd Response, Brafa)
    A phenomenon referred to as Gas Bubble Evolution (GBE) has plagued transformer testing laboratories for decades. The symptom of GBE in oil-filled bushings is high partial discharge (PD) observed during induced testing of the equipment in which they're installed. PD can occur for many reasons, so it is important that there is evidence supporting the theory that the PD observed is originating in the physical location of the transformer which coincides with the oil-end of an oil-filled bushing. Gone unresolved, GBE can result in the failure of the bushing or the transformer during subsequent tests.

    GBE occurs when the temperature of an oil-filled bushing is increased, like what may happen during long periods of operation at or over the full load rating of a transformer or laboratory heat run tests, and is quickly and unnaturally cooled at a rate that forces the gases which have saturated the gas-starved oil of the bushing to escape in the form of bubbles. Cooled slowly and under natural conditions, like those experienced during service, there has never been an example of GBE resulting in a bushing failure. GBE tends to occur exclusively during factory acceptance testing (FAT) after heat run tests have concluded when transformers are unnaturally (e.g. force-cooled) cooled to quickly lower the temperature of the equipment to safe conditions so the manufacturer can expedite the FAT process of the equipment and proceed into dielectric testing. If there is enough reason to suspect an oil-filled bushing is experiencing GBE, the practice of venting the bushings has been commonly used by transformers manufacturers for decades to resolve the concern before proceeding into dielectric testing. Not all bushing manufacturers may allow users to "vent" or "burp" a particular bushing style/model. Venting the bushings to atmosphere is performed in order to allow saturated gases in the gas-starved bushing oil to quickly escape to the gas space of the bushing in a de-energized state, but venting a bushing to atmosphere may also introduce harmful contaminants to the bushing, like moisture, humidity, and oxygen. **Contact the manufacturer of the bushing before attempting to open or vent a bushing. Opening a bushing after it has been sealed in a room temperature, laboratory setting by the bushing manufacturer can change the intended design of the bushing, and has the potential to result in other long term issues and can effectively void their warranty. Always consult with the bushing manufacturer before attempting to vent or open a bushing, especially those which contain hot oil and are under high pressures and have higher oil levels than they would otherwise have if they were at room temperature (20-22°C).**

As a precautionary measure, it is always good practice to follow the bushing manufacturer's recommendation with regard to the maximum allowable RATE of temperature change and set time before energizing a bushing or performing dielectric testing.

30. COMMENT: - Harold Moore

RESPONSE TO IEEE SURVEY ON PARTIAL DISCHARGE IN BUSHINGS

BACKGROUND

The various responses to the survey indicate that there is a need to clarify the source of the discharge. Perhaps it would be of value to outline the history of this issue on one bushing design.

In the late 1980's, two bushing technologies were combined. Design 1 had several years of successful service and low partial discharge during bushing and transformer tests. However, there was some mechanical issue such a poor quality oil level indicator.

Design 2 had a better mechanical design including a glass expansion chamber. However, there had been some issues with the condenser in service.

The study of the two designs indicated that an improved bushing could be obtained by using the Design 1 condenser in the Design 2 mechanical structure including the glass expansion chamber which served as an oil level indicator.

EXPERIENCES WITH THE COMBINED DESIGN

The first order with the combined design had high PD during the induced test. The induced test was made immediately after the thermal tests.
The source of the PD was thought to be the high pressure nitrogen that had been applied in the expansion chamber in line with the Design 2 procedures. The PD was reduced by opening the expansion chamber to the atmosphere. The pressure was reduced on subsequent deliveries because it was concluded that it was causing gas bubbles in the oil. The PD issue continued during induced test made after thermal test.

It is important to note that the PD issue does not exist on the same basic electrical design when the metal chamber is used on higher voltage bushings. The PD issue did not exist with the same condenser when it was used with a metal chamber.

ANALYSIS OF THE PD SOURCE

Some simple experiments demonstrated that the expansion chamber was going into vacuum during the thermal tests. The source of the PD was not determined until some time later.

The gas used above the oil in the expansion chamber is nitrogen. Nitrogen is the only gas in which the absorption of the gas into the oil increases as the oil temperature increases. Since air is predominately nitrogen, air is also absorbed into the oil as the temperature increases.

Therefore, the chamber goes into vacuum because the nitrogen goes into the oil as the oil temperature increases during the thermal tests. The PD is caused by the Phasen effect. The PD is the result of a U shaped curve. As the vacuum increases – pressure decreases- there is no PD until the vacuum reaches a critical value at the bottom of the U. If the vacuum is increased, the PD will cease. The PD occurs on bare electrodes, and it is low energy. These phenomena occurred on a power transformer on which the applied test was applied by mistake while the transformer was under full vacuum. Laboratory test subsequently demonstrated the U effect and that it was low energy on bare electrodes. I should have answered this question at the Memphis meeting on why some identical bushing had the PD and others did not. It appears that the answer is that some are at the critical part of the bottom of the U and the others are not.

Therefore, it appears that the source of the PD is the low energy discharge that occurs with the chamber is under vacuum. The question which arises is why it has not occurred with the metal chamber. The metal chamber is at the same potential as the bare conductor in the top assembly so that there is no reason why PD should occur. However, there is no shield effect with the glass chamber. There is a potential difference between the conductor and surrounding parts having a different potential.

Several responders referred to gas bubbles. It is possible that gas bubbles may have been involved in the early experiences when the high pressure nitrogen was used. However, bubbles do not appear to be involved in the present situation. The best proof that gas bubbles are not involved is that the problem disappears as soon as the vacuum is released. Gas bubbles in the condenser would not disappear in this short time. There is no reason for bubbles after releasing the vacuum because the pressure difference is less after release of the vacuum.

Responders stated their concern that this situation could occur in service. It will occur if the bushing oil gets to the same temperature as during the factory thermal tests. However, the evidence is that it is not damaging to the bushing. In addition, it will only occur at full load with a high ambient.

One responder stated that the bushings should have a positive nitrogen pressure in the expansion chamber. One major bushing manufacturer never had a positive nitrogen pressure. Nitrogen was used to "purge the chamber." This really resulted in a mixture of sir and nitrogen at atmospheric pressure rather than a positive nitrogen pressure.

POSSIBLE SOLUTIONS

A. The only solution in the short term appears to be the approval of the proposed change. However, the bushing manufacturers need to determine if there are really any issues when the chamber is exposed to the atmosphere. The detrimental effects are obvious - oxygen and water. Calculations should be made assuming that the humidity is 90 % at 30 C. If the water and oxygen levels are acceptable, there is no reason why the proposed change should not be made.
B. A way to get better proof that the bushings are satisfactory is to guarantee the PC at the enhancement voltage. A reasonable value of 300 PC is suggested.
C. The obvious solution is to change the glass chamber to a metal configuration. This would take time and added costs. Small openings in the metal chamber will have to be accepted for the oil level indicator.

Harold Moore 3/10/20

(2nd Response, Moore)

1. The reference to gas bubbles should be removed from the ballot. Gas bubbles cannot be initiated unless the oil is saturated with the nitrogen. The oil will not be saturated as long as the initial pressure above degassed oil is only 1 or 2 psi.

2. There is no reason to have nitrogen pressures greater than 1 or 2 psi because the only reason to have nitrogen is to exclude oxygen from the oil.

3. This PD condition will exist in service with bushings having glass expansion bowls, but it not damaging because it is a low energy discharge on the bare metal conductor in the expansion chamber

4. The proof that opening the expansion chamber to the atmosphere is not a problem is because this has been performed on at least one bushing type since 1989.

5. The solution is to use metal expansion chambers. It is not practical for the transformer to sit for days waiting for the vacuum to disappear. Conversion to metal chambers will take time and costs. The short term solution is to accept the opening of the chamber to the atmosphere if PD exists after the thermal tests. The bushing manufacturers should be required to make calculations to insure that the water ad oxygen in the oil after the exposure are acceptable. It seems to be generally accepted that the aging of cellulose is within limits if the oxygen is less than 2000 ppm. A good reference is CIGRE paper 12-5 from 1975.

6. It should be noted that the opening into the chamber must be closed immediately after the sound of the air going into the chamber stops.

31. COMMENT: - Paul Griffin

I think that the responses to venting of bushings that fail PD testing during factory transformer electrical testing covered all the significant issues. It would be useful to have a summary of some of the key thoughts that were given by various members. There are two issues caused by one phenomenon, which is non-steady state, non-equilibrium conditions caused by temperature changes during the thermal tests. The two issues are partial vacuum in the gas space which can be an inadequate dielectric and creation of gas bubbles in the core caused by supersaturation of gases in the oil. During thermal testing the transformer increases in temperature, including the bushings, causing the oil to expand and compress the gas space. This compression increases the partial pressure of all the gases which causes them to increase in concentration in the oil. There are some differences in solubility of the gases with temperature which tends to be secondary to the pressure change. For example nitrogen, oxygen and hydrogen increase in solubility with increasing temperature, methane is almost temperature independent and the hydrocarbon gases decrease in solubility with increasing temperatures. When the temperature decreases after the thermal tests, particularly if overload temperature tests are performed, the oil contracts and creates a larger gas space at reduced pressure. It takes time for the gases to equilibrate into the gas space resulting in partial vacuum. This can be exacerbated in part because the bushings are filled with degasified oil in the factory to make sure there are no bubbles in the core of new bushings. This leaves the bushing in a negative pressure state. Even if gas is added (and it is) then the bushing gases can still equilibrate to a negative pressure state unless the supplier works it until the oil is saturated and there is a slight positive pressure at ambient conditions. In addition, at this time the gases in the oil are in a state of supersaturation and if the temperature change is extreme enough gas bubbles can evolve from the oil in the core. In one case it can be seen that the PD is due to partial vacuum due to the reduced dielectric breakdown strength in the gas space and due to the dielectric stress at the oil / gas interface due to the different dielectric constants of gas and oil. However, if the bushing is really super saturated with gas and there is sufficient gas for bubble evolution in the core, this would be of greater concern. In the core there is potential to damage the insulation from discharges during electrical testing. It is important to have an understanding of where the PD is occurring to have full confidence that venting is corrective. That is the crux of the discussion and the concern. There seems to be no concern from some that the discharge activity is in the core based on some level of experience but I think that needs to be vetted by the committee for all bushings.