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The Risk of transformer fires and strategies which can be applied to reduce the risk

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SUMMARY

Whilst the risk of fire in transformers is relatively low, it is not negligible. Prevention of transformer fires and implementation of strategies to prevent loss of life, minimise the loss of adjacent assets and loss of supply is therefore an essential part of the management of transformer assets. The aims of this paper is to address and quantify the risk of such fires and provide guidance on how the fire risk can be managed cost effectively without escalating and causing loss of lives,

Key elements addressed in the paper include:

Risk assessment - Quantative and anecdotal data from number of countries is presented to establish typical risk scenarios.

The major causes fires in transformers are discussed and ranked as to determine the most cost effective methods of risk reduction to increase the reliability and availability of the supply.

Risk reduction - The question of which risk should be reduced first to get maximum reduction per dollar spend on risk reduction is discussed and guidance on ranking of risk reduction options is presented.

The design and layout of the substation can have a significant impact on the risk of adjacent plant catching fire or the risk of the fire spreading and causing damages to buildings. Risk reduction options applicable for different types of substation installations are presented.

Oil spills and potential for contamination of the environment is a foreseeable and preventable event. Many countries now consider oil spill and other forms of contamination from transformer fires a serious offence and have legislation prohibiting contamination of the environment by oil spills and other chemical effluent, including chemicals used in fire fighting. Severe fines may be imposed if accidental oil spills or fire fighting chemical are not contained within the site. The need for this to be managed proactively and taken into consideration at the design of the substation is discussed.

Selection and procurement of plant and equipment can have a significant impact on the risk of transformer fires, Selection of plant and equipment with lower fire risk is discussed.

KEYWORDS

Transformer fires, fire risk, oil spill, tank rupture, risk reduction strategies.

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1 INTRODUCTION

A very high percentage of power transformers contain large quantities of mineral oil and whilst the probability of an explosive failure is low it is not insignificant. If an explosive failure occurs in a bushing, a cable box or within the oil filled transformer, then there is a high probability that it will develop into a serious and at times disastrous oil fire causing loss of the transformer, possibly other assets and possible loss of supply. The potential risk of oil spill and an oil fire is therefore a serious risk, which must be considered by all owners of power transformers.

Cigre Study Committee A2 has recognised this risk and the seriousness of transformer fires and established Working Group [WG] A2.33 to investigate and report on “Transformer Fire Safety Practices”. This WG will complete its work and its technical brochure on Transformer Fire Safety Practices in late 2010.

The author of this paper is the convenor of WG A2.33 and the aim of this paper is to quantify the risk of transformer fires, discuss typical fire scenarios and some of the measures which can be taken to mitigate and reduces the risk and losses from transformer fires. The content of this paper draws on the contributions made from other members of the WG A2.33 during discussions within WG A2.33. However, the views and opinions expressed in this paper are the authors own and they may or may not be shared and endorsed collectively by the group in its final report.

2 RISK ASSESSMENT

2.1 Transformer Failure Rates

Unfortunately there seem to be very few published papers on studies with data listing the risk of transformer fires in quantitative terms, whereas there are more published papers on studies with data on transformer failures [1-4]. It is therefore considered useful to be able determine the ratio between failures and fires, to be able to draw on quantitative data from papers with failure rates to determine risk of transformer fires. It is also useful to look for common modes and the frequency of typical transformer fire scenarios to determine the risk of each type of failure mode causing a fire before trying to formulate effective strategies to reduce the risk of such fires and the consequential losses.

From [1-4] and other sources it can be concluded that the risk of major failures in transformers varies from about 0.5 to 2.5 % per transformer service year, with the average being approximately 1%. A few utilities have higher or lower failure rates, but they are rare exceptions. The rate of failure depends on the type and service condition of the transformer, and the maker’s and the user’s procurement and maintenance practices. The failure rates tend to be above the average rate for auto transformers and generator step up transformers and below average for transmission and sub-transmission two winding transformers in the 11- 300 kV range.

It is often assumed that the failure rate is a function of age that follows a “bath tub curve”, where failure rates are higher in the first few years of service followed by lower failure rate for many years and then rising to higher failure rates towards the end of the transformer’s service life. The published data on failure rates indicates that there is an increased risk of failure in the first few years of service, but it does not support the intuitive assumption that failure rate will increase towards the end of a transformer’s in service life. It is not clear why this is not so, but it could be due the fact that many utilities chooses to replace aged transformers and transformers “in poor condition” considering that they have reached the end of their useful service life before they actually “fail” whilst in service..

2.2 The Risk of Transformer Fires

When considering the risk of and damage caused by transformers fires it is useful to separate the fire risk into two categories: The risk associated with the “fire origin”, and the risk associated with potential “fire victims”. In the context of this paper the “fire origin” is the transformer and the potential “victim” is the rest of the substation installation. This paper does not consider the risk of a transformer becoming the victim of a fire originating from another source.

Reference [5] provides data on both rates of failures and fires for transformers owned by the major utilities in Australia and New Zealand. This source reports the average rate for serious failures being approximately 1% p.a. and that the percentage of transformer failures resulting in a serious fire to be in the order of 10%. I.e. the risk of a serious fire in a transformer is in the order of 0.1 % per year in service. (i.e. 1/1000 p.a)

Reference [6] contains data for rates of transformer and reactor failures and reactor transformer fires from a large Canadian transmission utility, covering system voltage levels from 120 to 735 kV. The paper does not separate the rates for reactors and Transformers. When considering data for reactors and transformers it is common to combine the two and just refer to the combined data as applicable for transformers, the same practice is followed in this paper. The data from [6] shows a significant increase in rates of failure and in fires as a function of voltage level, with the rates of both failures and fires for 735 kV being approx 3 times the rates of those at 315 kV and 4 times those for 230 kV and 120 kV. The average rate of major failures was 1.2 % per year and for fires 0.14 % p.a. The high failure and fire rates for 735kV transformers are possibly influenced by the fact that many of the 735 kV failures were for first generation 735 kV designs. There was no significant change in the number of fires per year between from 1965-86 and 2001-07. Whereas the rates of fires reported in [5] increased significantly from 1975-95 to 1997-2004. It is considered the main contributing factor to this is the increase in the percentage of transformers using Oil impregnated Paper Bushings [OIP].

The issue on how to determine the risk of transformer fires from the failure rates has also been discussed in depth among the members of WG A2.33, which has 16 members representing major utilities and manufactures from all five continents. There is general agreement among the members that the figure of approximately 10% can be used as a good estimate to determine the risk of a major failure resulting in a transformer oil fire.

The risk of a power transformer suffering a serious oil fire is therefore in the order of 0.05 to 0.25 % per service year for most utilities, with an average figure of approximately 0.1% per transformer service year i.e. one fire per year per 1000 transformers.

If one assumes an average service life of 40 years which is fairly typical for transmission and sub-transmission transformers, then the accumulated risk of a transformer catching fire during its service life is in the order of 2% to 10%, with an average risk of fire of 4% during 40 years in-service. This is a relative low, but certainly not an insignificant risk and a risk which is too high to be ignored and follow a “do nothing approach”. Utilities should therefore determine the risk profile, which is likely to apply for their transformers and consider the practical and cost effective risk mitigation measures, which can and should be applied to their transformer installations.

If a utility has good statistical data on the rate failure or risk of fire applicable for their system, then this will provide the most accurate basis for assessing the risk of fires applicable for their transformer installations. However, if they do not have such data then they can determine the approximate failure rate for their transformers and use the guidance given above to determine the likely risk of fires for their transformers.

Factors which influence the risk of a particular transformer and measures which can be used to reduce the risk of transformer fires will be discussed in more details in the remainder of this paper.

3 MAJOR CAUSES TRANSFORMER FIRES

3.1 Transformer Fire Initiated Bushings and Cable Termination Failures

There is clear evidence that transformers using OIP bushings or cables terminated in air or oil insulated cable boxes have a significantly increased risk of a fire following a bushing or cable termination failure. In the Australian-New Zealand transformer fire survey [5] it was found that 91 % of transformer fires originated from an OIP bushing or a cable termination failures, with bushing and cable terminations each accounting for 5 fires out of a total of 11 transformer fires and the one remaining fire (9 %) from an OLTC failure.

The Canadian failure data [6] included 24 transformer fires, 46 % of these fires were caused by failure of OIP bushings and the remaining 56 % of fires from failures from HV leads to bushing turrets or HV leads to tank wall. A high percentage of these arcing failures caused rupture of bushing turret or breakage of bolted flanges on bushing turrets (chimneys) and in a few cases rupture of tank spilling of oil and fire. A high proportion of the bushing/bushing turret (chimney) failures occurred in transformers at the 735 kV voltage level and were high arcing energy failures.

3.2 OIP Bushing Initiated Fires

OIP bushings are the single highest cause of transformer fires. The insulation in bushings is highly stressed and there are inherent fire risks in their design. Many OIP bushing uses a design where the lower and upper porcelains are clamped against O-ring seals at metal interfaces and the clamping force is provided by pre-stressing of the Central tube. If an arcing failure occurs within an OIP bushing, it frequently results in an explosive failure and shattering of the upper or the lower porcelain, which with this type of design will results in total loss of clamping force on both porcelains and in most cases causes dislocation of the condenser body relative to the bushing flange, arcing in air, oil spill and fire.

If the arcing failure occurs above the flange and the upper porcelain suffers explosive failure due to the pressure build up from of arcing gases, then the power arc will ignite the hydrogen and hydro-carbon arcing gases, the vaporised oil from the bushing and some of the oil saturated insulating paper. The condensor body will in most cases become dislodged from the flange and move downwards due to sudden loss of clamping pressure on the upper porcelain. This allows warm or hot to oil flow through the bushing flange and spill over the transformer, where it fuels the fire already ignited from the bushing failure and a serious and major oil fire will in most cases follow.

If the arcing occurs below the flange and the lower porcelain shatters, then arcing will initially occur under oil, which will not ignite the oil due the absence of oxygen. However, the loss of clamping pressure and the pressure from the explosion will in most cases cause the condenser body to move upwards and arcing will in most cases occur from the central tube to the flange or other earthed metal where oil spilling through the bushing flange and now exposed to air (oxygen) becomes ignited. The risk of a major oil fire following a failure in the lower part of the bushing is also very high, but slightly less than for arcing failures originating above the bushing flange.

Ph 1. OIP bushing failure and oil spilling into common cable trench causes fire in two 90 MVA transformers

Ph 2. OIP bushing failure causes fire in transformer but fire contained by sound enclosure

The risk of fires being initiated by a failure of a Resin Impregnated Paper [RIP] bushing or a Synthetic Resin Bonded Paper [SRBP] bushing is significantly less than for OIP bushings. The reason for this is that these types of bushings do not have porcelain insulators on the oil side (the lower end) of the bushing. A failure at the lower end of the bushing will therefore not cause breakage of porcelain and in most cases does not cause damage to air side (upper part) of the bushing or result in oil spill unless the arcing energy is very high.

A failure in the upper side of an RIP bushing will most likely cause fragmentation of the porcelain if the bushing uses a porcelain insulator, but in most cases no fire as a high proportion of RIP bushings do not contain any oil, or if it uses oil between the porcelain shell and the condensor body then in most cases only a very small fire. Oil free RIP bushings are common and available from most suppliers of RIP bushing. The use of polymer insulators on the air side is also common. This eliminates the risk of porcelain fragment being expelled in event of a bushing failure and also reduces the fire risk further as Silicone rubber will not sustain a fire without significant heat input.

The author is not aware of any oil fires having been initiated by a failure in a RIP or SRBP bushing. This is not a categorical statement that a fire could be not initiated by such bushings, but merely that the risk is much less than for OIP bushings.

3.3 Transformer Fires Initiated by Cable Termination Failures

Cable terminations failures in air or oil filled cable boxes also cause a high percentage of the transformer fires. The typical scenario with oil filled cable boxes is that an arcing fault is initiated in or at the cable termination. The pressure build-up from the arc ruptures the cable box explosively, ignites oil in/from the cable box which continues and escalates as it gets fuelled by oil spilling from either a pipe connected to the conservator or the main tank, and the fire develops into major fire which eventually may cause burning of gaskets and then gets fuelled from the larger quantity of oil in the main tank; refer Ph. 3 where the fire was caused by a failure in a 132kV cable termination on a 240 MVA transformer. The fire in this failure evolved to a major fire in the cable basement where it burnt 132, 33 and 11 kV cables to two 2 x 90 MVA transformers and 2 x 30 MVA transformers, in addition to causing other major damage to switchgear, control equipment and the building.

The common fault scenario for cable termination failures in 11-33 kV air insulated cable boxes is different, but the outcome is also a major oil fire. An arcing fault in an air insulated cable box without arc venting will often result in complete destruction of the cable box. Mechanical forces on the cables from the fault current and the blown away gland plate will often cause breakage of the bushings, which typically is an oil filled, solid stem type bushings. The oil spilling from the broken bushings will then be ignited by the arc. The oil in the conservator and possibly the main tank will then fuel the fire and cause it to develop into a major oil fire, refer Ph. 4 & 5.

If precautions have not been taken to seal cable ducts and cable trenches, then the oil may spill in and the fire travel along the cables and cause serious damage in cable basement and or adjacent plant if their cables share the same cable trench /basement, refer Ph. 1 and 3.

Ph. 3 Burnt out 240 MVA transformer after a 132kV cable termination failure

Ph. 4 Transformer fire caused by 11kV cable termination failure

Ph 5 cable box after fire in ph.4. Cables & gland plate blasted off by arcing fault

It is the author's experience that very few air insulated cable boxes on transformers have arc venting which could prevent damage to cable box, dislocation of the cables and breakage of bushings. Such deficiency is not tolerated in metal clad air insulated switchgear, which always is designed with arc venting. The arcing energy in an air insulated cable box can be very high, even at 11—33 kV.

3.4 Risk of a Transformer Fire being Initiated by an OLTC Failure

OLTC failures is the cause of 10-15% of fires, however these fires are often less destructive than bushing and cable termination fires, An arcing failure within the diverter switch or an "in tank" column type OLTC's will in most cases break the recessed rupture disc in the OLTC cover and initiate a fire. However, as the volume of oil exposed to air is small, a few hundred litres at the most, unless there has been a rupture of the barrier between the main tank and the OLTC diverter /arcing contact oil compartment then the fire may be small and short lived . If the arc energy is low and OLTC is equipped with PRD or has some other form of fire protection the cover then the fire may extinguish after the protection has cleared the fault current. If the oil barrier to the main tank has been broken and oil is spilling from the main tank /main conservator then there is a high risk that it may develop into a major oil fire.

3.5 Risk of a Transformer Fires being Initiated by a Tank Rupture

Oil fires originating from rupture of transformer tanks and bushing turrets are rare for voltages $\leq$ 300 kV. For voltages $\geq$ 330 kV the combination of longer flashover arc and high system fault energy often result in rupture of tank or bushing turrets before the protections have time to clear the fault. If a tank or turret rupture occurs whilst the arc is present then there is a very high probability that it will ignite the hydrogen and hydrocarbon gases from the arc and the oil spilling from the tank, resulting in a major oil fire.

Reference [6] reported that 13 of 24 fires (54 %) were caused by rupture of tank or bushing turrets (chimneys). 4 of these were HV lead to bushing turret faults and 9 were HV lead to tank faults. All faults causing fires had very high fault energies (calculated to be > 13 MJ**).** Reference [6] also reported in the same paper that there were 21 explosive failures caused by failures within windings and 9 explosive failures caused by faults in cores, OLTC’s, and other parts, <u>but none of the explosive failures caused fires</u> !!!. These findings are supported by the finding in [5] were none of the 11 fires reported in the Australian -New Zealand survey were caused by faults within windings.

Tank flexibility together with pressure withstand capability is an important factor when considering withstand against rupture of tanks and tank flexibility may be much more important than fitting of PRD’s. This becomes evident when considering the significant increase in volume which can be accommodated in a standard tank for only small pressure increases. The author has performed oil volume expansion/ pressure test on a 350 MVA transformer having an oil volume of 60,000 litres. The volume expansion was 600 litres for a pressure increase from 0.45 to 1.45 Bar, measured at base of the tank. This volume expansion capacity is very significant in comparison with the amount of oil which could be discharged from a conventional PRD with 127mm dia. opening with the fault clearing time of say 60 msec. The oil discharged via the PRD would only be a small percentage of the amount the volume expansion of the tank during the arcing. A larger volume expansion could have been achieved, if maximising volume expansion had been a design criteria. Tank flexibility (volume expansion) is an important factor when evaluating tank rupture withstands capability [14].

4 THE POTENTIAL FIRE VICTIM – OTHER SUBSTATION ASSETS

If a fire occurs as a result of a failure in a transformer, then the transformer is nearly always a total write-off. The strategy therefore is:

- Minimise the risk of the fire occurring.
- Protect the potential fire victim, the remainder of the substation installation, from also being fire damaged.
- Maintain supply during the fire, or if not possible then restore the supply as early as possible after the fire.
- Avoid pollution and contamination of the environment.

These points need to be considered and taken into account at the design stage of the sub-station. Processes methodologies [HAZOP, FMEA] have been developed for this purpose [4].

It often is useful to categorise substation into types of substation designs where specific standard strategies can be applied for fire risk management. Viz.

- Open air substations where land cost is low – in such installations space separation will often be the most economic fire victim risk management strategy.

- Compact air insulated substations where land cost is higher. In such installations fire barriers in the form of reinforced concrete panels/wall, sound/fire enclosures, or water spray “curtain” are common forms of fire protection.
- Underground or substation in city building. Such installation will normally have a very site specific, fire prevention and fire contingency management strategies. Japan has well developed designs for risk management in such installation, using a combination of large duct openings between the banks of single phase transformers and up to the conservator and high strength tanks design – up to 2-5 bar with plastic deformation and up to 5 Bars withstand before tank rupture . This combination gives the time for and provides large oil volume expansion and allows the oil to move rapidly into the conservator in event of internal arcing , resulting in reduced rate of pressure rise and containment the oil and arcing gases , for the time required for the protection to clear the fault without rupture of the tank [9] [10].
- For smaller power transformers dry type or transformers using high flame point fluids (low fire risk) are possible options for reduction of transformer fire risk.
- If the installation is in the basement of an occupied office building or people traffic area, then SF6 cooled transformers will be the safest option [11] [12] as such transformer can be made completely free of fire risk.
- Deluge or fogging water spray systems can be effective in protection of “fire victim” assets and are often used on unit and generator step-up transformers at power stations where high capacity and reliable water supply is readily available. It is important to recognise that water spray may also be required to cool nearby building structures or other critical assets, and not just the fire origin.

Other types of installation – Installation which is more unique and does not lend itself to be categorised must be considered on a case by case basis.

Standard precautions which apply to all installations and should be considered at the design stage include:

- Access to key areas of the substation with any one transformer on fire. Multiple access points may be necessary.
- Radiated or wind borne heat should not be able to initiate fires in other substation assets.
- Fire brigade access and availability of water/foam/other fire suppressants for fire fighting. Whilst water is generally not effective in extinguishing transformer oil fires and foam not effective in fighting oil fires with oil spilling over vertical surfaces, water can be very effective in cooling the fire to reduce heat output and in preventing a fire spreading to adjacent assets.
- Spilling oil outside the substation during a fire should not be considered an accident, but negligence and failure to foresee and manage the risk. Regulating authorities in many countries now apply heavy fines if oil spill occurs outside the substation boundaries. Oil containment systems are therefore becoming a standard feature in substation installations. The systems should be sized to ensure all oil from the largest transformer in the substation can be contained.
- Most utilities have developed oil containment system to suit their specific requirements. The key requirements of such systems are - that oil should be directed away from the fire zone rapidly so it is not available to fuel the fire, and should not contaminate the environment. The oil containment system must be fit for the climatic and other site specific conditions. Underground oil/water separation tanks are becoming widely used in Australia. Such a systems can separate transformer oil mixed with water to less than 10ppm of oil in the water at the outlet from the from oil separation tank at max flow rate through tank [7]. A Canadian utility [8] uses a mat/membrane system suitable for cold climate, which allows water to flow through, but will contain oil and prevent it from contaminating the ground water.
- Oil spilled from a fire source should not be able to travel along cable trenches or conduits and cause the fire to spread to buildings or other plant items (refer Ph. 1) Use of cable segregation and fire barriers should be used for this purpose.

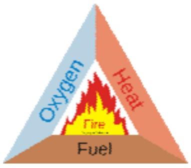
There are many more issues to be considered in terms of good fire safety practices; however it is outside the scope of this paper to address these in any further details.

5 RISK MITIGATION MEASURES

Some of the key questions which should be considered by the transformer owner and other key stakeholders when planning a substation are:

- What fire risk is acceptable?
- What fire risk reduction measures are available and at what cost?
- “It is important to consider and rank risk reduction measures in terms of economic efficiency = risk reduction /cost of risk reduction”.

For a fire to exist and propagate, it requires the three key elements of Heat, Fuel and Oxygen. If any one of these is absent then the fire will not start, or if removed after the fire has started, then the fire will extinguish. The single most effective risk management strategy should therefore focus on keeping the oil within the confines of the transformer tank, as this eliminates the risk of a fire and the cost of cleaning up the oil spill. The small quantity of oxygen dissolved in the trans-former oil is not available to initiate a fire.



The Following Listing of Risk Mitigation Measures is in Order of Economic Efficiency

- Avoid OIP bushings and cable terminations housed in cable boxes as these accounts for more than 70 % of transformer fires in transformers below 300kV and approx. 50 % of transformers above 300 kV.
- Use reliable and fast acting duplicate protection systems and high speed circuit breakers. The reduction in fault clearing time is directly proportional to the reduction in arcing energy and thus the most effective measure available to minimise the risk of tank rupture for a given tank design.
- If cable connections are used then they should preferably be terminated on a free standing structure a short distance away from the transformer and the connection to the transformer made to cover mounted bushing via a short bus bar with flexible shunts, to ensure that a cable termination fault will not cause breakage of transformer bushings and initiate an oil fire. The photograph to the left is from same installation as the transformer fire in Ph. 2. and whilst the purpose of separating the cable terminations from the transformer was to minimise the risk of a cable fault causing a transformer fire, it also ensured that the cable was not damaged by the transformer fire.

. Ph. 6 Cable terminations

- If cables are terminated in an air insulated cable box, then the cable box should be designed with a weakened section, which will vent excess pressure generated by an arcing fault to avoid damage to bushings and consequential spill of oil and fire.
- PRD’s with opening in the range of 100-150mm dia.,. should not be relied upon to prevent tank rupture. They have insufficient capacity to prevent pressure rises within the tank for high energy fault say > 2.5-3MJ. Tank flexibility together with pressure withstand capability is likely to be more important than fitting of PRD’s when considering withstand capability against tank rupture during arcing faults.
- PRD’s cannot provide protection against tank rupture for high arcing energy faults. Resistance against tank rupture for such faults can only be achieved if the transformer has been designed to withstand high pressures and is provided with large openings into the conservator or other forms for oil volume expansion [9] [10] [13].
- It is still recommended to follow the convention of providing one or two PRD’s on transformers to provide safety from over pressure damage during oil filling. They can also provide protection against tank rupture with low energy faults and slow acting protection and for transformers with gas cushions where pressure rises during arcing faults are much slower.
- The MVA rating for which hermetically sealed gas cushion transformer design can be accommodated has increases significantly in recent years [14]. Gas cushion transformers can provide

very good tank rupture withstand capability against tank rupture during arcing faults, provided the gas cushion is oxygen free, the tank is equipped with PRD and has good pressure withstand capability with a suitable margin above the opening pressure of the PRD. The benefit of this type of design is that a relative large amount of arcing gas will only produce a minor and relative slow pressure increase in the tank as the gas cushion is compressible. The relative slow pressure increase provides time for protection to interrupt the arcing current before the rupturing pressure is reached.

OLTC should be provided with oil surge trip relay and PRD. The PRD will not prevent OLTC vessel from rupture with high arcing fault energy, but may do so with lower arcing energy levels which is often the case for OLTC arcing faults, if the tapping winding is at the neutral end. The PRD may provide less protection against barrier board/cylinder rupture than a rupture disc, but has the benefit of resealing capability and thus prevent oil spilling and exclude oxygen from the OLTC vessel after the fault has been cleared, which can be a significant reduction in fire risk.

6 FINAL CONSIDERATIONS - SELECTION OF PLANTS AND COMPONENTS

There is clear evidence that some utilities have significant lower failure rates than others. Whilst the reason for this is difficult to prove in quantitative terms, there is anecdotal evident that this is linked to procurement, maintenance and operating practices by the asset owner.

The recommendation therefore are:

- Choose RIP bushing instead of OIP bushings.
- Avoid use of air and oil filled cable boxes where at all possible. Plug-in type cable terminations are preferable to air insulated cable boxes.
- If cable boxes are used, use cable boxes with arc venting.
- Consider tank flexibility and pressure withstand capability in specifications and procurement decisions. Prove by test that specified / offered pressure withstand capability is supplied
- Consider gas cushion type or flexible tank design with predefined and verified arcing withstands capability for medium sized power transformers (up to approx 60 MVA. This may increase to 100 MVA in the near future, beyond what has been proven by testing.
- Procure from suppliers with proven designs
- Use online DGA monitor for all large and medium size power transformers which have abnormal rates of gas generation unless cause for this is understood and is not of concern.

Verify loading and overloading capabilities by test. Do not overload beyond overload capability,

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