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Customer Q&A summary from the NHP Webinar Series - Talking Medium Voltage 'Session One (Dry vs Oil Transformers)' which aired on the 12th of October 2022

1) What is the insulation material used for the LV winding?

The low voltage windings consist of electrolytic aluminium foils, insulated by the material impregnated with 'H' class epoxy resin and heat treated in an oven to form a compact sealed unit, which provides sufficient strength which can withstand short circuit forces in the transformer.

This LV insulation material is typical for most applications and climate and environmental classes. It is also possible for the low voltage windings to be constructed using vacuum cast resin technology, the same as the high voltage windings.

2) Is the NHP dry type transformer vacuum type or air sealed for life?

NHP dry type transformer uses vacuum cast resin technology for HV winding, as the HV winding is cast in the oven under vacuum to form one solid block. It is sealed for life (>30 years). Cast resin technology provides the best protection of HV winding from the environment as well as mechanical strength for short circuit withstand. It also ensures best quality of the resin and minimised partial discharge (through extraction of any air bubbles under the vacuum). Cast resin technology is the most advanced of the available dry-type transformer technologies, and perhaps the most common in the industry these days.

3) Have you had had any experience of cast resin failure?

We have had one experience of cast resin transformer failure, which has happened in the commissioning process due to incorrect MV distribution system design for that site, which did not consider transient switching overvoltage in a specific application with back-up LV generators with floating delta winding of generator step-up transformer.

On that site, the LV generator is connected via a step up LV/MV transformer with the star LV and delta HV winding. Then power is distributed via a network of MV switchboards to the entire site. In normal operation, when the MV supply is coming from the utility feeder, the MV phases are referenced to earth via the earthed neutral of the HV/MV transformer located in the utility's HV substation, thus reducing the risk of abnormal switching overvoltage events.

However, in the case of a utility supply failure, the incomer CB is opened and MV the switchboard power circuit loses its reference to earth through the utility transformer. At the same time the LV generator starts, the MV delta winding of the step-up transformer becomes a new source of MV power to the MV switchboard and it is not reference to earth either.

Therefore, when the MV VCB feeding MV switchboard from the step-up transformer generator is switched on or off, the potential of MV phases on either side of this VCB is floating vs earth, so the level of switching overvoltages to earth is unpredictable and, in our experience, could exceed the BIL level and result in both switchgear and transformer insulation failure (refer to the answer to Question 3 above regarding cast resin transformer failure experienced by NHP).

After the thorough investigation by external consultants, the root cause was identified -the floating delta winding of the generator step-up transformer – which was addressed by improving the MV system design by changing HV winding from Delta to Star as well as installing Surge Arresters on the MV VCB. The installation has been in operation for many years since then without any further issues.

The failed transformer was repaired by NHP in a very short period (<2 weeks) with HV windings airfreighted from overseas and replaced in our local factory in Australia.

Importantly, from a safety perspective, during that fault the cast resin F1 fire class insulation behaved as a self-extinguishing fire-retardant material as expected, with only a momentary arc flash event that did not cause any lasting fire and stopped once the protection had cleared the fault. No one was injured and damage to the installation was very minimal.

4) **Could you comment on the impacts of installations where the monthly/annual averages are higher than the defaults in AS / IEC 60076? Similarly, where the peak exceeds the standard 40degC but only for short periods, how should this be addressed in specifications?**

The standard design temperature for a transformer is 40 degrees Celsius, as per IEC60076 standard. If the ambient temperature exceeds this even for a few days in a year, it is a good design practice to increase the design temperature of the transformer.
Keeping in mind that the power distribution transformer LV winding can reach the maximum temperature in only 3-4 hours, so on a very hot (40C+) day it could be approaching/exceeding the temperature limits, especially if the load is close to 100%. Normally in this situation, we design the transformer for 45 or 50 degrees Celcius ambient temperature, which is our recommended approach for technical specifications. Although it increases the cost slightly, it ensures the longer life of the winding and minimises the risk of a transformer overtemperature protection trip on a hot day, which is especially important if the transformer supplies critical loads.

If we are considering only a few extra-hot days per year, another option is to use a fan forced ventilation. However, it will not provide a cost benefit versus increasing a transformer design temperature by 5 or 10 degrees. Forced cooling technology obviously relies on reliability of fans, which have limited design life of

20,000 hours (2.3 years) only, so the forced cooling is designed only for occasional use over the transformer's service life of 30 years or so.

Ensuring that any reduction in the transformer life is minimised regardless of the type of construction (dry or oil) by not exceeding the specified temperature rises within the standards is good design practice.
Therefore, it is essential that any design parameters that could affect the life of the transformer, such as higher than average ambient temperatures, harmonic 'K' factors, transformer enclosure ingress protection ratings and solar gain be clearly nominated with the transformer specification requirements.

5) Is the amorphous core material a kind of sintered metal?

Amorphous alloys are a class of metallic materials that are not crystalline in nature as compared to most metals, but demonstrate great properties such as high strengths, high elastic strain limits of up to 2%, good corrosion resistance, etc. Most importantly, they have much smaller magnetic hysteresis loop on B-H curve. As a result, the no-load losses are reduced by 70% vs standard grain-oriented steel.

Amorphous core material as applies to distribution transformers is not produced by a 'sputtering' method and so is not sintered as such. Nor is it produced by powdered metal formed under pressure, as is the case for high frequency 'pot-core' types of small transformers. Rather, the amorphous core of a distribution transformer is typically a specially formulated alloy of steel, which is then cooled very rapidly from forming temperature down to room temperature, in order to avoid the typical crystalline structure that otherwise forms with normal cooling methods.

Transformers need to be specifically designed for the amorphous core material. It is not simply a case of substituting the amorphous material for the domain refined silicon steels typically used in the manufacture of distribution transformers. For instance, the maximum flux density of 1.35 tesla needs to be considered for an amorphous core, compared with 1.72 for a standard silicon steel core.

6) Are oil transformers in kiosk subs are hermetically sealed?

Yes. There is no point using the conservator type oil transformers in the kiosk. In kiosks, we don't install a transformer larger than 2.5 or 3 MVA, which are distribution transformers and are already available hermetically sealed. As we discussed, hermetically sealed provides many benefits such as less maintenance and more reliability versus conservator type.

7) **What are the fire protection/suppression requirements for MV oil filled transformers? What part of AS 60076 provides guidance on the transformer fire detection/suppression systems?**

This topic is not addressed in the AS 60067. However, it is very well addressed in AS 2067 'Substations and HV Installations', where there are very detailed tables (Table 6.1, 6.2) about fire clearances and fire suppression requirements, depending on the size of the transformer and type of the oil used in the transformer (mineral vs high flash point oil).

8) **How reliable are online DGA units? When doing condition monitoring for oil immersed transformers with online DGA, would you purely rely on their results or send samples for lab tests for benchmark?**

Online DGA is uncommon on distribution transformers (MV/LV). It is typically used on power transformers (HV/MV) or very critical applications.

Using an online DGA unit or dissolved gas analysis unit permanently fitted to the transformer regularly sampling the oil is a great diagnostic tool which can certainly give an early warning that hydrocarbons are present in the oil.

Like all diagnostic testing, it is the verification of the tested levels that is important as well as the rate of change over time. It would be prudent to get the online DGA levels also verified in a test laboratory as a benchmark.

9) **What does an externally installed IP rated cast resin look like?**

The above cast resin outdoor enclosures have an ingress protection rating of IP43. This 6MVA/ 8MVA AN/AF transformer has been supplied by NHP and installed in Alice Springs on a BESS project.

10) I have read about risk of cast-resin failures due to switching-induced transients from VCB chopping. How real/severe is this issue with modern transformer technologies?

VCB current chopping may occur when switching low level reactive currents, e.g reactive no load current (or even cable charging currents). Here, the current falls to zero before the voltage does, and so a transient recovery voltage appears which may indeed be more likely to damage the insulation of a dry/cast resin type transformer versus an oil filled type.

These days with the modern vacuum interrupters technology, the VCB current chopping presents less risk, as the current chopping level has been reduced vs earlier vacuum interrupter designs.

However, in any installation where there is a potential or known risk of transient over-voltages, it is recommended that surge arrestors be installed to protect the transformer from potential damage, whether the transformer is of a dry type or oil type construction.

11) To what degree can the fire and environmental risks of oil-type transformers be reduced by using different oils. What downsides are there and cost-implications when comparing with dry-type.

From ester oil to vegetable oil, you will get a higher flash point. From an environmental perspective they biodegrade quicker than mineral oil. Having said that, while the flash points are higher if you get to the situation where you ignite the oil it will continue to burn like mineral oil, it will obviously require a higher temperature to initiate that. If it leaks and goes to the waterways, it is a lot better than mineral oil.

Certainly, where transformers are installed indoors, cast resin transformers are a better option as they improve the situation, however, they don't 100 % mitigate a problem happening in extreme situations.

Also, in terms of price differences, as an indication, going from mineral oil to **FR3 vegetable oil** increases the price by approximately 10%.

Cast resin transformers are normally between 5% to 25% cheaper than mineral oil type transformers (depending on the size of the transformer - for larger sizes the difference decreases).

Depending on the IP rating and the material, adding an enclosure to a cast resin transformer adds 25% to 35% to the price. Therefore, it's common to see cast resin transformers at the same price as mineral oil types and maybe even higher.

In a practical point of view, installation of oil immersed transformers often entails the installation of oil bunds or the outdoor enclosures, and often fire walls.

Therefore, for outdoor installations, the overall cost of the transformer and installation is comparable or even less for cast resin type.

12) When installing dry type transformers outdoors in IP enclosures, is there are a standard regarding fencing / barrier for 22kV?

A location where transformers and/or HV SWGR installed can be categorised as a HV substation and therefore guidance for clearances should be taken from AS2067.

13) What Arc Flash mitigation is possible on a transformer and what standards cover this?

There are couple of points in AS 6271.202 on kiosk substations. We use plug in bushings with screen elbow connectors in our kiosk type substations with either cast resin or oil transformers. This technique minimises the chance of an arc fault by insulating the HV connections on transformer.

The other measure is that the accessible HV parts on cast resin, such as tap changing links, can be covered as well as insulating HV connections between windings on the cast resign transformer.

14) What is transformer derating like for a kiosk? Is a 80% loading ok?

We are going to have detailed discussion about this topic in our third webinar, but the general answer from our experience is that 80% is a reasonable derating factor for 1.5 and 2 MVA transformers. However, it depends on the design and it can be optimised with special technics.
For transformers below 1MVA, the deratings factor will improve to 85% or 90%

Alternatively, a kiosk (integrated substation) can be specified to deliver a given transformer kVA output when installed within the enclosure. This often results in a slightly larger sized kVA transformer being installed, allowing for the 10% to 20% derating.

15) When you refer to 'oil' transformers, you actually mean mineral oil transformers. An FR3 oil transformer would not burn like this.

As we discussed during the webinar, all oils have a flash point, but some, such as FR3, have a higher flash point than others and so are less likely to ignite. The fire point for FR-3 is twice that of mineral oil, so mitigates the risk, but certainly does not remove it 100%.

However, the calorific energy of mineral oil and less flammable (e.g. vegetable) oils are very similar (as can be seen in the table below), therefore if oil does ignite, the consequences will be the same.

Comparison of Properties of Less-Flammable Fluids

		Mineral	**R-Temp (Cooper)**	**Beta (DSI)**	**FR-3 (Cooper)**	**Bio-Temp (ABB)**	**Silicone (Dow Corning)**
Dielectric	Dielectric Strength KV	35	43	40	45	45	35
	Dielectric Constant	2.2	2.38	2.1	3.1	3.1	2.7
	Volume Resitivity ohm-cm @ 25°C	$1x10^{12}$	$1x10^{14}$		$30x10^{14}$		$1x10^{15}$
	Power Factor						
	25°C	>0.05		0.05	0.06	0.009	
	100°C	>0.30	0.4	0.1	0.59	1.85	0.9
Physical	Specific Gravity 15°C	0.89	0.87	0.87	0.92	0.919	0.96
	Interfacial Tension 25°C (dynes/cm)	45	40	38	24	26	31
	Neutralization Number (mg KOH/gram)	0.01	0.01	0.01	0.02	0.02	0.01
Viscocity	0°C	76			190	300	90
	25°C	16	350				50
	40°C	12	113	108	34	45	38
	50°C	6.7	85		27		30
	100°C	2.3	12	12	8	10	16
	150°C	--	5.5		3		12
Thermal	Flash Point °C	160	276	284	316	310	300
	Fire Point °C	173	312	308	360	320	370
	Pour Point°C	-40	-24	-18	-21	-15	-55
	Coefficient of Expansion cc/cc/°C	0.00086	$7.3x10^{-4}$		$7.4x10^{-4}$	$6.88x10^{-4}$	0.00104
	Specific heat cal/gm/°C @ 25°C	0.503	0.46	0.46	0.45	0.47	0.34
Biodegradability		20-30%	yes	100%	99%	97%	0%
Application		All Transformers	Small & Medium Power	Power Transformers	≤48 KV 10 MVA	≤69 KV 20 MVA	Small & Medium Power Transformers

16) **Can the less combustible transformers (K type) treat like a dry-type transformer for the fire situation?**

The fire point for FR-3 is twice that of mineral oil, so mitigates the risk, but certainly does not remove it 100%. This fact is supported by Table 6.1 and 6.2 of AS 2067 describing fire safety requirements for both outdoor and indoor transformers, that include fire clearances, fire rated walls and automatic fire suppression protection for various types of oil immersed transformers (mineral oil, K type and dry type)

It can be seen from these tables that such requirements are the highest for the transformers with mineral oil, reduced for K type and are very minimal for dry type transformers, especially of F1 fire behaviour class (which is NHP's standard offer for cast resin transformers and is common in the market).

Therefore, for the fire situation, K-type transformers require higher levels of precautions vs class F1 dry type transformers.

17) **Why does AS 2067 require larger clearances for K type oil transformers than air type transformers?**

AS 2067 indeed requires larger clearances for K type vs F1 class dry type. This is explained by fire retardant and self-extinguishing materials used in cast resin transformers, which is proven by fire behaver test to class F1 to AS60076.11.

Therefore, in the event of dry type transformer catastrophic fault, the instantaneous arc fault may occur, however once the electrical fault has been cleared by the upstream protection - typically in less than 1 second) the fire will self-extinguish. In other words, materials of F1 dry type transformers are endothermic (consume energy when they burn), so cast resin would require external fire source to keep burning.

As a result, the F1 dry type transformer poses a minimal risk to the entire installation (limited to the effect of very short time arc fault event, as opposed to the insulation material fire that may last for hours in the oil immersed transformer).

The K type transformer reduces the chance of fire due to the higher flash point of its oil, but doesn't eliminate it completely. If the K type does catch fire, it will last for hours in the same way as in mineral oil type transformer. Both types of oil are exothermic, so they release the energy while burning, so they are self-supporting the fire if it has started. They both have a very similar calorific energy, as mentioned in item 15 above, therefore consequences of oil fire are similar for both K type and mineral oil type.

18) Is cast resin more expensive than oil?

IP00 cast resin transformers price are in fact more cost-effective then oil immersed transformers, offering 5% to 25% cost savings vs mineral oil type transformers and even higher cost saving vs less-flammable oil types (depending on the size of the transformer - for larger sizes the difference decreases).

Adding an enclosure to a cast resin transformers adds 25% to 35% to the price, depending on the IP rating and the material.

At the same time, installation of oil immersed transformers often entails the installation of oil bunds or the outdoor enclosures to protect the oil bunds against the rainwater, and often fire walls and/or automatic fire extinguishing systems.

Therefore, the overall cost of the transformer and installation is comparable or less for cast resin type.

19) For new oil transformers, how long can they be in service before they need to have oil testing done? Assuming there are no issues, how often do they need to be tested after that?

Refer to the below extract from NHP/Trafo oil transformer manual for oil testing recommendations and other related checks:

Frequency	Interventio n
Every six months	Check and record the maximum oil temperature (if there is an oil thermometer)
Every six months	Check and record the variations in the oil level (if there is an indicator)
Every six months	Check and record the state of the overpressure valve
Every six months	Make sure there are no oil leaks
Every six months (for Conservator type)	Check silicagel breather and replace if necessary
Every 2 years (for Conservator type)	Collect and analyse an oil sample
Every 10 years (for Hermetically Sealed type)	Collect and analyse an oil sample

In addition to the above typical schedule, oil testing is recommended immediately after the transformer has experienced any abnormal events (overvoltage, short circuit trip on LV or HV side, significant overload etc). This would allow you to assess any possible damage done to the transformer and provide recommendations for rectification activities (e.g oil replacement etc).

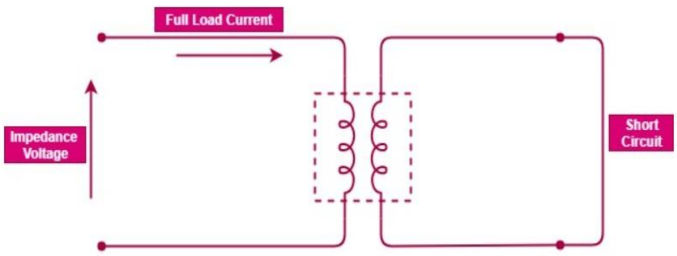
20) Could you explain the procedure to calculate the percentage impedance of a transformer, and why we need to know this?

The percentage impedance of a transformer is expressed as a percentage voltage drop, at full load, of the rated voltage. It is also the percentage of the rated voltage required to circulate full-load current under short circuit conditions. The percentage impedance can therefore be used to calculate the magnitude of prospective short circuit fault currents. For example, if the voltage impedance is 5%, under short circuit fault conditions the transformer can produce a prospective fault current of 20 x rated current.

Calculation of Percentage Impedance

In order to determine equivalent impedance, one winding of the transformer is short-circuited. And a just enough voltage is applied to the other winding to create full load current to flow in the short-circuited winding.

This voltage is known as the impedance voltage.



Percentage impedance of transformer testing

From a practical perspective this is how the test is conducted.

IEC 60076.5 recommends the following minimum values of S/C impedance:

Table 1 – Recognized minimum values of short-circuit impedance for transformers with two separate windings

Short-circuit impedance at rated current	
Rated power kVA	**Minimum short-circuit impedance** %
25 to 630	4,0
631 to 1 250	5,0
1 251 to 2 500	6,0
2 501 to 6 300	7,0
6 301 to 25 000	8,0
25 001 to 40 000	10,0
40 001 to 63 000	11,0
63 001 to 100 000	12,5
above 100 000	>12,5

NOTE 1 Values for rated power greater than 100 000 kVA are generally subject to agreement between manufacturer and purchaser.

NOTE 2 In the case of single-phase units connected to form a three-phase bank, the value of rated power applies to three-phase bank rating.

21) Can the transformer be disassembled to any degree to allow access to existing indoor areas?

Yes, under exceptional circumstances, dry type transformers can be disassembled and re-assembled at a site due to access issues. The windings can be separated from the core as these are the major components.

The level of disassembly will be on a case by case basis, based on egress and space available in the transformer room. If you would like to know more for your specific application, please reach out to your local NHP Account Representative.

22) I've been told that PD tests are not very effective at 3.3kV and lower. Is PD an effective test for an old dry 3.3kV to 415 tx? Other than clean and tighten, what other tests would you do on an aging dry tx?

PD at 3.3kV and below is unlikely and so effects on insulation life are negligible, so PD tests are not required at such voltages.

Using a megger to check the insulation integrity at these lower voltages would probably be the most practical test.