OLSUN Electrics
Engineered Transformer Solutions

Liquid vs Dry Type (VPI) Medium Voltage Transformers

Looking at the history of the development of Dry Type Medium Voltage Transformers they became increasingly specified in the late 1950's and early 1960's due primarily to the improved insulation systems (220° C) and acceptability of aluminum windings. Prior to the improvements in Dry Type Medium Voltage Transformer design, indoor installations were very often either Mineral Oil Filled which required a vault per NEC or PCB (Polychlorinated biphenyls) liquid filled transformers. The TSCA (Toxic Substance Control Act) of 1976 prohibited the manufacture of PCB's and also the phase out of existing uses (40 CFR Part 761). Due to a number of advantages Dry Type Medium Voltage Transformers became the preferred choice for most indoor and some outdoor installations.

As a result of the development of the "less Flammable" Liquid filled transformers, a comprehensive comparison between Liquid filled transformers and Dry Type Transformers seems to be in order.

This article will discuss the comparison of Liquid Filled Transformers and Dry Type (VPI) Medium Voltage Transformers. The topics discussed are as follows:

NEC (National Electric Code NFPA® 70) Installation requirements

Factory Mutual Global clearance requirements

Inspection and Testing prior to Energizing for the first time

Maintenance requirements

Fan Cooling capacity

Basic Impulse levels

Continuous overload capacity

Efficiency

Operating Life Expectancy

Dimensional Comparison

Pricing and lead time Comparison

NEC Installation Requirements

The installation requirements for Dry Type Medium Voltage Transformers per NEC (National Electric Code NFPA 70®) are summarized in Table I. Essentially there are very few restrictions regarding Medium Voltage Dry Type Transformers. However, proper clearances need to maintained around the Dry Type Transformer for cooling purposes and maintenance.

Indoor installations for Less Flammable liquid filled transformers (fire point not less than 300°C) have several options. Refer to Table I. The most common option for 35 KV or less, Less Flammable liquid filled transformers in TYPE I or TYPE II buildings requires a liquid confinement area and the installation must comply with the restrictions provided in the listing of the liquid.

Outdoor installations for Less Flammable liquid filed transformers are permitted attached to, adjacent to, or on the roof of Type I and TYPE II Non combustible buildings as long as they comply with the restrictions of the listing of the liquid. If the installation is a combustible building or combustible ®®materials are stored in the area then the installation would need to meet the requirements of Oil insulated transformers mounted outdoors per NEC Article 450.27.

Indoor installations of Oil insulated transformers would need to installed in a vault per NEC Part III of Article 450.

For Outdoor installations of Oil insulated transformers if a fire hazard is present, Space separations, Fire Resistant barriers Automatic fire suppression systems or Enclosures for confinement of the oil in case of a ruptured tank may be required depending on the degree of hazard.

Factory Mutual Insurance Company

FM Global publishes Property loss prevention recommendations. Property Loss Data sheets 5-4 covers the loss prevention recommendations related to fire protection of all transformers for large and critical distribution, power and specialty transformers. Recommended Minimum separation recommendations for Liquid insulated transformers are listed in Table II. In addition, refer to FM Global Data sheets 5-4 for loss preventive recommendations for electrical protection, electrical testing, maintenance and operation.

FM Approvals®" Approval Standard for **Less or Nonflammable Liquid insulated** Transformers" Class Number 3990 includes the following installations requirements.

Containment of the liquid is required for all indoor installations. For TYPE I and TYPE II Non combustible buildings the transformer needs to be mounted at least 3 ft. from building walls. For combustible buildings in addition to being mounted 3 ft. from walls an automatic fire suppression system must be provided or the transformer must be located in a 3 hour fire rated vault.

Outdoor installation of Less Flammable liquid filled transformers must be installed at least 3ft. from walls and 5 ft. from doors, fire escapes and windows. In addition, containment of the liquid is required for transformers containing 660 gal. or more of liquid.

Table I

NEC -2014 Installation Requirements

Type of Transformer	Indoor Installation	Outdoor Installation
Dry Type - over 112.5 KVA with insulation system of 155° or greater, completely enclosed except for ventilation openings and rated less than 35KV	Article 450.21 (B) Exception No. 2 No Restrictions	Article 450.22 No Restrictions
Less Flammable liquid Filled with fire point not less than 300° C	Article 450.23 (A) Indoor installations are permitted if in accordance with one of the following	Article 450.23 (B) Outdoor installations are permitted attached to, adjacent to,or on the roof of buildings where installed in accordance of (1) or (2)
	(1) In type I or Type II where all of the following are met; (a) Transformer is rated 35 KV or less (b) no combustible materials are stored (c) A liquid confinement area is provided (d) Installation complies with all restrictions provided in the listing of the liquid	(1) For Type I and Type II buildings installation shall comply with all restrictions provided for in the listing of the liquid *
	(2) Automatic Fire Extinguishing system and liquid confine ment area providing transformer is rated 35KV or less	(2) In accordance with 450.27 - Oil insulated Transformers Installed Outdoors
	(3) In accordance with 450.26 - Oil insulated Transformers installed Indoors	
Oil insulated Transformers	Article 450.26** Installed Indoors, Oil insulated transformers are to be installed in a vault per Part III of Article 450	Article 450.27 Combustible material, combustible building and parts of building, fire escapes, door openings and window openings shall be safeguarded from fires in oil insulated transformers installed on roofs, attached to or adjacent to a building or combutible material

*NEC 450.23 (B) (1) Informational Note: Installations adjacent to combustible material fire escapes, or door and window openings may require additional safeguards such as those listed in 450.27

* *Refer to NEC Section 450.26 exceptions 1 thru 6

References:

National Electric Code - NFPA -70 - 2014

Table II

Recommended Minimun Separation for Outdoor Liquid-insulated Transformers**

Fluid or Transformer Type	Fluid Volume (gal.)	Minimum Horizontal Distance from Containment to Exposed Build ing Wall		
		2-hour fire-rated wall (ft.)	Non-combustible wall (ft.)	Combustible Wall (ft.)
FM Approved transformer or equivalent	Per Approval listing	3		
FM Approved Liquid in Non-Approved transformer	≤ 10,000	5		25
Non-Approved transformer liquid	<500	5	15	25
	≤5,000	15	25	50

**For other options refer to Factory Mutual Global Prevention Data Sheets 5-4

References

Factory Mutual Global Property Loss Prevention Data Sheets 5-4

Installation Requirements

Mineral Oil filled transformers

The transformer must be mounted on a level pad and should not be tilted beyond two degrees from Horizontal. The ambient should not be below -20° C for Mineral Oil, - O°C for RTemp™ and -10° C for FR3™. Special procedures are required when energizing below -20°C.

Visually Inspect all seals, gaskets, gauges, bushing, etc. for liquid leaking. Leaks and/or improperly tightened gaskets or seals should be repaired prior to energizing the transformer.

Determine if liquid level is correct

Check pressure. The transformer may have a positive or negative pressure which is acceptable. Zero pressure could indicate a gas leak and should be investigated. A leak test may need to be preformed.

Recommended tests are insulation resistance (Megger test) and turns ratio test

In addition, Liquid samples should be taken per ASTM D923 and tested per ASTM D-877. If dielectric strength is below acceptable level liquid should be filtered.

Less Flammable Liquid filled Transformers

Same recommended installation requirements as for Mineral Oil filled transformer. Recommended tests for less flammable liquids include dielectric strength, moisture content and flash and fire points.

Dry Type Transformers

Visual inspection should be done to insure there has not been any damage to the internal components of the Dry Type transformer

Recommended tests prior to energizing a Dry Type Transformer are Insulation resistance (megger test), turns ratio test and applied potential test. .

References:

Cooper Power S210-15-10 Substation Transformer Installation, Operation and Maintenance Instructions

Howard Industries 2.4.126 Rev 2 Three Phase Pad Mounted Distribution Transformers

IEEE C57.106 Guide for Acceptance and Maintenance of Insulating Oil in Equipment

IEEE C57.93 Guide for installation of Liquid- Immersed Power Transformers

IEEE C57.94 Recommended Practice for Installation, Application, Operation , and Maintenance of Dry Type General Purpose Distribution and Power Transformers

Recommended Maintenance

Mineral Oil filled transformers

Inspect and tighten all bolted connections and check for leaks. Zero pressure could indicate a gas leak and should be investigated

Regularly inspect all gauges and liquid level. Check gaskets for deterioration and replace if necessary

Liquid samples should be taken periodically and tested per ASTM D-877. If dielectric strength is below acceptable level liquid should be filtered.

If spill should occur refer to applicable local, state and federal guidelines

Less Flammable Liquid filled Transformers

Same recommended maintenance as for Mineral Oil filled transformer. Recommended tests for less flammable liquids include dielectric strength, moisture content and flash and fire points

Dry Type Transformers

Visual inspection should be done at regular intervals. Frequency of inspection depends on the operating conditions.

Inspect for any accumulation of dirt, contamination or loose connections. The transformer windings can be cleaned using a vacuum cleaner, blower or compressed air.

References:

Cooper Power S210-15-10 Substation Transformer Installation, Operation and Maintenance Instructions

IEEE C57.106 Guide for Acceptance and Maintenance of Insulating Oil in Equipment

IEEE C57.94 Recommended Practice for Installation, Application, Operation , and Maintenance of Dry Type General Purpose Distribution and Power Transformers

Fan Cooling Capacity

The increase in KVA capacity for Dry Type Transformers when provided with Fan Cooling (AA/FA) is 33 1/3% for both Substation Type and Pad Mounted Dry Type Transformers. For Liquid filled Transformer the increase in capacity is only 15% for 750 KVA through 2000 KVA and only 25% for 2500 KVA through 10,000 KVA. Fan cooling is not available for liquid filled Pad Mounted transformers. Refer to Table III.

Basic Impulse Levels

We occasionally hear the statement liquid filled transformers have a higher BIL ratings than Dry Type Medium Voltage Transformers. It is true the IEEE standard BIL levels for Medium Voltage Dry Type Transformers are lower than the IEEE Standard BIL levels for Liquid Filled Transformers. However, the IEEE Standard C57.12.01 lists optional BIL levels for Medium Voltage Dry Types that are either equal to or exceed the BIL levels of Liquid Filled Transformers as listed in IEEE C57.12.00. Refer to Table V.

Continuous Overload Capability

When operated at rated load and with a rated winding temperature rise of 65°C liquid filled Transformers do not have any continuous overload capability without shortening its life expectancy. Likewise, Dry Type Medium Voltage Transformers (VPI) when operated at rated load and with a rated winding temperature rise of 150°C do not have any continuous overload capability without shortening its life expectancy.

However, a the Liquid filled transformer with a 120° insulation system and with a winding temperature rise of 55°C can be overloaded by 12% of it's KVA rating continuously without any shorting of it's life expectancy. Dry Type Transformers (VPI) with a 220°C insulation system and a winding temperature rise of 115°C can be overloaded continuously by 15% without any shortening of its life expectancy. With a winding temperature rise of 80°C rise and a 220°C insulation system a Dry Type Transformer (VPI) can be overloaded continuously by 30% without any shorting of life expectancy. Refer to Table IV.

For information on Short Time overload capability refer to IEEE C57.96 Guide for Loading Dry Type Transformers and IEEE C57.91 Guide for Loading Mineral Oil Filled Transformers.

Efficiency

For the most part, Liquid Filled Transformers have a higher efficiency than Dry Type Medium Voltage Transformers. Due to the liquid cooling medium the core and coil of the liquid filled transformer is smaller than the equivalent Dry Type Medium Voltage Transformer which relies on Air for its cooling medium. However, Dry Type Medium Voltage Transformers are very efficient electrical devices. The minimum efficiencies required by DOE 10 CFR 431 Part K are listed in table VI for several KVA sizes. Although the efficiencies of the Medium Voltage Dry Types are slightly less than the corresponding Liquid Filled Transformers, the efficiency of the Dry Type Medium Voltage Transformers listed in table VI exceeds 99%.

Table III

Fan Cooling Capacity

Transformer Type	KVA	Fan Cooling Rating
Dry Type - substation type	225 - 10,000	33 1/3 %
Dry Type -Pad Mount	225 - 5000	33 1/3 %
Less Flammiable liquid - substation type	500 and below	**Fan cooling Not available
	750 - 2000	15%
	2500 -5000	25%
Less Flammiable liquid - Pad Mount	Through 5000	**Fan Cooling not available
Oil Filled - substation type	500 and below	Fan Cooling Not available
	501 -2000	15%
	2501 - 10,000	25%
Oil Filled - Pad Mount	through 5000	Fan Cooling not available **

** If fan cooling is provided the Pad Mount Transformer is no longer tamper resistant

References

Dry type per C57.50 and C57.51

Liquid filled - Cooper Power CA202001EN and CA202003EN

TABLE IV

Continuous overload capability without shortening life expectancy

Transformer Type	Temperature rise	Insulation Class	% over nominal nameplate rating
Dry Type - substation type and Pad Mount	150° C	220°C	None
	115 °C	220°C	15%
	80°	220°C	30%
Liquid filled - Substation type and Pad Mount	55°	120°C*	12%
	65°	120°C*	None

References

Dry type per C57.50 and C57.51

Liquid filled - Cooper Power CA202001EN and CA202003EN

* 80°C Hot Spot + 40°C ambient 120°C

Table V

Basic Impulse Levels

Nominal L-L System Voltages	Dry Type Standard BIL (KV) per C57.12.01	Dry Type - Optional Rating (KV) per C57.12.01	Distribution Class - Liquid filled (KV) per C57.12.00
1.2	10	20 or 30	30
2.5	20	30 or 45	45
5	30	45 or 60	60
8.7	45	60 or 95	75
15	60	95 or 110	95
25	110	125 or 150	125 or 150
34.5	150	200	150 or 200

Referances:
IEEE C57.12.00
IEEE C57.12.01

Table VI

Minimum Efficiency at 50% load per DOE 10 CFR 431 -2016

KVA	Dry Type - three phase, 46-95 KV - Efficiency %	Liquid Filled - Efficiency %	% Difference
750	99.12	99.40	0.28
1500	99.30	99.48	0.18
2500	99.41	99.53	0.12

Life Expectancy

There have been various comments published regarding the " Normal" Life Expectancy of Liquid filled transformers vs. Dry type Medium Voltage Transformers (VPI). However, if Liquid Filled transformers and Dry Type transformers are operated under usual conditions per C57.12.00 and C57.12.01 the life expectancy from experience is estimated to be 20 years or more as indicated in IEEE C57.91 and IEEE C57.96.

Quoting from IEEE C57.91 Guide for loading Mineral Oil Filled Transformers and IEEE C57.96 Guide for Loading Dry Type Transformers "it is not possible to predict with any great degree of accuracy the length of life of a transformer even under constant or controlled conditions, much less under widely varying service conditions". Based on service conditions, both Liquid Filled Transformers and Dry Type Medium Voltage transformers have been known to operate successfully for over 40 years.

For Dry Type Medium Voltage Transformers (VPI) with a winding temperature rise of 80°C rise or 115°C in addition to having continuous overload capability as mentioned previously, the life expectancy is increased significantly compared to a 150°C rise design when operated at their rated temperature rise. . The insulation system of the VPI Dry Type is normally rated 220°C. The winding hot spot for a 150°C rise design over ambient is 180°C compared to at hot spot temperature of 140°C for a 115°C rise design and a hot spot temperature of 100°C for an 80°C rise design. Since the windings of the 115° C rise and 80° C designs are operated far below the temperature rating of the 220° C insulation system the life expectancy is increased significantly. One old rule of thumb was that the life expectancy was doubled for every 10°C below the rating of the insulation system.

For information on the effects of short time overloads, ambient temperature and altitude on life expectancy refer to IEEE C57.96 Guide for Loading Dry Type Transformers and C57.91 Guide for Loading Mineral Oil Filled Transformers.

Dimensions and Weights

Liquid filled transformers are generally heavier and require more space than a Medium Voltage (VPI) Dry Type. It is true that the foot print of a Liquid filled transformer is less than a Medium Voltage Dry Type. However, if we take into consideration of the radiators and Primary and secondary flange ends the space required for the Liquid filled transformer is much greater than a Medium Voltage Dry Type. A typical 1500 KVA Liquid filled Substation Style has a base foot print of 67" wide by 35" deep. If we include the space required for the primary and secondary flange ends the width becomes 76" and the depth becomes 80" when including the dimensions required for the radiators. This compares to 78" wide and 48" deep for the Medium Voltage Dry Type. The space required for the Liquid filled transformer becomes 42.2 sq. ft. vs. 26 sq. ft. for the Dry Type Medium Voltage transformer. Refer to table VIII.

The dimensions and weights of the liquid filled transformers can also be impacted by the accessories or liquid containment requirements.

Table VIII

Substation Style - Primary and Secondary bussed to opposite ends

	Height (in.)	Width (in.)	Depth (in.)	Approx. Weight (lbs.)	Floor Space Required (Sq. ft.)
Liquid Filled- 55/65° C Rise, 15 KV Class, Aluminum windings					
750	83	68	60	7200	28.3
1500	83	76	80	10100	42.2
2500	93	84	92	15300	53.7

Height includes pressure relief Device
Width includes Primary flange and secondary throat
Depth includes cooling radiators

Dry Type 15KV Class, 95 KV BIL, 150° Rise, Aluminum windings, NEMA 1, DOE 2016					
750	90	72*	48	5500	24
1500	90	78*	48	8200	26
2500	106	86*	54	12000	32.3

*Primary flange and secondary throat are not required for a Dry Type

Pad Mounted Tamper-resistant

Liquid Filled- 55/65° C Rise, 15 KV Class, Aluminum windings				
750	64	89	57	6500
1500	73	89	86	10300
2500	73	72	99	14500

Dry Type 15KV Class, 95 KV BIL, 150° Rise, Aluminum windings, NEMA 3R, DOE 2016				
750	86	78	78	6300
1500	90	88	78	9000
2500	106	92	84	13000

References:

Liquid Filled - Cooper Power - CA202001EN and CA202003EN
Dry Type - Olsun Electrics standard dimensions and weights

Conclusion

The selection of the type of transformer to be specified needs to take into consideration many factors. These factors were outlined previously and are intended to assist in the selection process of the type of transformer to be specified. Dry Type Medium Voltage Transformers are the obvious choice for indoor applications and for many outdoor applications. The lack of a fire hazard, less floor space required, less installation issues, less maintenance requirements and no possibility of liquid leaking into the environment are the obvious advantages. The Dry Type Transformer internal connections and coils and be easily inspected by removing a few panels. The inspection of the internal connections of a liquid filled transformer is not generally possible since the liquid filled tank is sealed and pressurized. Samples of the liquid must be taken and analyzed by testing per applicable standards to determine the condition of the liquid.

Liquid filled transformers have the disadvantage of increased possibility of leaks and/ or replacement of gaskets which can be costly and may require significant down time. Accessories and or additional components can not only increase the cost of the Liquid filled transformer but can also increase the possibility of leaks or gaskets needing to be replaced. Special considerations may be necessary when shipping and installing a Liquid Filled transformer. The forces the transformer tank experiences during shipment and installation may affect the welds of the tank or the condition of the radiators. If a leak is detected, depending on the location of the leak, it may be difficult or impossible to repair at the installation location.

This article is not intended to be used as a guide for installation and/or maintenance of Dry Type Medium Voltage Transformers and Liquid Filled Transformers. Refer to the applicable National Electric Code requirements, Factory Mutual Insurance Co. recommendations and applicable IEEE/ANSI standards.