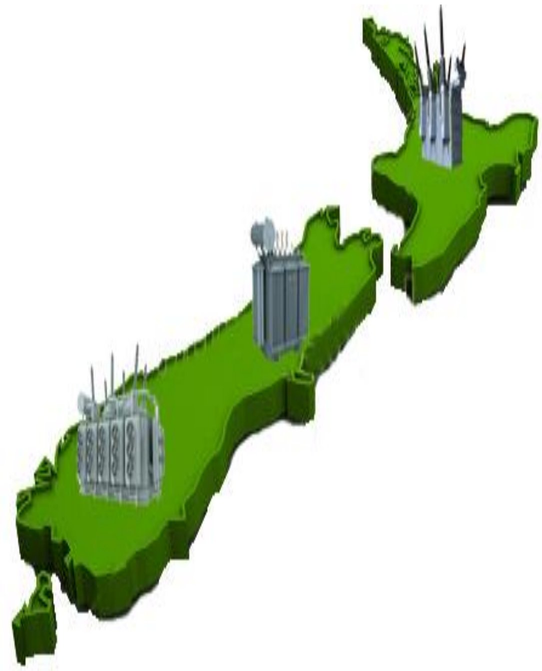
Power Transformers in New Zealand: A Review of Current Fleet Age, Asset Management Strategies and Procurement Practices



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EEA Conference & Exhibition 2014, 18-20 June, Auckland

Abstract

It is widely accepted that the average age of power transformers in New Zealand is higher than those in the international comparators. Based on this, the questions that have to be asked are:

- what are the demographics or statistical distribution of the transformer fleet age;
- what maintenance activities are being undertaking on these assets;
- what are the common trends with transformer defects;
- what transformer procurement practices are being followed;
- what transformer monitoring practices are being embraced;
- what will New Zealand transformer fleet potentially look like in the next 10 or 15 years.

This paper attempts to respond to these important questions so that asset owners of power transformers in New Zealand have a snapshot of present transformer life cycle practices.

Information used in this paper is either available on public domain or in most cases has been supplied by the asset owner(s) in confidence. As in-service transformer fleet carries commercial sensitivity, details on location, manufacturer, and in some cases ratings of transformer are not disclosed.

It is anticipated that the content from this paper will be referenced by asset owners of power transformers in New Zealand to benchmark its assets against overall demographics and identify trends in power transformer procurements. Manufacturers of power transformers and refurbishment contractors can use this information to prepare themselves for servicing New Zealand’s power transformer industry.

1. Introduction

This paper reviews the life cycle of power transformers in New Zealand power generation, transmission and distribution network applications. As various drivers influence operating parameters in these sectors it is not reasonable to combine or compare practices between these sectors. As a result, generator step up transformers, transmission (supply and interconnecting transformers), and network transformers are analysed independently.

The paper places additional focus on generator step up transformers, as content relating to these transformers has not been published in this detail previously. Conversely information on supply and interconnecting transformers relating to a single entity and has been published recently and is therefore is not repeated [1]. Information relating to network transformers has been extracted from various sources including asset management plans.

A number of power transformer applications have not been included in this study: a detailed list of all exclusions and assumptions are listed in Appendix A1.

2. New Zealand's Power Transformer Fleet

New Zealand has approximately 1,650 in-service power transformers[1]. The largest proportion of the power transformers is in the 41-50 year range, and then closely followed by the 0-10 year range.

Approximately 13% of the total power transformer population is over 50 years old.

Out of the three electricity sectors utilising power transformers, the largest percentage of the total transformer fleet is from the network utilities.

The nominal power rating of the power transformers varies from 0.5 to 485MVA.

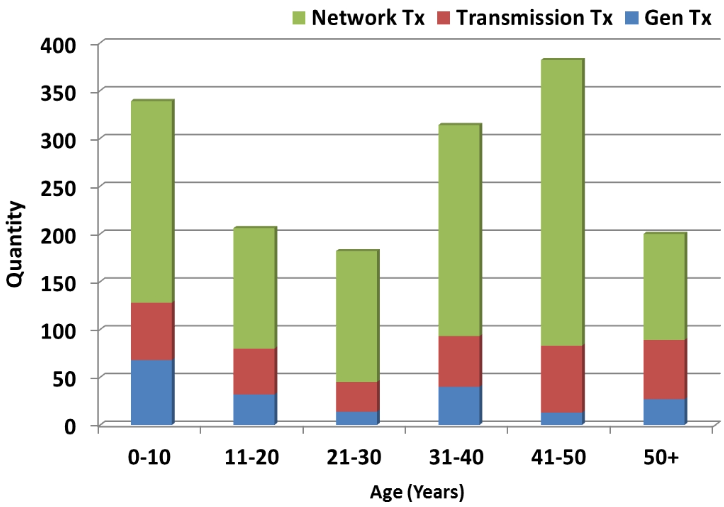


Figure 1: Age distribution of power transformers in New Zealand

3. Generator Step-Up Transformers

3.1 *Fleet – Age, Size, and Composition*

194 in-service generator transformers[1] from a large pool of generator utilities is analysed. The generator transformer fleet is diverse in terms of transformer rated power, voltages (h.v. - 220, 110, 66, 33 and 11kV), vector group, cooling classes and the number of manufacturers.

About 35% of the total generator transformer fleet is aged less than 10 years, while 13% of the total transformer fleet is aged above 50 years.

The average age of 220kV and 110kV generator transformers is 25 years[2].

About 85% of the total generator transformer fleet have a rating less than 100MVA, suggesting that New Zealand has a large number of smaller sized generator transformers.

The average MVA size of 220kV generator transformers[2] is 95MVA, and it is 42MVA for 110kV generator transformers[2].

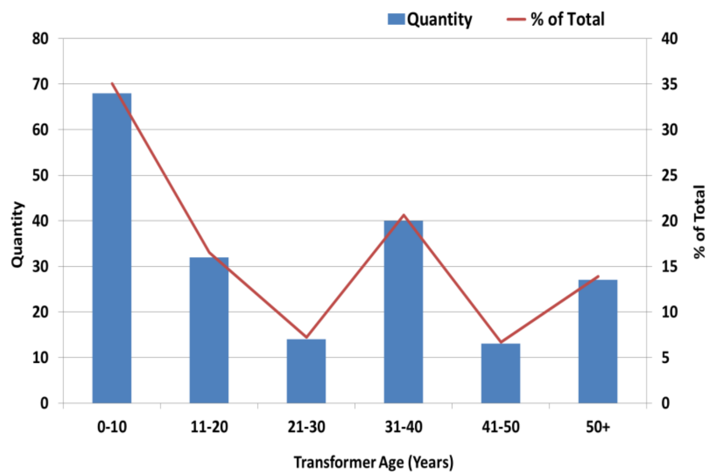


Figure 2: Age distribution of generator transformers

[1] Refer Appendix A1 for details on definitions applied, assumptions and exclusions.
[2] Refer Appendix A2 for details on 220kV and 110kV generator transformer age distribution.

The combined MVA of all generator transformers is approximately 11,270MVA. Details of MVA and transformer quantities are noted in Figure 3.

The generator transformer fleet originates from 22 transformer manufacturers[3].

15% of the generator transformer fleet comprises of single-phase transformer banks[3], whilst remaining 85% consists of three phase transformers.

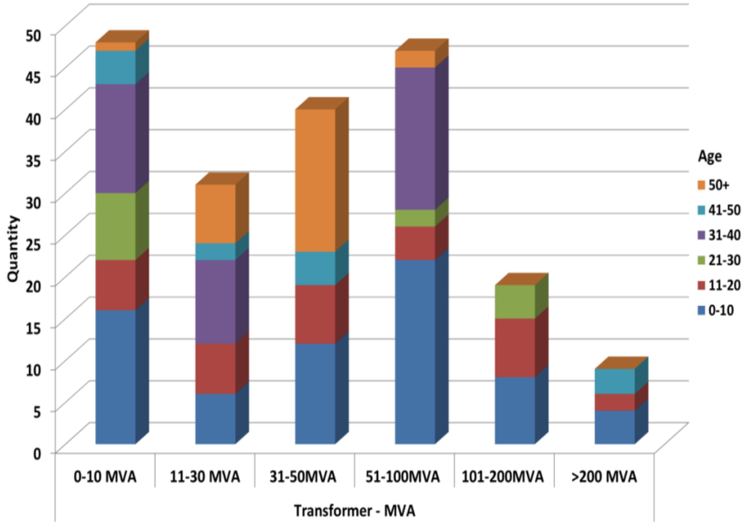


Figure 3: Rated MVA of generator transformers[2]

33% of the total generator transformers have on-load tap changers, while 43% and 37% of the 220kV and 110kV generator transformers respectively have on-load tap changers[4].

A large proportion of 220kV generator transformers have oil directed, water forced cooling, while the oil natural, air natural is the most preferred cooling class for 110kV generator transformers. Refer Appendix A4 for breakdown of cooling class details.

3.2 *Online Monitoring Systems*

A large number of generator transformers have top oil and calculated winding temperature monitoring.

44% of 220kV generator transformers have online gas-in-oil monitoring. A similar percentage is noted on 110kV generator transformers. Analysis into type of monitoring, i.e. detection or diagnostic type is not carried out.

Possible reasons for high numbers of transformers with online monitoring are:

(a) Higher risk adverse nature of the power generation industry on managing service-aged assets with incipient faults.
(b) The cost of online monitoring has reduced significantly over the years.
(c) Gas in oil monitors can be installed with the transformers in-service.
(d) Recent transformer procurements have specified online gas-in-oil monitoring.

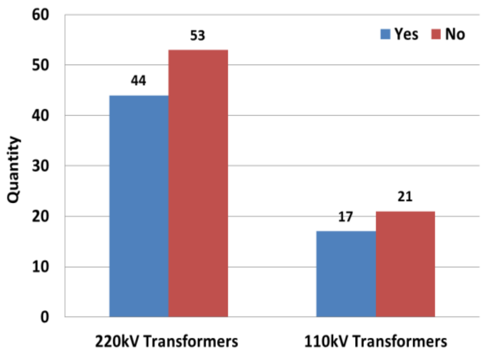


Figure 4: Generator transformers with gas in oil monitoring

[3] Refer Appendix A3 for details on number of transformer manufacturers, single and three phase transformers.
[4] Refer Appendix A4 for on-load tap changer and cooling class details.

Only 17 (220kV) and 7 (110kV) generator transformers have embedded fibre optics[5] for winding hot spot temperature monitoring. The inability of adding fibre optics to an in-service transformer may be one reason for the low numbers. Mid-life refurbishment presents an opportunity to monitor critical areas in the transformer assembly.

Only 1 generator transformer has online partial discharge and bushing health monitoring system. A low number suggests that asset owners are relying on other traditional methods such as dissolved gas analysis and acoustic testing for partial discharge monitoring.

3.3 Asset Management Practices

3.3.1 In-Service Equipment Defects

Commonly noted defects with in-service generator transformers, in order of occurrence:

(a) Ancillary equipment failures, includes oil - water flow switches, oil level indicators, cooling fans and oil pump motors control equipment, and water ingress in terminal boxes;
(b) Oil leaks due to gasket sealing issues;
(c) Incipient faults associated with transformer main tank equipment and off-circuit tap changers.

3.3.2 Spare Transformer Fleet

New Zealand has 12 spare three-phase generator transformers that are a direct replacement for in-service transformers. 3 of the 12 have a h.v. of 33kV, 2 of 110kV, while the remaining 7 have h.v. of 220kV.

None of the spare three-phase transformers were purchased after site construction as a risk mitigation measure.

Asset owners of generator transformers may need to re-consider their three-phase spare transformer strategies, particularly with assets above 50MVA rating where a greater risk to revenue may be present.

New Zealand has 23 spare single-phase generator transformers.

A large proportion of the single-phase transformers are old in-service transformers that have been replaced with modern three-phase equivalents. The single-phase transformers are held as emergency spares for the remaining in-service transformers.

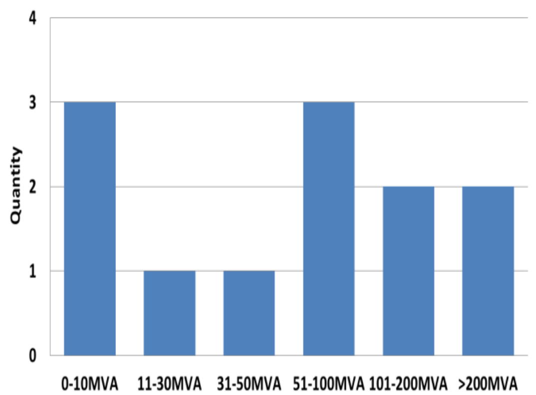


Figure 5: Spare three-phase generator transformers in New Zealand

[5] Refer Appendix A5 for details on generator transformers with fibre-optic monitoring.

Transformer Refurbishments (Future)

Mid-life refurbishments on generator transformers are generally only implemented based on evaluation of remnant life assessments. It is estimated that less than 10 mid-life refurbishments have been carried out on generator transformers in past 5 years.

Six (6), 220kV generator transformers are in the 21-30 year range; mid-life refurbishments for these transformers may need to be considered by the asset owners.

3.3.4 Transformer Replacements (Future)

27 of the 194 generator transformers have a service age of > 50 years. 19 of these 27 are 220kV transformers, while 7 are 110kV transformers. Replacement for these assets may need to be planned in the upcoming years.

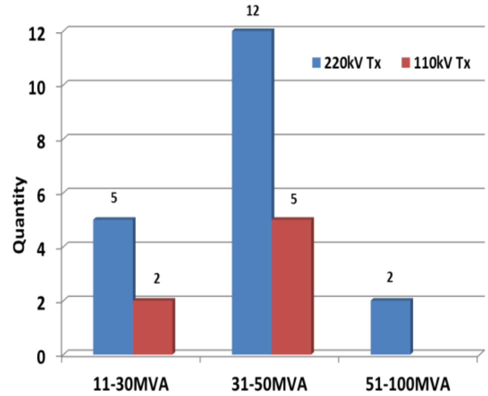


Figure 6: 220kV and 110kV transformers with a service age of >50 years

3.3.5 Transformer Replacement: Reasons

Only 2 of the 27 generator transformers (220 and 110kV) procured in the past 5 years [2009-13] were due to failure of in-service transformers. These failures were at two separate locations.

A large number of procurements were driven by condition assessments.

The numbers suggest that procurement of new transformers is as part of proactive asset replacements and not due to failure of in-service transformers.

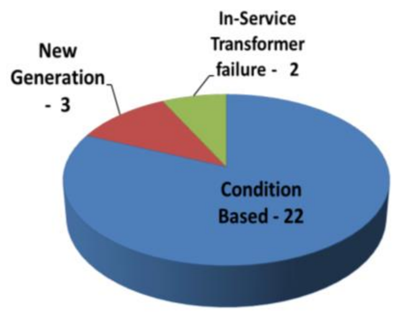


Figure 7: Reasons for generator transformer procurements in past 5 years

4. Transmission Transformers

4.1 Fleet – Age, Size, and Composition

Recently published document notes that 352 transformers (supply, interconnecting, and traction) are in-service [1]. The average age of these transformers is approximately 31 years.

40% of the transformers are 220kV transformers, 48% are 110kV transformers, while the remaining 11% are 66kV and below.

4.2 Online Monitoring Systems

Online gas-in-oil monitors are proposed to be installed on transformers with known issues [1]. It is understood that around 30 procured transformers have online gas-in-oil monitoring. Online gas-in-oil monitoring will be installed on all power transformers procured with a criticality rating of 'high' [1].

Fibre optics are embedded in a number of recently procured transformers, however, there are only limited number of fibre optic temperature monitors.

4.3 Asset Management Practice

4.3.1 In-Service Equipment Defects

Tap changers and bushings on aged single-phase transformers are a particular cause of unreliability. Details of further defects and mitigation measures are in [1].

4.4 Recent Procurements

125 transformers have been purchased since 1992 [1]. A panel contract arrangement is in place with a number of transformer suppliers [2]. 30 aged and high-risk power transformers are scheduled for replacement between July 2015 and June 2020 [1, 2, 3].

5. Network Transformers

5.1 Fleet – Age, Size, and Composition

1105 network transformers from 24 electricity networks are analysed. Refer Appendix A1 for details on assumptions and exclusions.

The average age of 1105 network transformers from 24 electricity networks is 31years[1].

2 network utilities dominate the transformer fleet numbers with a total of 385 out of 1105 transformers, or 34% amongst the two network utilities.

27% of the transformer fleet lies in the 41-50 years age range.

The oldest in-service transformer(s) is 77 years old.

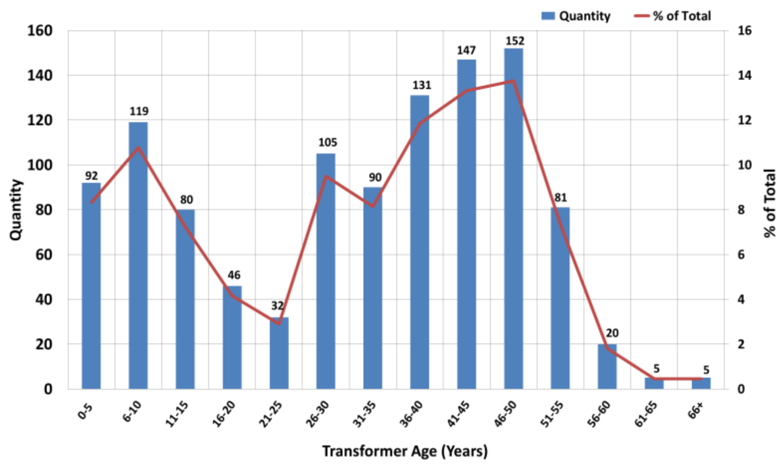


Figure 8: Age profile of 1105 transformers owned by network utilities

[1] Refer Appendix A1 for details on definitions applied, assumptions and exclusions.

5.2 *Online Monitoring Systems*

Not all of the network transformers have remote indication of top oil temperatures. A number of utilities are establishing remote indications of top oil temperatures and using this information for transformer loading purposes.

Only a limited number of network transformers have online gas in oil monitoring. A leading supplier of online gas in oil monitors in New Zealand estimates this number to be less than 10.

5.3 Asset Management Practices

5.3.1 In-Service Equipment Defects

On-load tap changers

On-load tap changer related defects appear to be a common feature on network transformers. Specific issues relate to mechanical problems, worn contacts, corrosion on contacts and failures from excessive carbon deposits in tap changer compartment.

Oil Leaks and Tank – External

Oil leaks are a primary concern for many utilities. Premature failure of protective coating systems or in proximity to coastal environment has led to tank corrosion. Excessive rust on radiators, both internal and external is experienced on a number of transformers. It is also noted that oil containment systems are not in place on a number of transformers.

Other Practices

High hydrogen concentrations due to galvanising in tank reacting with oil has been noted in some recent purchases. Buchholz relay with mercury switches and replacement of old dehydrating breathers are being undertaken by some utilities.

5.3.2 Asset - Service Expectation

111 transformers are aged above 50 years; four network utilities comprise nearly half of these numbers.

It is evident from asset management plans that the network owner has an expectation that the transformer will deliver a service age of 50 years, or in some cases, a life expectancy of 70 years is anticipated.

The impact of operating transformers beyond its designed life is not investigated.

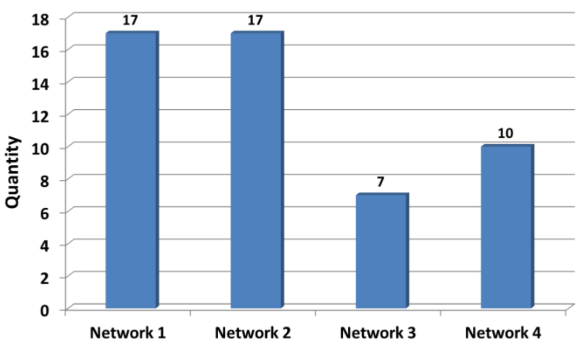


Figure 9: Transformers age > 50 years from a number of utilities

5.3.3 Recent Procurements

Four (4) network utilities make up more than half of 92 transformers procured in the past 5 years. Procurements from a previous 6-10 year period for the same four networks is also compared.

18 of the 24 networks analysed in the past 5 years procured transformers.

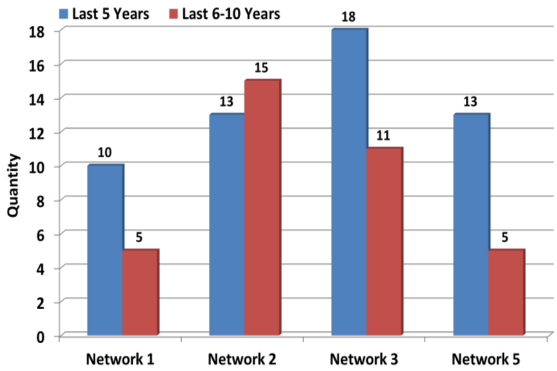


Figure 10: Transformers procurements in past 10 years[6,7]

6. New Zealand Power Transformers – Maintenance Gaps Identified

Maintenance activities undertaken by asset owners of power transformers in New Zealand are evaluated against guidelines in international publications [4, 5, and 6]; identified gaps are:

6.1 On-load Tap Changer Diagnostic Tools

On-load tap changer appear to be the prominent source of defects associated with power transformers in transmission and network sector.

Use of vibro-acoustics for on-load tap changer condition monitoring [4] is a tool that is not included in maintenance strategies. Asset owners may need to consider use of this technology.

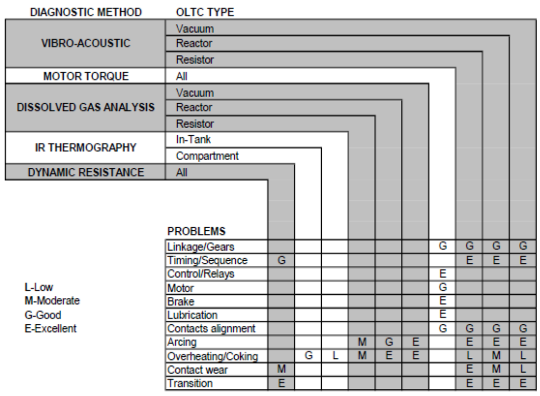


Figure 11: On-load tap changer diagnostic tests [4]

Use of motor torque sensor and differential temperature monitoring are effective tap changer monitoring tools [4, 5]; but haven't been widely used in New Zealand.

6.2 Ancillary Equipment Checks

Checks on ancillary cooling equipment such as oil pumps and fans was not included in most asset maintenance plans. Experience shows that these rotating machines require periodic maintenance checks [4].

6.3 Diagnostic Testing

A number of electrical diagnostic tests were not included in a number of asset management plans; these tests include transformer and bushing polarisation depolarisation current/frequency domain spectroscopy, frequency response of stray losses and dynamic winding resistance tests.

[6] Assumes that all transformers in 0-10 year band are procured by 24 network utilities.
[7] For clarity, networks 1-3 are same as those mentioned in Figure 9.

7. Procurement Practices

New Zealand has purchased 155 power transformers in past 5 years[8,9]. This equates to about 31 transformers a year.

Nearly 60% of the replacement transformers are from the network sector, while generator and transmission- supply and interconnector transformers each contribute to about 20% of total numbers.

As only information relating to generator transformers is known, these procurements are discussed in a case study.

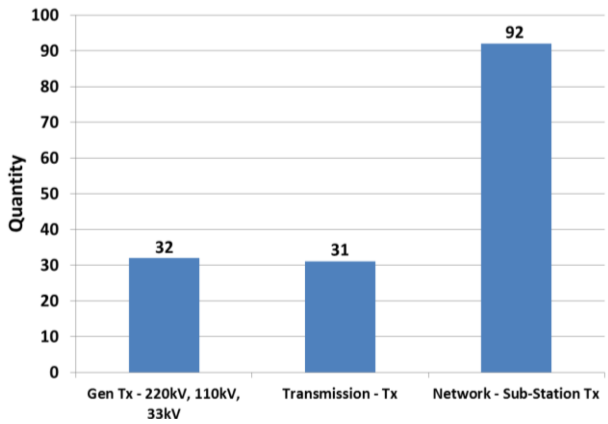


Figure 12: Transformer procurements in past 5 years

7.1 Case Study: Generator Transformer Procurement

Of the 32 generator transformers, 25 have a h.v. of 220kV, 2 of 110kV and remaining 5 with a h.v. of 33kV.

27 generator transformers with h.v. of 220kV or 110kV have been purchased by asset owners in the past 5 years [2009-13]. This number is expressed as a three-phase bank.

The rating of 27, 220kV and 110kV transformers varies from 28MVA to 225MVA, with the average size of 27 transformers being 74MVA.

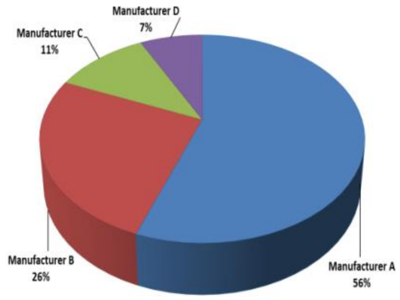


Figure 13: Manufacturers of generator transformers from past 5 years.

Only 2 single-phase banks (i.e. 6 single-phase transformers) were procured in past 5 years.

The 27 generator transformers have been procured from 4 transformer manufacturers; all of these manufacturers are reputable suppliers.

15 of the 27 transformers had oil directed, water forced (ODWF) cooling. A large proportion of OD, and WF cooling possibly presents an opportunity to rationalise on the oil pumps, oil flow switches, and oil-water heat exchangers for any future procurements.

All 27 transformers have on-load tap changers.

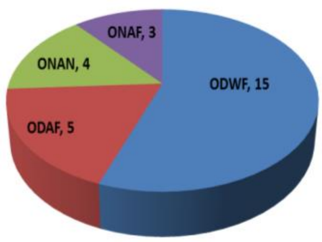


Figure 14: Cooling class of recent generator transformers purchases

[8] Assumes that all transformers in 0-5 year band are procured by network utilities.
[9] Transmission transformer numbers are calculated based on data in [1].

25 of the 27 transformers have online gas in oil monitoring; a high proportion suggests that asset owners of generator transformers prefer early detection of incipient faults.

Embedded fibre-optics for winding hot spot monitoring has moderate numbers; 16 of the 27 transformers have fibre optics. Only 1 of 27 transformers has online partial discharge and bushing health monitoring system.

7.1.1 Design Review and Quality Audits

17 procurement contracts[10] were used for purchasing 27 generator transformers. A detailed design review was carried out on 16 contracts, indicating asset owner's desire of ensuring that manufacturer understands specification deliverables and technical compliance to international standards.

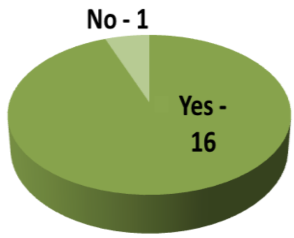


Figure 15: Number of transformer procurement contracts with design review undertaken

A quality assurance audit during transformer manufacturing was only carried out on 6 of the 17 procurement contracts. Possible reason for low numbers may be project budget constraints, lack of understanding on checks that need to be undertaken, or having adequate confidence in an established manufacturer.

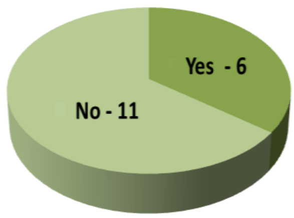


Figure 16: Number of transformer procurement contracts with quality audits completed

The asset owner or its representatives witnessed factory acceptance testing for all 17 procurement contracts.

8. What Does the Future Hold

Approximately 200 power transformers have a service age of above 50 years; majority of these are in the network utility sector.

With an average of approximately 20 transformers (based on past 15 years data) procured each year by the network utility sector, it is likely that a number of these service aged transformers may be replaced within the next 10 year timeframe.

Asset management plans from network utilities suggest that a large number of transformer replacements are driven by network developments as compared to transformer condition assessments.

30 aged and high-risk transmission transformers are scheduled for replacement within next 5 years (2015-2020) [1].

Description	Qty above 50 years
Generator Transformers	27
Transmission Transformers	74
Network Transformers	111
Total	**212**

Table 1: Quantity of transformers above 50 years

[10] Assumes that a procurement contract was established for procurement of transformer(s) at respective site.

40 generator transformers are aged above 40 years[11]. The rated power of these vary from 0.5MVA to 300MVA. With an average of approximately 6 transformer purchases a year, it is likely a number of replacements may occur over the next 6-8 years.

A capital of $106.2m is forecasted for replacement of 30 aged and high-risk transmission transformers [1, 2, 3]. The cost of generator transformer varies with the MVA rating[12]. Based on the projected number of generator transformer replacements, an estimated capital of $24m-51m[12] is required for these replacements.

With a number of transformer replacements forecasted for next 6-8 years, an estimated representation of present and future transformer demographics is shown.

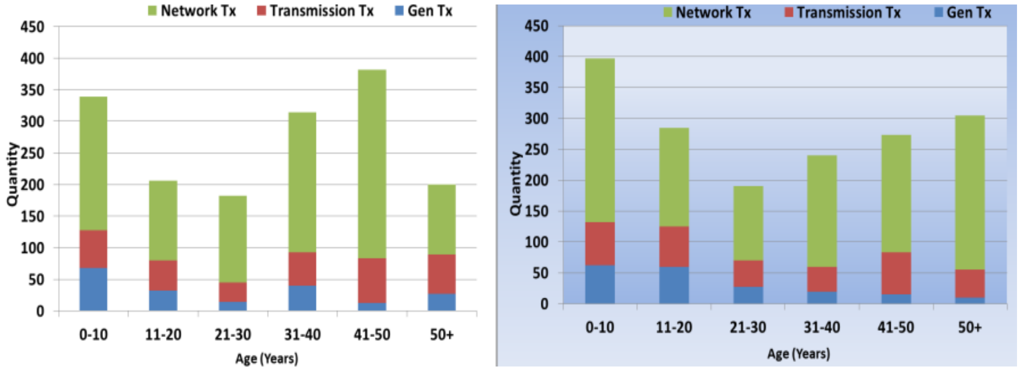


Figure 17: Power transformer age distribution in New Zealand: Present (L) and Estimated representation in next 6-8 years (R)

A number of transformer replacements in the upcoming years present an opportunity for asset owners of power transformers in New Zealand to standardise as much as practicably feasible on the following:

(a) Technical specifications, including specified standards, design review deliverables, ancillary equipment, factory and site acceptance tests, and;
(b) Number of manufacturers and factories utilised for purchasing transformers.

[11] Refer Appendix A6 for details on generator transformers above 40 years of age.
[12] Refer Appendix A6 for details on estimated generator transformer replacements and cost estimates.

9. References

[1] Transpower TP.FS.20.01, ACS Power Transformers Fleet Strategy, November 2013.

[2] Transpower Procurement Methodologies for Identified Work Programmes, 01 October 2013.

[3] Transpower Expenditure Proposal, Regulatory Control Period 2, December 2013.

[4] CIGRE Brochure 445, Guide for Transformer Maintenance, WG A2.34, February 2011.

[5] IEEE C57.143-2012, Guide for Application of Monitoring Equipment to Liquid-Immersed Transformers and Components.

[6] IEEE C57.93 – 2007, Guide for Installation and Maintenance of Liquid-Immersed Power Transformers.

[7] Large Power Transformers and The U.S. Electric Grid, U.S. Department of Energy, April 2014.

Appendix- A1: Power Transformers- Definition, Assumptions, and Exclusions

Inclusions and Notes:

Generator Transformers

(a) The in-service generator transformers includes data from a pool of large and small generation utilities in New Zealand.
(b) The h.v. of generator transformers include 220kV, 110kV, 66kV, 33kV and 11kV.
(c) A number of GXP transformers owned by a generation utility are included.
(d) No specific attention is placed if the transformer is grid connected or associated with embedded generation.
(e) Where the actual transformer manufacturing date is not known, the later date of machine site commissioning has been used.
(f) Calendar year – 2014 has been used for calculating the transformer age.
(g) If the transformer has multiple power ratings, the highest MVA rating is used.
(h) A bank of three, single-phase phase is considered as a single entity.

Transmission Transformers

(a) Transmission transformers include supply, interconnecting, and traction transformers referenced in [1].
(b) Transformer average age is calculated based on data in [1].

Network Transformers

(a) Network transformers primarily include zone-substation transformers.
(b) Where the network owns the GXP transformer, information on this transformer is included.
(c) A total of 1105 sub-station transformers from 24 electricity networks is analysed.
(d) 2 networks that do not have any zone sub-station transformers have not been included; whilst data from 2 other networks was incomplete or required further clarification and is not included.
(e) Out of the 24 networks, clarifications were asked and provided by a number of network utilities.
(f) Transformer data in network utility's 2013-asset management plan is used.
(g) Calendar year – 2013 is used for calculating the transformer age.

Exclusions: The following transformers are not included in the study:

(a) Power transformers installed at large electricity consumer facilities;
(b) Distribution transformers (11kV/415V) owned by network utilities;
(c) Voltage regulators;
(d) Station supply transformers located at power generating stations;
(e) Individual wind turbine's step up transformer.

Appendix- A2: 220kV and 110kV Generator Transformer Distribution

Generator Transformer Fleet: Age and MVA distribution of 194 in-service generator transformers is shown in Table A2(i) below:

Transformer Age (Years)	Transformer – MVA Range					
	0-10 MVA	11-30 MVA	31-50 MVA	51-100 MVA	101-200 MVA	>200 MVA
0-10	16	6	12	22	8	4
11-20	6	6	7	4	7	2
21-30	8	0	0	2	4	0
31-40	13	10	0	17	0	0
41-50	4	2	4	0	0	3
50+	1	7	17	2	0	0

Table A2 (i): Age and MVA distribution of in-service generator transformers

220kV Generator Transformers:

97 generator transformers have a h.v. rating of 220kV, while 38 transformers have a h.v. rating of 110kV. 2 transformers have a selectable dual h.v. configuration of 220-110/11kV. These 2 transformers are included in both 220kV and 110kV transformer numbers. Details are below.

Transformer Age (Years)	Transformer- MVA Range						
	0-10 MVA	11-30 MVA	31-50 MVA	51-100 MVA	101-200 MVA	>200 MVA	*Total Number*
0-10	0	1	10	15	8	4	38
11-20	0	0	1	2	7	2	12
21-30	0	0	0	2	4	0	6
31-40	0	0	0	17	0	0	17
41-50	0	0	2	0	0	3	5
50+	0	5	12	2	0	0	19

Table A2 (ii): Age and MVA distribution of 220kV generator transformers

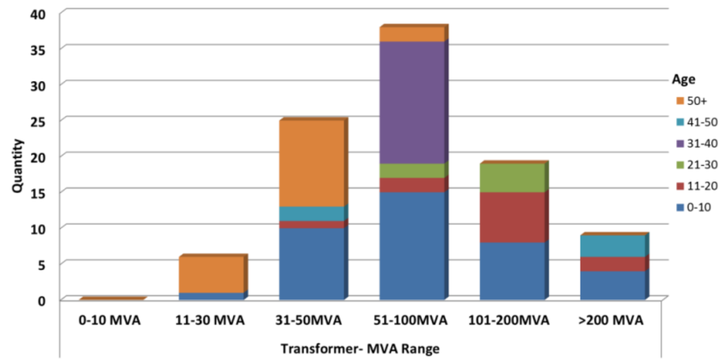


Figure A2 (i): Rated MVA of 220kV generator transformers

Transformer Age (Years)	Transformer – MVA Range				
	0-10 MVA	11-30 MVA	31-50 MVA	51-100 MVA	*Total Number*
0-10	2	5	1	7	15
11-20	0	4	0	3	7
21-30	0	0	0	0	0
31-40	0	5	0	0	5
41-50	0	2	2	0	4
50+	0	2	5	0	7

Table A2 (iii): Age and MVA distribution of 110kV generator transformers

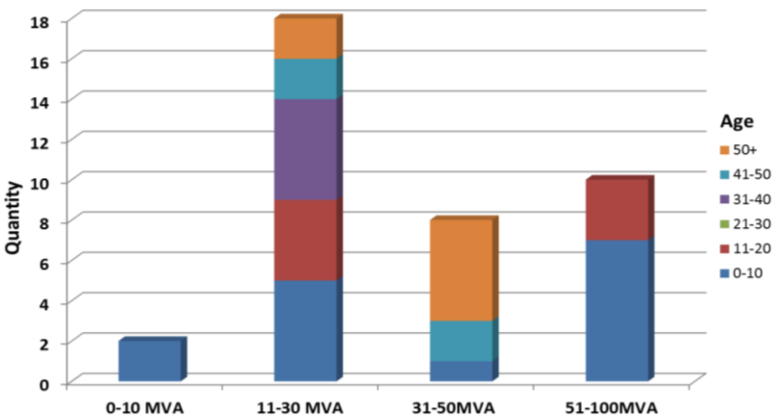


Figure A2 (ii): Rated MVA of 110kV generator transformers

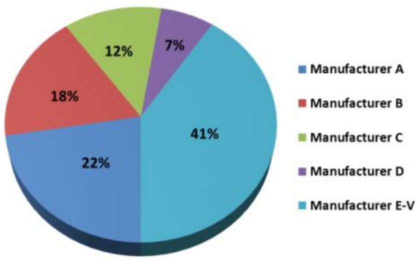
Appendix- A3: Number of Generator Transformer Manufacturers and Single/Three Phase Configuration

Number of Generator Transformer Manufacturers

The generator transformer fleet originates from a total of 22 transformer manufacturers.

Over the years, Manufacturer A has amalgamated with a number of transformer manufacturers to form a single entity; therefore, this entity is considered as a single manufacturer.

Four key transformer manufacturers dominate the generator transformer market share with a total of 58% among the four manufacturers. It is fortunate that all four manufacturers are still in the production business.



	Number of Transformers	MVA Range	%
Manufacturer A	43	0.5-140	22.16
Manufacturer B	34	10-225	17.53
Manufacturer C	24	2-300	12.37
Manufacturer D	13	3-100	6.70
Manufacturer E-V	80		41.24

Figure A3 (i): Market share of key transformer manufacturers.

Manufacturer A- D are 4 key suppliers, whilst remaining 18 (total of 22) manufacturers are grouped in Manufacturer E-V category.

Single and Three Phase Configuration

164 out of the 194 generator transformers are of three-phase configuration whilst the remaining 30 transformers consist of single-phase banks (i.e. 90 single-phase transformers in total). Almost all of the single-phase transformers are located at hydroelectric power stations.

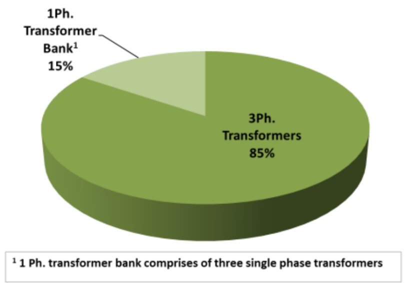


Figure A3 (ii): Single and three-phase transformer configurations

Appendix- A4: Generator Transformers - On-Load Tap Changer and Cooling Class Details

On-load Tap Changers

Out of the 194 generator transformers, details on type of tap changer on one 220kV transformer is not known, therefore, a sample size of 193 transformers is used.

Only 33% of the total transformer numbers have on-load tap changers, while 43% and 37% of the 220kV and 110kV transformers have on-load tap changers.

The Electricity Industry Participation Code (EIPC) rules may require use of on-load tap changer when replacing generator transformers. In some cases, on-load tap changers are installed on new generator transformers when no changes to the off-circuit tap changer position was carried out on the previous transformer in its entire service life.

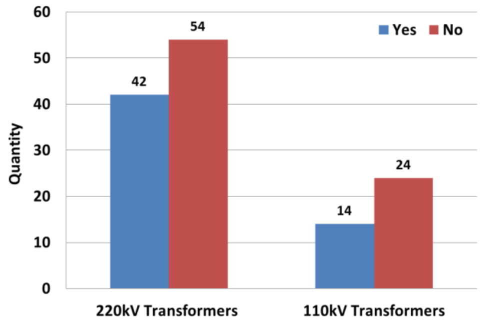


Figure A4 (i): Generator transformers with on-load tap changers

Cooling Class

Out of the 97 generator transformers (220kV), the cooling class on 4 of these transformers is not known. 58 transformers (62%) are of oil directed, water forced (ODWF) cooling class, while oil directed, air forced (ODAF) follows with 15 transformers (16%). Oil natural, air forced (ONAF) appears to be the least preferred cooling class with a total of only 4 transformers with this arrangement.

When considering replacement transformers, asset owners of 220kV generator transformers may need to consider alternative water forced cooling in order to reduce the environmental risk of possible oil-water interface. This is particularly applicable to hydroelectric power stations.

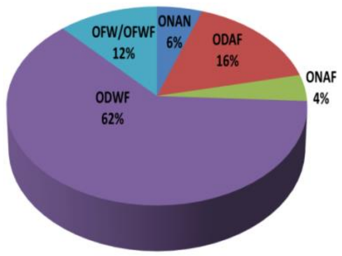


Figure A4 (ii): Cooling class of 220kV generator transformers

The diversity on the type of cooling class on 110kV generator transformers is rather interesting. 15 of the 38 transformers or 39% of total 110kV fleet has oil natural, air natural (ONAN) cooling configuration; whilst 10 transformers or 26% are oil directed, water forced (ODWF). The reason for preference of ONAN cooling class is not reviewed; this may be due to smaller MVA range associated with the 110kV transformers.

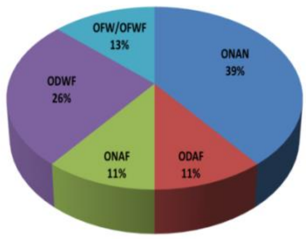


Figure A4 (iii): Cooling class of 110kV generator transformers

Appendix- A5: Generator Transformers – Fibre Optics Winding Hot Spot Monitoring

Use of fibre optics for winding hot spot temperature monitoring has not been widely implemented on New Zealand generator transformers. Only 17 (220kV) and 7 (110kV) transformers have embedded fibre optics.

Fibre optics for transformer monitoring is a relatively new technique when compared to the age of the generator transformer fleet.

The inability of adding fibre optics to an in-service transformer may be one reason for the low numbers. Mid-life refurbishment presents an opportunity to monitor critical areas in the transformer assembly.

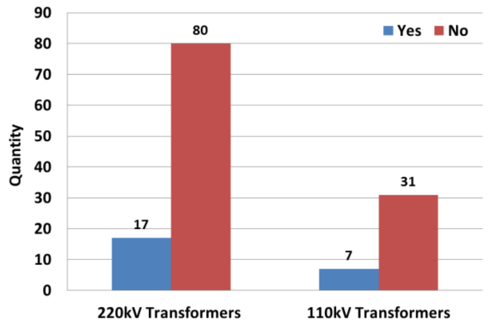


Figure A5 (i): Generator transformers with embedded fibre optics

Appendix- A6: Generator Transformers – Service Aged Asset Distribution and Purchasing Estimates

40 generator transformers are aged above 40 years. The rated power of these vary from 0.5MVA to 300MVA. Figure A6 (i) shows the quantity and MVA rating of these transformers.

It is noted that three (3), 300MVA generator transformers identified in Figure A6 (i) may not be replaced with modern equivalents.

A 65MVA transformer aged above 50 years currently in the midst of transformer replacement programme is included.

It is estimated that the total MVA of generator transformers to be replaced is approx. 1100MVA.

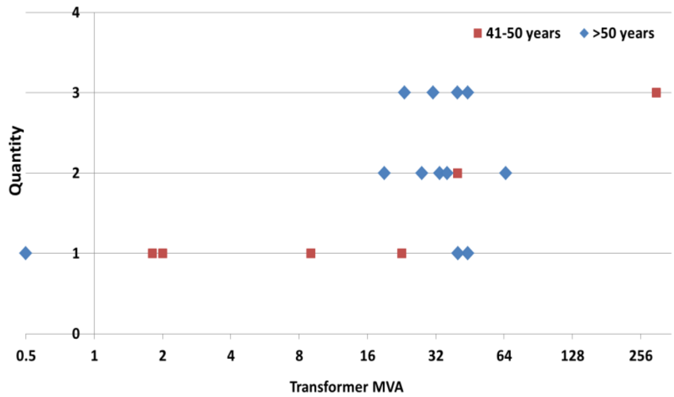


Figure A6 (i): Generator transformers aged above 40 years

Budgetary estimate of generator transformers for purchases in U.S. is given in [7]. Recent generator transformer purchasing experience indicates that the cost (NZD $/MVA) for New Zealand generator transformer purchases is higher than in [7]. New Zealand experience shows that NZD $/MVA for generator transformer purchases is dependent on various factors, including MVA, technical specification etc. Budgetary $/MVA commonly applied for generator transformer estimates is between $22k/MVA and $46k/MVA. Based on these values estimated cost for generator transformer replacements varies NZD $24m - $51m.