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Quantifying the Number of 138/25 kV 25 MVA Spare Transformers Required Using Probabilistic Risk Assessment

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Summary: This report investigates the number of three-phase 138/25kV 25MVA spare transformers required to backup a group of 138/25kV transformers with rating between 10 – 30 MVA in order to maintain system reliability during the 10 years planning period (2006 – 2015). Fixed winding and load tap changing transformer types are separately considered in this report. The SPARE software is used to conduct the probabilistic risk analysis. A historical reliability performance of BCTC is used as a specified reliability criterion to determine the number of spare transformers needed during the planning period as well as the timing requirement to have these spare transformers in place.

1. Introduction

System Planning and Performance Assessment Department provides an assistance to Asset Program Management Department to determine the number of 138/25 kV 25 MVA spare transformers required during a 10 years period (2006 – 2015). The methodology used in quantifying the number of transformers is based on the reliability analysis, and the SPARE software [1] is utilized in this study. There are 50 existing three-phase 138/25 kV transformers with rating between 10 – 30 MVA. These 50 units can be categorized into two transformer types; 34 fixed winding and 16 load tap changing. The use of fixed winding spare transformer to replace a transformer with LTC may create unsatisfactorily operating condition, and therefore this report will consider spare transformers for these two transformer types separately.

Theoretically, transformers could be grouped by their practical utilizations either being used in single-transformer substations or multi-transformer substations. Then, the number of spare transformers for each group could be examined. However, this is unlikely the case in practice as both single and multi-transformer substations would share the same group of spare transformers. Another concern is that there might be an overlapped utilization between mobile and spare transformer concepts. For example, if a transformer at a single-transformer substation fails (N-0) due to either forced outage or aging failure, the mobile transformer will initially be brought to the site in order to quickly reinstall the substation load back in service until a spare transformer is brought to the site and replaced the mobile transformer later. This example indicates a common use of mobile and spare transformers due to the same failure event. Such a situation can also have an influence on determining the number of both spare and mobile transformers. In the above example, if there is no spare transformer reserved for single-transformer substations, the mobile transformer would be put in there until a new transformer (ordered) has arrived and this could take up to one year duration. The mobile transformer in this case is actually acting like a spare transformer. In order to solely separate the concept of mobile transformer from the spare transformer, the utilization criterion of mobile transformer should be identified, i.e. a mobile transformer will not be put in the site longer than 30 days. If the criterion is clearly adopted, there would be no overlap when dealing with spare and mobile transformers for single-transformer substations. In this case, it is also necessary to consider spare transformers to cover single-transformer substations.

This report focuses on determining the number of spare transformers required to cover both single and multi-transformer substations. The mobile transformer concept is not considered in this study and is solely separated as another reliability issue.

2. Probabilistic Risk Assessment Methodology

In this study, it is very difficult to directly apply an economic or cost/benefit analysis for a spare transformer project justification. This is due to the fact that the project is aimed for ensuring a high reliability level of the 138/25 kV substations in the system, which consist of both single and multi-transformer substations. Application of cost/benefit analysis for single transformer substation is considerably straightforward as the loss of a transformer at the substations will directly lead to the loss of load (unserved energy) resulting in a monetary loss to customers. However, this is not the case for multi-transformer substations as the loss of one transformer in the substations will not directly lead of loss of load (if N-1 criterion is still held). Consequently, there is no monetary loss under these circumstances, which means that there is no direct input to the cost/benefit justification. Instead of using the cost/benefit justification, the specified reliability criterion is used as a benchmark in this study in order to justify the optimum number of 138/25 kV spare transformers. The objective for utilizing the reliability criterion is to maintain the future system reliability at a similar level to a historical reliability target.

This report uses a probabilistic technique to examine the number of common spare transformers required. When compared to the deterministic N-1 security design criterion in each substation, common spared transformers shared by multiple substations can avoid considerable capital expenditure and still assure a sufficient reliability level [2]. The challenges when utilizing common spares transformers are [2]:

- How many spare transformers are needed in a region to provide sufficient reliability?
- To avoid degrading in power supply reliability due to the transformer aging problem, what is the timing to have the first, second, third spare (and so on) in a long term planning?

This report performs risk assessment to solve the above questions in regard to common spare transformers.

The SPARE software [1] is used in this study. The SPARE program can incorporate both repairable (forced) and non-repairable (aging) failures of components. Weibull distribution model is used in this study to represent aging failure characteristics. A mean life and standard deviation of the mean life for all three-phase 138kV transformer groups (148 units in total, i.e. 138/25kV, 138/12kV, etc.) are obtained using an in-house software, designated as MeanLife program. The transformer group used in a mean life calculation is shown in Appendix A. The transformer data shown in Appendix A were provided by Asset Program Management Department. The resulting mean life and standard deviation for this transformer group based on Weibull distribution model are 57.1 and 14.5 years respectively.

In this study, spare transformers are separately considered for two transformer types; fixed winding (34 units) and load tap changing (16 units). Lists of fixed winding and load tap changing transformers are respectively shown in Appendices B and C. An average operating year for the fixed winding transformer group is 30.3 years while an average operating year for the load tap changing transformer group is 27.0 years. Each transformer in this group has its failure unavailability. When it fails, a spare must be put in service to assure the normal operation of the system. The number of spare transformers required is dependent on the transformer group reliability. The SPARE software can be used to evaluate the group unavailability with and without spare transformers. The spare transformer analysis for the 3-phase 138kV transformer group includes the following steps [3]:

Step 1: Calculate the unavailability of transformers in the group.
Step 2: Evaluate the individual failure event probabilities and the total group unavailability.
Step 3: Perform the spare transformer analysis based on a specified reliability criterion.
Step 4: Repeat Steps 1 – 3 for all the years in consideration.

3. Study Results

3.1 Fixed Winding Transformer Group

A historical reliability performance of the BCTC, SAIDI = 2.1 hrs/yr/delivery point, is used as the specified reliability criterion. Since there are 34 transformers located in 29 substations (delivery points), the SAIDI is therefore converted to availability for this transformer group as follows:

Voltage class: three-phase 138/25 kV transformers with fixed winding (10-30 MVA)
The number of transformers considered in this group = 34
These 34 transformers are located in 29 substations (delivery points)
Historical reliability performance (SAIDI) = 2.1 hrs/yr/delivery point

Total average interruption duration = SAIDI×(delivery points) = 2.1×29 = 60.9 hrs/year

$$\text{Availability} = 1 - \frac{60.9}{8760} = 0.9930 \text{ (or } 99.30\%\text{)}$$

The availability of 0.9930 is used as the specified reliability criterion for the 34 fixed winding transformers located in 29 substations. The transformer group reliability must be held equal or above this specified reliability level all the time during the planning period (2006 – 2015). The results obtained using SPARE program are shown in Table 1 and graphically presented in Figure 1. Table 1 shows the annual availability of the 138/25 kV fixed winding transformer group associated with/without the number of spare transformers (up to 3 spares).

Table 1: Availability (/year) of the 138/25 kV fixed winding transformer group (34 units) associated with spare transformers using a Weibull distribution model (mean life = 57.1, S.D.= 14.5).

Year	Number of Spare Transformers			
	0	1	2	3
2006	0.8757	0.9922	**0.9997**	**1.0000***
2007	0.8651	0.9908	**0.9996**	**1.0000***
2008	0.8537	0.9891	**0.9995**	**1.0000***
2009	0.8417	0.9872	**0.9993**	**1.0000***
2010	0.8289	0.9849	**0.9991**	**1.0000***
2011	0.8154	0.9824	**0.9989**	**0.9999**
2012	0.8011	0.9794	**0.9986**	**0.9999**
2013	0.7862	0.9761	**0.9982**	**0.9999**
2014	0.7706	0.9723	**0.9978**	**0.9999**
2015	0.7542	0.9680	**0.9972**	**0.9998**

* The resulting 1.0000 were rounded up in order to present only 4 digits after decimal.

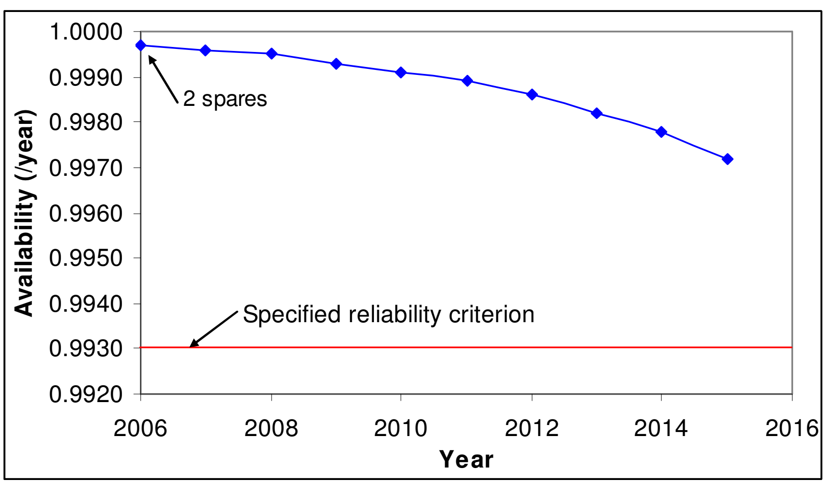

Figure 1: The number of spare transformers (fixed winding) required to meet the specified reliability level.

Figure 1 shows that two fixed winding spare transformers are needed in year 2006, and these two spare transformers are able to maintain a specified reliability level (0.9930 availability) until the end of a planning period (2015).

3.2 Load Tap Changing Transformer Group

Quantifying the number of spare transformers for fixed winding transformer group is presented in the previous section. Determining the number of spare transformers for load tap changing transformer group is presented in this section. The main reason for categorizing these two different transformer types separately is that the use of fixed winding spare transformer to replace a transformer with LTC may not be operationally desirable in practice. This section therefore focuses on examining the number of spare transformers required to backup the 16 existing 138/25kV transformers with LTC. The list of transformers with LTC is provided in Appendix C. The following information is used to calculate a specified reliability criterion for this transformer group.

Voltage class: three-phase 138/25 kV transformers with load tap changer (10-30 MVA)
The number of transformers considered = 16
These 16 transformers are located in 12 substations (delivery points)
Historical reliability performance (SAIDI) = 2.1 hrs/yr/delivery point

Total average interruption duration = SAIDI×(delivery points) = 2.1×12 = 25.2 hrs/year

$$\text{Availability} = 1 - \frac{25.2}{8760} = 0.9971 \text{ (or } 99.71\%)$$

The availability of 0.9971 is used as the specified reliability criterion for the 16 load tap changing transformers located in 12 substations. The transformer group reliability must be held equal or above this specified reliability level all the time during the planning period (2006 – 2015). The results obtained using the SPARE software for a group of 16 138/25kV transformers with LTC are shown in Table 2 and graphically presented in Figure 2.

Table 2: Availability (/year) of the 3-phase 138/25 kV transformers with LTC (16 units) associated with spare transformers using a Weibull distribution model (mean life = 57.1, S.D.= 14.5).

Year	Number of Spare Transformers		
	0	1	2
2006	0.9514	**0.9989**	**1.0000***
2007	0.9470	**0.9987**	**1.0000***
2008	0.9422	**0.9984**	**1.0000***
2009	0.9371	**0.9981**	**1.0000***
2010	0.9316	**0.9978**	**1.0000***
2011	0.9257	**0.9974**	**0.9999**
2012	0.9194	0.9969	**0.9999**
2013	0.9127	0.9963	**0.9999**
2014	0.9055	0.9957	**0.9999**
2015	0.8979	0.9950	**0.9998**

* The resulting 1.0000 were rounded up in order to present only 4 digits after decimal.

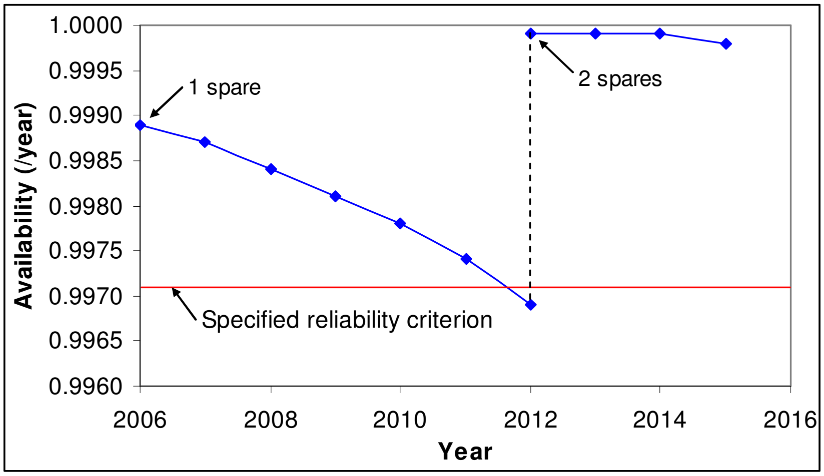

Figure 2: The number of spare transformers (load tap changing) required to meet the specified reliability level.

Figure 2 indicates that one LTC spare transformer is required in year 2006 in order to maintain a specified reliability level (0.9971 availability) for the group of 138/25kV transformers with load tap changer. In year 2012, the first spare transformer is no longer met the specified reliability criterion and the second spare LTC transformer is required in this year.

3.3 Considering Fixed Winding and LTC Transformer Groups Together

This section is extended for the spare transformer study after the meeting with Asset Program Management Department in April 19, 2006. As discussed in the meeting, the advantage of LTC spare transformer is that it can replace both fixed winding and LTC transformer types. The issue is that how many LTC spare transformers the BCTC need to cover all 138/25 kV fixed winding and LTC transformers if all the current three fixed winding spare transformers are eliminated/retired due to their physically unsatisfied conditions. The section is therefore considering all fixed winding and LTC transformer groups together in order to determine the number of LTC spare transformers to cover all 138/25 kV transformers with rating between 10 – 30 MVA. The following information is used to calculate a specified reliability criterion for all 138/25 kV fixed winding transformers (34 units) and LTC transformers (16 units).

Voltage class: three-phase 138/25 kV transformers (10-30 MVA)
The number of transformers considered = 34+16 = 50
These 50 transformers are located in 35 substations (delivery points)
Historical reliability performance (SAIDI) = 2.1 hrs/yr/delivery point

Total average interruption duration = SAIDI×(delivery points) = 2.1×35 = 73.5 hrs/year

$$\text{Availability} = 1 - \frac{73.5}{8760} = 0.9916 \text{ (or } 99.16\%)$$

The availability of 0.9916 is used as the specified reliability criterion for the 50 transformers (fixed winding and LTC) located in 35 substations. The transformer group reliability must be held equal or above this specified reliability level all the time during the planning period (2006 – 2015). The results obtained using the SPARE software for a group of 50 138/25kV transformers are shown in Table 3 and graphically presented in Figure 3.

Table 3: Availability (/year) of both 138/25 kV fixed winding and LTC transformer types (50 units) associated with spare transformers using a Weibull distribution model (mean life = 57.1, S.D.= 14.5).

Year	Number of Spare Transformers			
	0	1	2	3
2006	0.8331	0.9856	**0.9992**	**1.0000***
2007	0.8192	0.9829	**0.9989**	**1.0000***
2008	0.8044	0.9799	**0.9986**	**0.9999**
2009	0.7887	0.9764	**0.9983**	**0.9999**
2010	0.7722	0.9724	**0.9978**	**0.9999**
2011	0.7548	0.9678	**0.9972**	**0.9998**
2012	0.7366	0.9626	**0.9964**	**0.9997**
2013	0.7175	0.9566	**0.9955**	**0.9997**
2014	0.6978	0.9499	**0.9944**	**0.9995**
2015	0.6772	0.9423	**0.9931**	**0.9994**

* The resulting 1.0000 were rounded up in order to present only 4 digits after decimal.

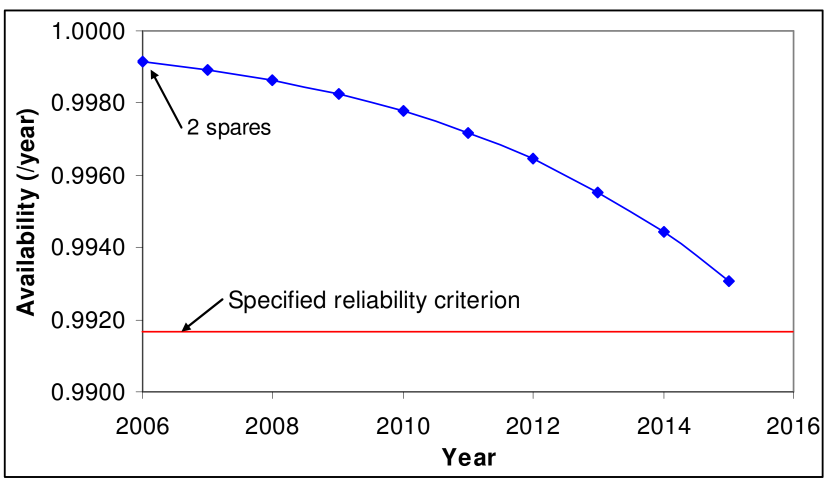

Figure 3: The number of LTC spare transformers required to meet the specified reliability level for the transformer group composed of both fixed winding and LTC transformers.

Figure 3 shows that two LTC spare transformers are needed in year 2006 to backup both fixed winding and LTC transformer types, and these two spare transformers are able to maintain a specified reliability level until the end of a planning period (2015).

4. Conclusions

This report performs probabilistic risk analysis to determine the number of 138/25kV 25MVA spare transformers required for the group of the three-phase 138/25kV transformers with rating between 10 – 30 MVA. Two transformer types; fixed winding and load tap changing are considered separately. The number of spare transformers determined in this report is considered to be used to backup (cover) both single and multi-transformer substations. A SPARE software is used in this study to quantify the number of spare transformers required for individual transformer groups. A specified reliability level for each transformer group is used as a fixed criterion to decide the number of spare transformers needed over the planning period. The transformer group reliability has to be maintained well above this specified criterion at all the time during the years 2006 – 2015.

For a fixed winding transformer group considering (34 units), the results indicate that two spare transformers are required in years 2006. These two spare transformers are able to maintain the group reliability level until the end of the planning period (2015).

For a load tap changing transformer group (16 units), the results indicate that one spare transformer with LTC is required in year 2006, and the second spare transformer is required in year 2012 in order to meet the specified reliability criterion.

In Section 3.3 (extended), if LTC spare transformers are considered to apply for both fixed winding type (34 units) and LTC type (16 units), there are only two LTC spare transformers are required during year 2006 – 2015 to meet the specified reliability criterion.

5. Recommendations

- As reported by Asset Management Department, there are currently 3 fixed winding spare transformers. There is, therefore, no need to have more fixed winding spare transformers (138/25kV 25 MVA) to backup the 34 fixed winding transformers shown in Appendix B.
- As reported by Asset Management Department, there is no load tap changing spare transformer at this moment. One 138/25kV 25 MVA spare transformer with LTC is therefore required in year 2006 to backup the 16 LTC transformers shown in Appendix C, and the second spare transformer with LTC is required in year 2012.
- In order to maximize the spare transformer utilization in the future, new spare transformers to be purchased (after all existing spare transformers are used up) should come with load tap changing (rather than fixed winding type) as the LTC transformer type can also be used for a fixed tap setting.
- As discussed in the April 19, 2006 meeting with Asset Program Management Department, if all the current 3 fixed winding spare transformers are to be eliminated or retired and the LTC spare transformers will be considered to

replace these 3 fixed winding spare transformers, the analysis shows that 2 LTC spare transformers are required in year 2006 to backup all the 34 fixed winding and 16 LTC transformers. These 2 LTC spare transformers will be able to maintain the specified reliability level until the end of the consideration period (year 2015).

References:

[1] Wenyuan Li, *User's Manual for the SPARE Computer Program Version 5.0*, BC Hydro, June 2001.

[2] Wenyuan Li, E. Vaahedi and Y. Mansour, "Determining Number and Timing of Substation Spare Transformers Using A Probabilistic Cost Analysis Approach", *IEEE Transactions on Power Delivery*, Vol. 14, No. 3, July 1999, pp. 934 – 939.

[3] Wenyuan Li, *Risk Assessment of Power Systems: Models, Methods, and Applications*, John Wiley & Sons, Hoboken, NJ, 2005.

Appendix A: All Three-Phase 138kV Transformers

(including all types, i.e. 138/25kV, 138/12kV, etc. and ratings)

No.	Component ID	In-Service Year	Retired Year
1	Unknown-744903	1970	2004
2	Unknown-796935	1976	1986
3	ARM-T1-0000744848	1976	--
4	ARM-T2-0000745550	1977	--
5	AVO-T1-0000744737	1976	--
6	AYH-T1-0000744832	1966	--
7	BAB-T1-0000744855	1976	--
8	BAR-T1-0000744935	1976	--
9	BKL-T1-0000744940	1976	--
10	BKL-T3-0000744941	1976	--
11	BLU-T1-0000745540	1976	--
12	BRN-T1-0000744938	1976	--
13	BRN-T2-0000747946	1981	--
14	CBL-SPT0833-0000755467	1976	1979
15	CBL-T1-0000746723	1980	--
16	CBL-T2-0000746023	1979	--
17	CHS-T2-0000744922	1976	--
18	CLD-T2-0000744947	1976	--
19	CLD-T3-0000744996	1976	--
20	CLW-T1-0000745001	1976	--
21	CMX-T1-0000748212	1983	--
22	CMX-T2-0000748854	1984	--
23	CWD-T1-0000744805	1976	--
24	CWD-T2-0000744830	1976	--
25	DAW-T1-0000745951	1979	--
26	DAW-T2-0000746048	1979	--
27	DUG-T1-0000746133	1979	--
28	DUG-T4-0000746166	1979	--
29	EFD-T1-0000744930	1976	--
30	EFD-T2-0000744831	1967	--
31	END-T1-0000744834	1974	--
32	END-T2-0000782001	2002	--
33	FJN-T2-0000744905	1976	--
34	FJN-T3-0000744901	1976	--
35	FVW-T1-0000741107	1974	--
36	FVW-T2-0000741341	1975	--
37	GCL-T1-0000744762	1976	--
38	GIB-T1-0000742435	1978	--
39	GIB-T2-0000739575	1974	--
40	GLD-T2-0000744833	1976	--

No.	Component ID	In-Service Year	Retired Year
41	GLD-T3-0000744852	1976	--
42	GLN-T3-0000744857	1976	--
43	GLN-T4-0000744924	1976	--
44	GLS-T1-0000744934	1976	--
45	GOW-T1-0000744807	1976	--
46	GOW-T2-0000744808	1976	--
47	GOW-T3-0000744806	1976	--
48	GOW-T4-0000744809	1976	--
49	GPT-T1-0000739585	1974	--
50	GPT-T2-0000739588	1974	--
51	GTP-T11-0000745385	1976	--
52	GTP-T12-0000748433	1983	--
53	GTP-T13-0000745384	1976	--
54	HFY-T1-0000744902	1976	--
55	HLD-T1-0000744738	1976	--
56	HLD-T4-0000754604	1996	--
57	HUS-T2-0000749938	1976	--
58	HUS-T3-0000749974	1979	--
59	HWD-T1-0000748128	1982	--
60	HWD-T2-0000749198	1984	--
61	HZN-T1-0000749946	1976	--
62	HZN-T2-0000744856	1976	--
63	JOR-T1-0000744929	1976	--
64	JOR-T2-0000746024	1979	--
65	JPT-SPT2-0000755604	1976	1987
66	KAL-T1-0000744909	1971	--
67	KAL-T2-0000747762	1976	--
68	KDS-T5-0000744836	1967	--
69	KDY-T10-0000744217	1974	--
70	KGH-T4-0000744916	1976	--
71	KSH-T2-0000748844	1984	--
72	KSH-T3-0000748845	1984	--
73	LDY-T1-0000752460	1989	--
74	LDY-T2-0000747258	1978	--
75	LTZ-T1-0000752647	1990	--
76	LTZ-T2-0000752596	1990	--
77	LU2-T1-0000745053	1976	--
78	LU2-T2-0000746066	1977	--
79	MEZ-T1-0000776936	1999	--
80	MFE-T1-0000744912	1976	--
81	MO1-T1-0000744860	1968	--
82	MO3-T50-0000745050	1976	--
83	MON-T1-0000744828	1976	--
84	MON-T2-0000745402	1961	--

No.	Component ID	In-Service Year	Retired Year
85	MON-T5-0000744105	1976	--
86	MRT-T1-0000744817	1976	--
87	MRT-T2-0000744818	1978	--
88	MWN-T1-0000744904	1976	--
89	NFD-T1-0000756059	1999	--
90	NFD-T2-0000745381	1976	--
91	NFD-T3-0000744854	1976	--
92	NTL-T1-0000744948	1976	--
93	NTL-T2-0000745067	1976	--
94	OYR-T1-0000771586	1998	--
95	PAL-T11-0000747505	1980	--
96	PAL-T12-0000747506	1980	--
97	PHR-T1-0000741160	1975	--
98	PHR-T3-0000744157	1983	--
99	PHY-T1-0000747507	1980	--
100	PHY-T2-0000744923	1976	--
101	PML-T1-0000747700	1981	--
102	PML-T2-0000748955	1984	--
103	PPS-T1-0000744803	1976	--
104	PPS-T2-0000744804	1976	--
105	PUN-T3-0000744906	1976	--
106	PUN-T4-0000745386	1976	--
107	PVL-T1-0000752861	1991	--
108	PVL-T2-0000747287	1979	--
109	PVO-T1-0000744783	1976	--
110	PVO-T2-0000744784	1976	--
111	PVO-T3-0000744939	1976	--
112	PVO-T4-0000744921	1976	--
113	QLC-T1-0000757336	1999	--
114	QLC-T2-0000777824	2001	--
115	SAL-T1-0000752909	1991	--
116	SAL-T2-0000753116	1991	--
117	SAM-SPT6-0000755614	1974	1980
118	SAM-T1-0000746170	1978	--
119	SAM-T3-0000746289	1978	--
120	SAM-T6-0000747446	1980	--
121	SEC-T1-0000742850	1981	--
122	SEC-T2-0000742364	1977	--
123	SHA-T1-0000744847	1976	--
124	SHA-T2-0000746696	1980	--
125	SNY-T1-0000749760	1985	--
126	SNY-T2-0000745936	1979	--
127	SOO-T1-0000747761	1981	--
128	SOO-T2-0000746804	1979	--

No.	Component ID	In-Service Year	Retired Year
129	SRS-T1-0000749940	1976	--
130	SRS-T2-0000749941	1976	--
131	STO-T1-0000748004	1982	--
132	STO-T2-0000745522	1977	--
133	STW-SPT2441-0000755847	1976	1993
134	STW-T3-0000751350	1989	--
135	TSV-T1-0000744933	1976	--
136	TSV-T2-0000744825	1966	--
137	VBY-T1-0000744917	1976	--
138	VLM-T3-0000747185	1979	--
139	VNT-T12-0000751011	1993	--
140	VNT-T4-0000744931	1972	--
141	VNT-T5-0000745059	1973	--
142	VNT-T6-0000747590	1981	--
143	WBK-T1-0000745389	1972	--
144	WBK-T2-0000744910	1971	--
145	WBK-T3-0000753694	1993	--
146	WOS-T1-0000751376	1988	--
147	WSP-T1-0000752853	2000	--
148	WSP-T2-0000780925	2000	--

Appendix B: Transformers with Fixed Winding

Three-phase 138/25kV Transformers with fixed winding (rating between 10-30 MVA).

No.	Component ID	In-Service Year	Operating Years (up to 2006)
1	ARM-T1	1976	30
2	AYH-T1	1966	40
3	BAB-T1	1976	30
4	BAR-T1	1976	30
5	BLU-T1	1976	30
6	CLW-T1	1976	30
7	CWD-T2	1976	30
8	END-T1	1974	32
9	GIB-T2	1974	32
10	GLD-T2	1976	30
11	GLS-T1	1976	30
12	GPT-T2	1974	32
13	HFY-T1	1976	30
14	HUS-T2	1976	30
15	HUS-T3	1979	27
16	HZN-T1	1976	30
17	HZN-T2	1976	30
18	KAL-T1	1971	35
19	KAL-T2	1976	30
20	KDS-T5	1967	39
21	KGH-T4	1976	30
22	LU2-T1	1976	30
23	MFE-T1	1976	30
24	MWN-T1	1976	30
25	PHR-T3	1983	23
26	SEC-T1	1981	25
27	SHA-T1	1976	30
28	SRS-T1	1976	30
29	SRS-T2	1976	30
30	STW-T3	1989	17
31	TSV-T1	1976	30
32	TSV-T2	1966	40
33	VBY-T1	1976	30
34	VLM-T3	1979	27

Appendix C: Transformers with Load Tap Changer

Three-phase 138/25kV Transformers (Delta-Wye connection) with LTC (rating between 10-30 MVA).

No.	Component ID	In-Service Year	Operating Years (up to 2006)
1	ARM-T2	1977	29
2	BRN-T1	1976	30
3	BRN-T2	1981	25
4	END-T2	2002	4
5	FVW-T2	1975	31
6	GIB-T1	1978	28
7	LU2-T2	1977	29
8	PHY-T1	1980	26
9	PHY-T2	1976	30
10	PML-T1	1981	25
11	PML-T2	1984	22
12	SEC-T2	1977	29
13	SHA-T2	1980	26
14	STO-T2	1977	29
15	WBK-T1	1972	34
16	WBK-T2	1971	35