Case study : effectiveness of Transformer firefighting (deluge) System in Oman Electricity Transmission Company (OETC) network

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SUMMARY

Mineral oil transformers are considered to be one of the most critical assets in the electrical company's network that contribute directly to the availability and reliability of the system. Many issues can affect the transformer from performing the required job. One of these issues is the presence of fire caused by any reasons during transformer service life. This issues are not limited to the cost and time of replacing of transformer. However, they exceed to human safety and environmental consequences especially if it is located in residential area and it exploded and produced thick clouds of black smoke during fire which can make a serious human health effects, company reputation and some other issues with regulatory with respect to system reliability and availability. Depending on the size of the power transformer, it contains at least 20000 litres of mineral oil which is used as cooling and insulation media in the transformer, but –on the other hand - it is a flammable liquid at high temperature cause by overheating or short circuit. Moreover, this huge volume of oil can cause a massive disaster if it caught fire. Several transformer fire reports shows one of the most important fact that most of the fires in the transformers is that it cannot be extinguished using normal firefighting system of the transformer. That is because it needs a huge volume of water to extinguish the fire in the oil which may cause total damages of the transformer and it needs a lot of money and time to clean and replace the transformer. Some times the normal water is not sufficient to extinguish the fire, so foam can be added to water to be more efficient The question arises here, how far OETC can depend on the current firefighting system (deluge) to extinguish the fire in the transformer.

This case study will discuss the following parameters:

1. Review the current firefighting system configuration.
2. Study the OETC network for past 11 years and how many transformers fire occurred and what is the role of transformer firefighting system.
3. Study the local authority's rules of installing transformers firefighting system and effect of fires on the human being and the environment.
4. Study the current maintenance and inspection practice performed on the transformer firefighting system and observations.

After completion in this paper, OETC will be able to identify the following:

1. How much cost and time will be saved that spend in installation, maintenance and disposal firefighting system.
2. Risk and impact associated with / without of firefighting system.
3. What is the alternative solutions and strategies?
4. What is the proactive actions to prevent any fire in the transformer and how it will impact the maintenance and inspection regime of the transformer?
5. What is the action required in case transformer caught fire.

KEYWORDS

Mineral oil transformer, Fire, firefighting system, risk, deluge system, safety, explosion, environment, smoke, standards and specifications, availability, reliability, water, foam

1. Introduction .

1.1 Overview.

As per Oman Electricity Transmission Company (OETC) standards and specifications, transformer firefighting system must be available in each transformer with its associated accessories . The utility is using water spray fixed system or deluge system (electrical motor, diesel engine and associated pipes and water tank) and the oil catchment pit underneath each transformer to collect the spilled oil in case of oil leak based on the company standard and specifications. OETC has 65 grid stations till end of 2015 and 171 auto and power transformers. This means that there are 65 number of firefighting rooms, 65 water tank and 171 fire pipe net fixed in the transformers. Moreover , there are 6 SERGI system was built as a pilot project. All transformers in OETC network are mineral oil type transformers. Mineral oil is used for insulation and cooling purpose for the transformer. The characteristics of this type of oil is considered to be flammable liquid if it reaches certain temperature level or it caught fire.

The utility`s standard and specifications indicated that the transformer firefighting system must contain the following:

1. Water tank.
2. One electrical motor.
3. One diesel engine.
4. Two auto-switching electric motor driven jockey pump.
5. One (1) water/air-pressure vessel of ample size.

Besides, oil catchment is specified in the OETC standard and specifications to be underneath each transformer to containment 110% of the transformer oil capacity in case of oil spill.

1.2 Regulations and Rules.

The local Civil Defense is following National Fire Protection Association (NFPA 850) about Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations. This code provides recommendations (but not requirements) for these transformers which is not meeting the separation or fire wall recommendations or as determined by proper risk assessment for fire protection should be protected with automatic water spray or foam-water spray systems. As it is clear from this code that deluge system can be dispensed with necessity of presence of other means. Moreover , there are regulations related to minimize the air pollution and prevents any oil leak to the soil. In 2007, health and safety audit was conducted by Authority for Electrical Regulation and it has been found that transformers at some stations were found without fire system (Deluge piping). It can be concluded that there are some concerns regarding transformer fire system by Authority. Insurance companies have also their concern and requirements regarding safety procedure for each equipment inside thestation.

1.3 Transformers fire incidents background.

Table 1 : Transformer Failures Vs Fire 2005-2015

SN	Grid Station	Capacity (MVA)/ Voltage Level	Fire	Parts
1	Wadi Wdai	125/132 kV	Yes	Cable box
2	Seeb	63/132 kV	No/Explosion	Winding failure
3	Seeb	63/132 kV	No/Explosion	Winding failure
4	Boushar	125/132 kV	Yes/Explosion	Bushings
5	Wadi Khabir	125/132 kV	No	Winding failure
6	Mudabi	63/132 kV	No	Bushings
7	Izki	125/132 kV	No	Winding failure
8	JBB	125/132 kV	No	Bushings

Table 2 : Transformer fire rate 2005-2015

SN	Year	Transformer population	Failures/Major Incidents	Fire
1	2005	71	0	0
2	2006	73	0	0
3	2007	75	0	0
4	2008	92	1	1
5	2009	112	1	1
6	2010	124	2	0

7	2011	144	1	0
8	2012	156	1	0
9	2013	160	1	0
10	2014-2015	171	1	0

From table 1, there was 8 transformers failures/ major incidents during period 2005 to 2015. Among these eight incidents, still 3 transformers in service and one of incidents was fire .Moreover, there were two fire incidents occurred only even there were three explosions among the 8 incidents. Also it is noticeable that half of in incidents were due to transformer winding insulation failure and two of them caused a transformer explosion, but none of them caused a fire in the transformer. On the hand there are also three incidents due to bushings and one incidents due to cable box which they are considered to be an external parts of the transformer where two of them caused fire in the transformer. As conclusion, the probability of transformer fire in case of external failure in the transformer is higher than if the incident occurred inside the transformer. On the other words , due to absence of free oxygen and presence of high pressure due to large quantity of the oil inside the transformer the probability of transformer fire is very rare , but that doesn't mean the transformer will not catch fire if the failure was inside the transformer , it can catch fire if the fault is very high and it didn't clear in the proper time , it may cause tank rapture due to high pressure of the high temperature and generated gases which will allow the very high temperature gases that released from the oil to access to free oxygen which may cause fire if the temperature is high enough for auto ignition [1].

Table 2 shows the transformer fire rate between 2005 and 2015. During these 11 years, there were 2 fire incidents occurred due external terminals of the transformer .As it will be explained below, one of the transformers still in service till today and the other was damage totally due to the fire. The fire rate in 2008 is 1.1% and in 2009 is almost 0.9% while there is no fire incidents in the other 9 years even there were some serious transformer failures. Again , this is an indicates that the transformer fire probability is very low, but it cannot be ignored due to the high consequences. Below is more details about two fire incidents that occurred in OETC network.

- **Wadi Adai Transformer**: in 2008, 125 MVA transformer caught fire while it was in service during the summer time. There was no investigation was performed to describe this incident so the existing information is not enough to make root cause analysis of this incident. However, the fire was occurred in the cable box of the transformer which maybe caused by hotspot in the cable box that produced heat which in turn was enough to cause a fire. Although deluge system is the most common firefighting system in OETC installed in the most of the stations , but there was no firefighting system installed at that time in this grid station and the fire was extinguishing by civil defense after some time. There was no significant damage in the transformer, cable terminals had been replaced and the transformer still in service.

2. **Baushar Transformer:** in 2009, 125 MVA transformer was burn totally. As per the investigation report , transformer firefighting system operated , but it was not sufficient to extinguish the fire. Civil defense reached the site and the fire was controlled after 5.5 hours of incident but the smoke was rising from the transformer for 24 hours at least. The transformer got fire again after 7 days of the incident due to retained heat in the transformer. Fire brigade used foam to extinguish the fire after several attempts to extinguish the fire using normal water. Moreover, the field investigation showed that the causal factor for the transformer failure and fire was the flash over in the transformer bushing of phase V (middle phase), OIP type. it is worth mentioning that the transformers was loaded with more than 90% of its rated capacity and the transformer`s winding temperature was more than 95 C during the summer season . Additional to these transformer`s fire incidents, in 2015 , there were a fire incident in the firefighting room in one of the grid stations. An explosion was heard due to the fire and most of the equipment were totally burned. The field investigation report stated that there was a water leakage in the pressure switch of the jock pump and the main cause of the fire was due to wrong rectification by the contractor.

3. Cost of Installation and Maintenance of Firefighting System.

Figure 1: Installation cost of transformer firefighting system (1975-2020)

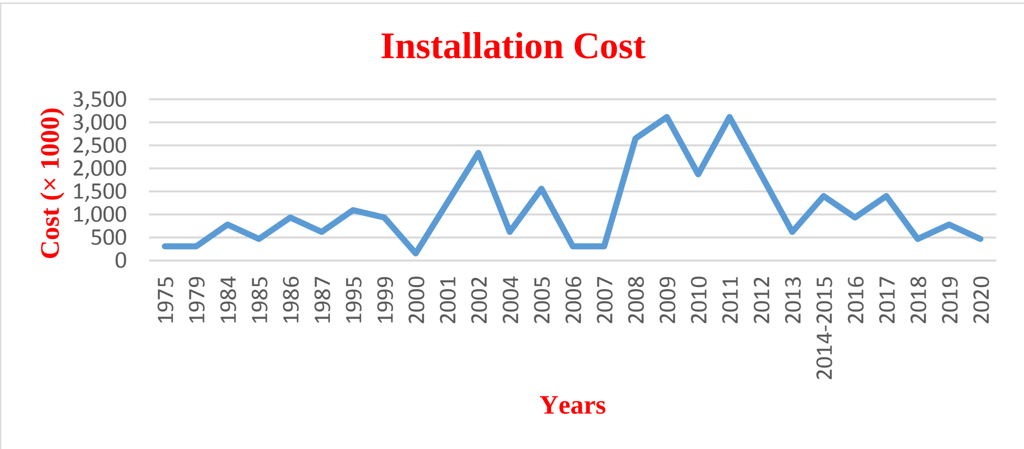

Figure 1 shows the approximate installation cost graph of transformer firefighting system within OETC during period of since 1975 to 2020. OETC is spending approximately 156,000 USD for each grid station with two transformers installed . The largest spending on the transformer firefighting system was in 2009 and 2011 with 3,120,000 USD for each year. For the next 5 years (2016-2020) there will be about 26 new grid stations to be constructed and the estimated cost for the transformer fire system is 4,056,000 USD without considering the cost of firefighting system for adding new transformers in the existing transformer is not included.

Figure 2 : Maintenance and installation cost

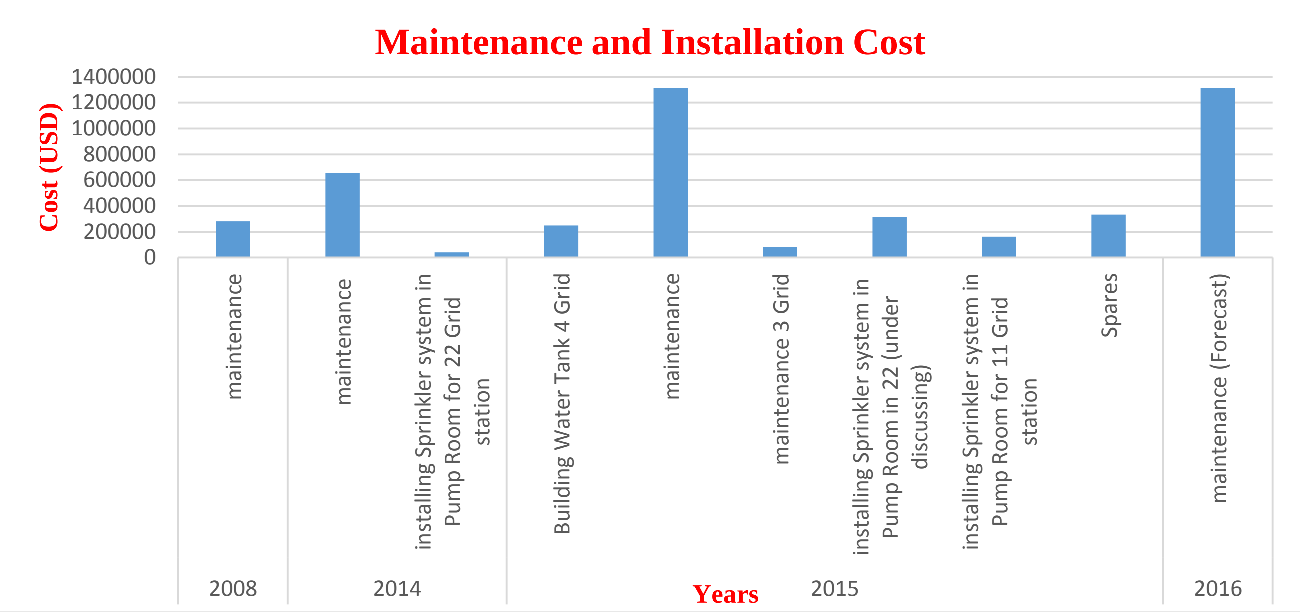

Figure 2 shows the approximate installation (modifications) and maintenance cost in the mentioned years. As one of the insurance's requirements in 2013, sprinkler system must be available in each fire room and based on these requirements, approximately OETC will spend amount of 513,760 USD as shown in the figure 2 . Moreover, this requirements will be an extra cost for the future projects and cost of maintenance as well. For maintenance purpose OETC spent total amount of 2,332,399 USD in 2008, 2014 and 2015 and the estimated cost that OETC is going to spend in 2016 is 1,313,000 without considering the cost of maintaining firefighting system for the newly commissioned grid stations. However, the scope of the maintenance activity is limited to clean, inspect and check the operations, and for any replacement or spare parts, OECT shall pay that extra amount. For 2015, OETC spent approximately 333,762 USD for the spare parts which formed about 12.5% of the total OPEX of transformer firefighting system as shown in figure 2. Another cost is not included above is installing of crane in the fire pump room based on the HSE audit that was conducted in 2015.

From the above , OETC is investing a lot of money in installing and maintaining the transformer firefighting system with total cost of 314,1746,6 USD , with yearly average cost of 785436.6 USD since 1975 without considering new transformer fire systems from 2016 and onward.

4. Fire Probability.

For unforeseen events such as design defects, voltage surges, lightning strikes, structural damage, rapid unexpected deterioration of insulation, sabotage, and even maintenance errors can and do lead to transformer fires and the consequences can be severe. A transformer fire that involves several thousand gallons of combustible insulating oil can result in severe damage to nearby grid station structural components such as concrete walls and damage or destroy electrical components such as nearby transformers, bus work, and circuit breakers [2] and it may extends to nearby houses.

The probability of transformer fires are in the order of 0.1 % per transformer service year i.e. 1 fire per 1000 in service transformers per year. This is not a high probability, but the consequence is nearly always total loss of the transformer and often with collateral damage to other adjacent and often with some environmental pollution and loss of supply for various durations. Also whilst 0.1% may appears low, the accumulated probability of the event happening is on average in the order of 4% per transformer over a typical service life of 40 years [1].

Table 3 : Transformer Failure and Fire Risk Rate - Data Other Sources[1]

Utility	**Transformer population**	**Rate of Serious Failures (%p.a.)**	**Rate of Transformer Fires (%p.a.).**
Germany National Statistics	-	0.6	0.06 (Anecdotal - 10 % of Serious Failures)
RTE, France	1300	0.6	0.05
Eskom, SA	600	-	0.16
National Grid, UK	780	0.3	0.015
Swedish State Power Board Transmission	1300	-	0.02 (3 fires in 10 Years)
Swedish State Power Board	100	-	< 0.05 (no fire in 20-30 years)
Japan (1991-2001)	-	0.054	0.00012
OETC (2005-2015)	171	-	0.13 (2 fires in 11 years)

Table 4 : Statistics by a major Canadian Utility 1965 -1985: Fault Location vs. Fire Rate[1]

Fault location	**Explosion**	**Fire**	**Fire rate %**
Bushings	25	11	44
HV lead to tank	15	9	60
HV Lead to bushing turret	8	4	50
Within windings	21	0	0
OLTC, Core and others	9	0	0

From table 1 and 2 in clause 1.2 for the duration of the past 11 years, OETC faced 8 transformer incidents. Transformer fire incidents form 25% of the incidents and it also shows that the fire rate with same mentioned years is 0.13 and the cause of the fire was due to an external failure in the transformer, whereas the transformer failure due to an internal issue forms 50% of the total failures. Although some of the failures caused a heavy oil spill, but there were no fire developed.

These statistics come compatible with table 3 and 4 for survey that was done by CIGRE WG A2.33 in 2013. Table 3 shows transformer failure and fire risk rate for 7 different companies. The annual rate of transformer fires is very low and the transformer fire rate in OETC is slightly higher than most of the companies within the survey. A summary of transformer fire hypothesis is shown in table 5:

Table 5: Transformer Fire Hypothesis

Fire Hypothesis	**Very unlikely**	**unlikely**	**Possible**	**likely**	**Very likely**
Cable Box					✓

HV lead					✓
Bushing					✓
Winding		✓			
Core		✓			
OLTC		✓			
Oil		✓			

5. Fire Risk.

Due to the lack of global experiences and researches that show how much is the effectiveness of the transformer fire freighting system during fire for different scenarios , it is very hard to judge its impact during the fire incidents. Depending on the size, strength and the location of the fire, the probability is high to extinguish the fire using firefighting system, whereas the probability is low if the fire spread to the inner side of the transformer . However, as it is was illustrated in clause 3 the international and local surveys show that the transformer fire probability is low during the lifetime of the transformer, but it cannot be ignored because the consequences can be catastrophic and it can be summarized as the following:

1. Risk to the Human : Due to the load requirements , grid station can be located in the middle of crowded areas which make the house very close to the grid station. Transformer could be exploded during fire which in turn may cause fatality or injury .Moreover, nearby houses may get damage during the transformer explosion. Also thick smoke will be generated from the fire which can be spread for miles. This smoke can be harmful to the environment and it can cause suffocation to the neighbor houses.
2. Risk to adjacent assets: adjacent assets can be affected during transformer fire and explosion especially if there is no proper risk assessment has been done for fire zone.
3. Environmental: beside the smokes generated from the fire which can cause air pollution, explosion/ fire can cause a major oil spill to the ground which can be near to farm lands or rivers. Even transformer oil catchment can be useful to containment oil, but depending on the design specifications and the size of the oil catchment, during the fire extinguishing, large amount of water is used and with oil spill can cause fullness in the oil catchment thus it will seep to the soil resulting in environmental issues.
4. Financial: transformer fire is considered as unexpected event which will cost the utility amount of the money that is not part of the budget. This cost will be used for repairing or replacement

transformers and cleaning up the remnants of the fire . This cost may extend to neighboring assets and homes that affected by the transformer fire.

5. Future projects: as it is mentioned above, transformer fire is considered as unexpected event which will lead to use part of the assigned budget to repair the effect of fire , this in turn will lead to postpone some projects due to unplanned cost and time used for repairing .in term of the society, transformer fire can cause a huge explosion and it may cause concern to the society which will lead to refusal to construct any grid stations near to their homes.
6. System security: It is very important for every electrical utility to maintain and increase the performance of the system by enhancing the reliability and availability of the system. Fire can totally destroy the transformer and replacing it may require period of time , during this period of time system security will be a source of concern.
7. Reputation: when the utility has a good reputation, it can get the stakeholder support, increase the utility value in the financial marketplace , number of costumers that will want to deal with the utility will be high.
8. Regulatory issues. Every electrical utility has to obligate to the regulator's requirements which human safety ,environments and system availability and reliability are one of them. Non-compliance with those requirements may cause to financial penalties or it can lead to withdrawal of the license.

6. International Practice and Statistics.

OETC made a survey within International Transmission Operation and Maintenance Study (ITOMS) in order to seek for the other experiences in transformer firefighting system ti be one of the evidences in this study. The survey was including the following inquiries:

1. Proper risk assessment for the fire zones.
2. Fire walls are constructed left and right of the transformer
3. Construct a central oil catchment pit safely located away from the transformers and linked to the transformer oil catchment pit. Thereby, in case of transformer oil release it will be drained to the central pit leaving minimal amount of oil that can fuel the fire.
4. Use powder trolley (to be used for small fires) and depend on fire brigade for large fires.
5. Use suitable fire detection and alarming system to alarm the control room in case of fire.

Table 6: ITOMS Survey Summery

Comp.	Risk Assess.	Fire Wall	Cent.Oil Catc.	Deluge Sys.	Trolley exting.	Fire Bridget	Fire Alarm Sys.
1	Yes	Yes	Yes	No	Yes(insurance)	Yes	Yes
2	Yes	Yes	Yes	—	—	Yes	—
3	Yes	Yes	Yes	Yes	Yes	—	Yes

4	Yes	Yes	In the past. Now underneath the transformer	No	No	Yes	No
5	——	Yes	Yes	Yes	——	Yes	Yes

From the table 6, all the companies are using proper risk assessment for the fire zone and building firewall to prevent spreading of the fire to adjacent assets in the grid station. Due to high maintenance cost of the drainage systems and the central pits, one of the companies decided to replace it with the oil catchment pit built as closed and drain-less oil catchment pit underneath each transformer and it is covered with fire protection gratings that prevent oil from ignition and burn in the case of an oil leakage from a damaged transformer. Some of the companies have deluge system and some of them are using portable powder trolley for smaller fires, Although they believe these means are not sufficient to extinguish big fire but due to regulations and insurance policies , these systems must be available at site .Depending on the Fire brigade are the most common solution and considered as one of the best practice followed by these companies to face the risk of fires . Fire detection system are also commonly used as an alternative system to help detecting fire in early stages and minimize the risk of fire.

7. Conclusion and Recommendations.

As a conclusion, removing the existing transformer firefighting system from standard and specifications can be an opportunity to OETC rather than a risk in term of saving cost and time. There are sets of observations have been noted which will provide a good reference to the below recommendations as the following:

1. Transformer Deluge System Installation CAPEX is about 156,000 USD per grid station and OPEX is about 13,000 USD grid/ year.
2. The cost is not only limited to installation and maintenance , it extends based on the other stakeholder`s requirements (HSE , insurance , authority ,etc.)
3. Transformer firefighting system can be effective in case of small fire which remains on the surface in the external part and doesn't not spread inside the transformer which will become very difficult to extinguish and it may leads to serious issues.
4. Globally , There is no enough conviction regarding installation of transformer firefighting system , just it is built to fulfil the regulatory and insurance requirements.

So this study is recommend the following:

- Stop installing Transformer Deluge system and replace it with the following practice:
  1. Align OETC standards and specifications with IEC 61936-1 2002 recommendations for separation distances between outdoor transformer and buildings and conduct proper risk assessment during design stage.

2. Conduct transformer fire incidents drills with Fire Brigade teams and agree with them to add foam in the water in case of transformer fire.
3. Installation of fire walls as it is mentioned in the OETC standards (based risk assessment result).
4. Installing fire detectors in the transformers.
5. Use central oil catchment pit (in line with new specs). Taking into the consideration the central oil catchment must containment whole oil in the transformer and the water in case of fire.
6. Monitoring the Transformer temperature during high load and high ambient temperature.
7. Cover the Transformers yard with Close Circuit Television (CCTV) project which is already under construction.
8. Fire pump is not only connected to transformer, it is also connected to other rooms, i.e.: offices, basement, etc. so further risk assessment need to be done to examine all possible scenarios and apply the proper mitigation plan.
9. Risk control program and procedures should be put in place and they must reviewed and updated periodically.

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