Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Cost vs. Risk for Partial Underground Transmission Lines Near NPP

Dhuhair, Mohammad*; Adviser: Prof. Jay James
KEPCO International Nuclear Graduate School – KINGS;
1456-1 Shinam-ri, Seosaeng-myeon, Ulju-gun, Ulsan, 689-882, Korea
*Corresponding author: madhuhair@hotmail.com

1. Introduction

As a part of a KEPCO International Nuclear Graduate School (KINGS) Thesis Report, I investigated the ability of using underground high voltage transmission cable for at least one transmission line connected to the Nuclear Power Plants, to lower core damage frequency (CDF) by minimizing the probability of Loss of Offsite Power (LOOP).

2. Transmission Lines at Fukushima Accident

The earthquake that occurred in Fukushima affected the off-site power supply equipment of Fukushima Daiichi and Fukushima Daini NPPs to a great extent, as shown in below table. In addition to the damage incurred at the Fukushima NPPs, the transmission system, the on-site switchyard circuit breakers and the transformer equipment at Shin Fukushima Substation were also damaged. Furthermore, the collapsing embankments at the adjoining area caused the transmission line steel tower to fall down. As a result, all of the six lines as well as the line between Unit 1 and Units 5 & 6, at the Fukushima Daiichi NPS, were out of service. At the Fukushima Daini NPS, three out of four lines became out of service and hence only one line continued to provide power to the NPS.

		Daiichi (6 Units)	Daini (4 Units)
AC	Off-site Power	All Lost (5 tripped, 1 out of service)	1 Available (2 tripped, 1 out of service)
	Emergency Diesel Generators	Unit 1-5: None Unit 6: 1 Available	Unit 1-2: None Unit 3: 2 Available Unit 4: 1 Available

The design criteria in the safety design review guidelines requires to have at least two power transmission lines connected to the power system. Despite the fact that the Fukushima Daiichi NPP has complied with the above, the off-site power was lost due to the earthquake. Hence, in this report, I am proposing to analyze the use of at least one underground transmission cable to improve the reliability of off-site power.

3. Life-Cycle Cost

The life-cycle costs of electric transmission lines include various costs such as costs to permit and build a line, operate the line with electrical energy losses and maintain the line over its useful life, which is projected to be 40 years. The net present value (NPV) of the total life-cycle costs converts all of the above-mentioned costs to a single equivalent cost at the beginning of that time period.

In the case of overhead transmission lines, the cost of materials constitutes a significant component in the life-cycle costs. For instance, the total life-cycle cost of steel delta overhead lines is roughly 40 percent higher than that of wood H-Frame lines. Moreover, vegetation maintenance for overhead lines is another significant factor that contributes to its life-cycle cost. These costs have increased since 2007 due to Helicopter patrol requirements. Some of the additional maintenance activities for overhead lines include climbing inspections, foot patrols, and infrared inspections to identify hot spots on splices and conductors.

In the case of underground transmission lines, the maintenance costs of the same have been unsteady in the last few years, due to required maintenance inspections, cleaning of ducts, manholes, etc., and moving or repairing boxes and potheads. Additionally, it has proven to be challenging to predict the future maintenance costs of underground transmission lines. Lastly, in underground transmission lines, the total life-cycle cost of XLPE (solid dielectric cable) is found to be 31 percent higher than for HPFF (fluid-filled cable) systems partly due to factors such as larger splice vaults and material cost escalation.

Line Type	Total NPV of life-cycle costs
OHL 345 kV Wood H-Frame	$9,671,719
OHL 345 kV Steel Delta	$13,528,109
UGC 345 kV HPFF	$28,557,298
UGC 345 kV XLPE	$37,466,407

In general, the total life-cycle cost of underground transmission lines has been observed to be roughly three to four times higher than that of overhead transmission lines at the same voltage level. Despite this, deciding whether or not to use underground versus overhead transmission is a complex decision since cost is just one factor.

4. Overhead Transmission Combined with Underground Transmission Cable

In some areas, there are constraints on the transmission capacity such as thermal limits of transmission lines and where re-conductoring of existing lines is not feasible. In these areas, the only possible solution to meet the increased power demand and maintain the transmission grid reliability is to construct a new transmission line. However, constructing new overhead transmission lines may sometimes be difficult particularly in the densely built-up areas. In such cases, a more feasible option would be to place a critical section of the transmission line underground.

That is, wherever possible, cables are buried in a trench or in concrete duct banks. In the built-up areas, tunnels are built using modern tunnel boring technology in order to minimize the impact of the same on the infrastructure above the tunnel line. In order to connect the overhead line to the underground cables, transition stations have to be built at both ends of the underground cable section.

The 400 kV single circuit transmission line TurbigoRho in Italy is an example of combined overhead/underground line. This transmission line is 40 km long and it has an underground section that is 8.4km long between Pogliano Milanese and Rho transition stations. The underground cable section consists of 6 cables (2 per phase) that are of XLPE type. Furthermore, the conductor sectional area is $2000mm^2$ and the maximum power rating of the combined line is 2,200 MVA.

5. Impact of Offsite Power System Reliability on NPP Safety

Data on LOOP and offsite power restoration have been analyzed in several reports for overhead lines. The results from the NRC study are shown in below table.

Type	Mode	LOOP Category Data	Data Period	Num. of LOOP Events	Reactor Years	Mean Freq.	Freq. Units
Overhead Transmission	Power operation	Plant centered	97–04	1	724.3	2.07E-03	/rcry
		Switchyard centered	97–04	7	724.3	1.04E-02	/rcry
		Grid related	97–04	13	724.3	1.86E-02	/rcry
		Weather related	97–04	3	724.3	4.83E-03	/rcry
		All	97–04	—	—	3.59E-02	/rcry
	Shutdown operation	Plant centered	86–04	19	383.2	5.09E-02	/rsy
		Switchyard centered	86–04	38	383.2	1.00E-01	/rsy
		Grid related	86–04	3	383.2	9.13E-03	/rsy
		Weather related	86–04	13	383.2	3.52E-02	/rsy
		All	86–04	—	—	1.96E-01	/rsy

Since underground cables are not affected by weather conditions, the "Weather related" impact on both Power Operation and Shutdown Operation for Underground Cables is set to zero. As a result, the mean frequency will improve from 3.59E-02 to 3.11E-02 in Power Operation and from 1.96E-01 to 1.60E-01 in Shutdown Operation respectively, as shown in below table.

Type	Mode	LOOP Category Data	Data Period	Num. of LOOP Events	Reactor Years	Mean Freq.	Freq. Units
Underground Cable	Power operation	Plant centered	97–04	1	724.3	2.07E-03	/rcry
		Switchyard centered	97–04	7	724.3	1.04E-02	/rcry
		Grid related	97–04	13	724.3	1.86E-02	/rcry
		Weather related	97–04	0	724.3	0	/rcry
		All	97–04	—	—	3.11E-02	/rcry
	Shutdown operation	Plant centered	86–04	19	383.2	5.09E-02	/rsy
		Switchyard centered	86–04	38	383.2	1.00E-01	/rsy
		Grid related	86–04	3	383.2	9.13E-03	/rsy
		Weather related	86–04	0	383.2	0	/rsy
		All	86–04	—	—	1.60E-01	/rsy

This improvement in the Mean Frequency will thereby result in improving the CDF for the underground cable by about 20% better than the overhead transmission as shown in below table.

Cable Type	Mode	LOOP frequency	CDF
Overhead Transmission	Power Operation	3.59E-02	1.50E-05
	Shutdown Operation	1.96E-01	8.19E-05
Underground Cable	Power Operation	3.11E-02	1.30E-05
	Shutdown Operation	1.60E-01	6.69E-05

6. Cost vs. Risk Trade-off Study & Conclusion

The cost vs. risk trade off study was done using the SWOT (Strength, Weakness, Opportunity & Threat) analysis method and a survey that was distributed to all KINGS Korean & International students (12 countries).

Based on the above methods, it was concluded that if the country was likely to have frequent natural disasters, Underground Cable will be deployed despite the Cost incurred for improving the CDF; otherwise the existing overhead system will be sufficient.

REFERENCES

[1] Fukushima Nuclear Accident Interim Report: Effects of the Earthquake and Tsunami on the Fukushima Daiichi and Daini Nuclear Power Stations, especially on electric and I&C systems and equipment; Tokyo Electric Power Company; July 27, 2011 at IEEE Nuclear Power Engineering Committee
[2] Life Cycle 2012: Connecticut Siting Council Investigation into the Life-cycle Costs of Electric Transmission Lines; Prepared by KEMA, Inc. for the Connecticut Siting Council; September 14, 2012
[3] Assessment and Analysis of the State-Of-the-Art Electric Transmission Systems with Specific Focus on High-Voltage Direct Current (HVDC), Underground or Other New or Developing Technologies; Alberta Energy; December 23, 2009
[4] Impact of Offsite Power System Reliability on NPP Safety; University Of Ljubljana Faculty of Mathematics and Physics; 2008