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PS2: Beyond the oil-immersed transformer and reactor

ID10688

Development of Transformer using Natural Ester for a Modular Substation

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LS ELECTRIC

Motivation

- Recently, substations have been increasingly demanded in mountain and offshore areas to serve the electricity by connecting with renewable energy such as photovoltaic and wind power systems.

Introduction of a Modular Substation

- Unlike the conventional substation, a modular substation(as shown in Fig. 1) is a new paradigm substation to respond to power demand.
- A modular substation is applied for special places such as islands, jungles, and seas.
- The purpose of the modular substation responds to mid or long term electricity demand by connecting to renewable energy facilities, where it is difficult to build new substations rather than replacing conventional substations.
- Equipment of substation such as transformer, switchgear, and control panel was modularized and installed on a trailer or in a container. It can be applied to supply power temporary in mid/short term when a substation facility is faults and to connect renewable energy.
- The modular substation has several advantages. First of all, it can be reduced construction period, cost and site area of substation. The other is to install and move freely than conventional substation and each equipment is connected by plug and play for convenience of installation.

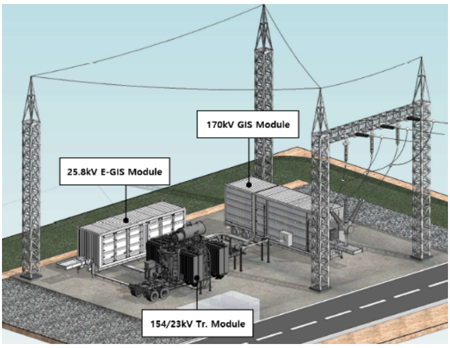

Fig. 1 Layout of modular substation

Transformer for a Modular Substation

- There are no standards for transformer for modular substation, the specifications of the developed transformer were decided referring to the standards of the existing KEPCO 154kV transformer.
- To minimize environmental pollution problem, natural ester was applied to transformer for a modular substation.
- To install and move freely, the design of transformer for modular substation needs to consider limitation of road transportation in Rep. of Korea.
- As the rate capacity increases, the weight of transformer increases. So, a feasible rate capacity of the transformer was decided to 30MVA.
- To consider the limitation of road transportation, some parts are transported separately such as oil, radiators, fans and conservator(as shown in Fig. 2).
- To reduce maintenance point, a cooling method without a pump was selected.
- The specifications of the transformer for modular substation developed are shown in Table 1.

Table 1 Development specifications of transformer

Description			Spec.
Phase			3
Frequency			60 Hz
Rated voltage (HV/XV/TV)			154 / 23 / 6.6 kV
Ratio			154 kV ± 8 x 1.25%
Rated capacity			30 MVA
Cooling type			KNAF
Insulation liquid			FR3
Impedance (HV – XV)			12 ± 7.5%
Peak Efficiency Index			99.671%
Dielectric test level	HV	FW	650 kV
		CW	715 kV
		AC	275 kV
	HVN	FW	325 kV
		AC	140 kV
Max. ambient temperature			40 degree Celsius
Temperature Rising	Average winding		65 K
	Hot – spot		78 K
	Top oil		60 K

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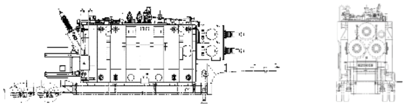
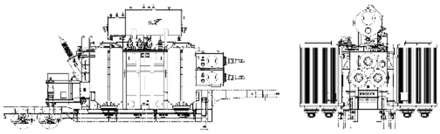


(a) Transportation



(b) Installation

Fig. 2 Transformer for a modular substation on trailer

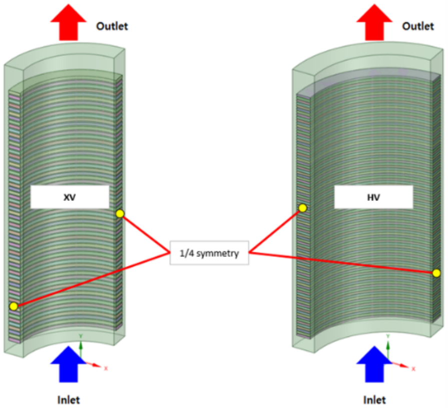


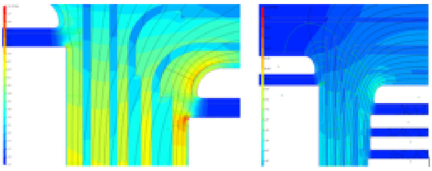
Fig. 4 Analysis model for CFD anslysis

Table 2 Results of CFD analysis

	Inlet oil (ºC)	HV (K)		XV (K)	
		Avg.	Hot-spot	Avg.	Hot-spot
Mineral oil	66.9	52.6	55.8	52.9	57.9
Natural ester	69.9	57.1	62.2	57.8	64.8
Temp. gap	+3	+4.5	+6.4	+4.9	+6.9

Insulation design

- Insulation design is the most important design step in a transformer. insulation design and analysis of most of the insulating structures, including parts considered week point for example especially the main end-insulation.Thus, it could be manufactured to have an insulating distance similar to that of the mineral oil transformer.



(a) Mineral oil condition (b) Natural ester condition

Fig. 3 Results of electric field anaylsis with different oils

Cooling design

- There are two aspects to decide cooling performance of transformer. First aspect is the structure such as cooling ducts in winding, radiator size, pump capacity and performance of cooling fan. And second aspect is material properties like kinetic viscosity, heat conductivity and specific heat. In case of natural ester filled transformer, though structure is similar with mineral oil one, cooling performance is mostly determined to consider its material characteristics.

- Average winding temperature of the developed transformer is raised to 4~5 degree Celsius, hot-spot temperature is raised to 6~7 degree Celsius by CFD analysis. Results of CFD analysis in windings are shown in Table 2.

Type test and interworking test

- The type tests were carried out for the developed transformer to verify its performance. The developed transformer has passed all the tests. It is confirmed that the developed transformer has sufficient performances.

(a) Dielectric test (b) Temperature rising test

Fig. 5 Type test of transformer for modular substation

- The modular substation consist of modular type equipment such as the transformer, 170kV GIS and 25.8kV E-GIS. Due to connect by many power and control cable of plug and play type, interoperation test was needed before move to install.To install and move freely, the design of transformer for modular substation needs to consider limitation of road transportation in Rep. of Korea.

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Accelerated degradation test setup

- In the experiment, the degradation of the insulation paper impregnated in natural ester is investigated at each sampling interval in terms of the degree of polymerization. The thermal behaviours under natural ester are also compared with under the conventional mineral oil.
- First, steel cylinders are prepared, in which the thermally upgraded insulation paper, the non-thermally upgraded pressboard, copper bar, core, and insulation oils are maintained. Before placing into the cylinders, the thermally upgraded insulation paper and the non-thermally upgraded pressboard are dried under vacuum in order to reach the acceptable moisture content less than 0.5% moisture content, which are close to new transformer conditions. Then these are impregnated in the conventional mineral oil for one set, and in natural ester for the other set. The commercially available Envirotemp FR3 fluid is used as the natural ester in this experiment.
- Second, both the two sets of steel cylinders are tightly sealed and headspaces of the cylinders are filled with dry nitrogen blanket in order to eliminate the oxidation effect of the insulation oils.
- Third, the cylinder sets are then placed inside two temperature-controlled chambers for ageing up to 8,000 hours. In detail, the cylinder set filled with mineral oil are aged at 130 degree Celsius for up to 3,500 hours. While, the cylinder set filled with FR3 are aged at both 130 degree Celsius and 150 degree Celsius for up to 8,000 hours. These aged sealed cylinders are sampled at each appropriate intervals to analyse the degradation behaviours of the insulation papers and the insulation oils.

Accelerated degradation test results

- The decreases in the degree of polymerization (DP) values of the aged insulation papers impregnated in both mineral oil and the FR3 fluid, aged at the temperature of 130 degree Celsius, are compared in Figure 7.
- The insulation paper impregnated in FR3, the natural ester shows a slower degradation than that in the conventional mineral oil.(Figure 8)
- The expected lifetime of the insulation paper can be estimated from the slopes of the reaction rate versus the ageing time. Figure 9 shows the plots of the reaction rate in terms of the degree of polymerization of the insulation paper with the ageing time. The expected lifetime of the insulation paper in the natural ester is much longer than that of in the conventional mineral oil.

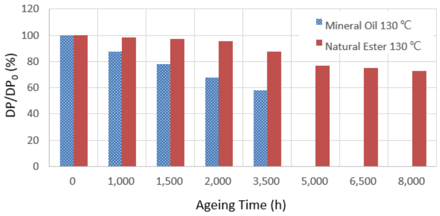

Fig. 7 DP values of the paper impregnated in MO and NE

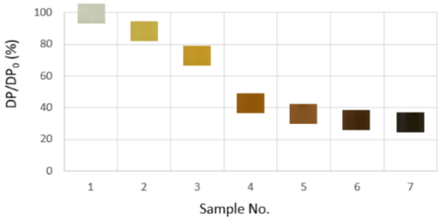

Fig. 8 Colour changes of the natural ester, FR3 with the degradation of the TUK

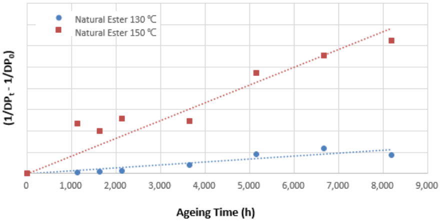

Fig. 9 The reaction rate of the insulation paper with ageing time

Conclusion

- A 154kV transformer using natural ester for modular substation has been developed. The type tests has been carried out. The test results showed that the developed transformer has sufficient performances.
- The resulting expected lifetime of the insulation paper in natural ester is predicted to about 43 years at the operating temperature of 110 degree Celsius, which is based on the degree of polymerization of 200.
- At the end of 2021, full arrangement of modular substation is installed at on site for pilot test. After a certain period of pilot tests will be performed for the modular substation, the monitoring data of the transformer will be acquired.