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"**Electricity Supply to Africa and Developing Economies …. Challenges and opportunities."**

Preferential Topic: Technology solutions and innovations for developing economies

Alternate & sustainable materials in Power sector for developing countries

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Summary

To continue unlocking economic potential and improving living standards, the world's fast-growing economies such as Brazil, Russia, India, china, south Africa (BRICS) must deliver electricity in an accessible, affordable, reliable and sustainable manner. To do so, they will need to unleash a new level of capital and resources to move the energy system towards more efficient business models with the least environmental impact. While some see this as a challenge, we see it as an opportunity for these countries to optimize their energy options, using lessons learned and technological progress to shift towards a cleaner, low-carbon energy systems and more affordable generation and distribution system.

Electricity grid systems are strategic infrastructure and play a significant role for a developing country's economy. Their primary challenge is transmitting electrical energy as inexpensively, efficiently and environment friendly as possible. To do so there is need to integrate transmission systems with renewable energy sources. In the electricity grid system, Transformer is vital part. Reliability and service life of transformers is significantly influenced by the quality of the insulating system. Now days, the research in the field of insulation liquids is focused on environmental friendly fluids. Therefore, the normal mineral oil is compared to the perspective fluid based on natural esters.

Natural Ester based sustainable alternate fluids are now available in market for transformers. Market leader is Natural ester Envirotemp™ FR3™ dielectric fluid, helps to reduce lifecycle costs and provide fire safety benefits with green solution for the transformers in power utility & industrial market.

As Per IEC 60076 part 14 annexure, By using less-flammable, having high fire point natural ester liquid as a coolant and dielectric insulator instead of traditional oil, the risks associated with a potential transformer fire are significantly condensed. To improving the reliability, high temperature capability and preventing thermal ageing of the power transformer, natural ester

Envirotemp™ FR3™ dielectric fluid plays key role in building better transformer with improved performance.

Natural ester Envirotemp™ FR3™ dielectric fluid is an *advanced biodegradable* electrical insulating fluid sourced from high renewable natural agricultural sources (Soybean seed) to be friendly to the environment. The fluid has excellent dielectric characteristics with high temperature stability and superior fire point 360°C against mineral oil 160°C. Natural ester Envirotemp™ FR3™ dielectric fluid has excellent compatibility with solid insulating materials and is biodegradable in within 28 days.

Envirotemp™ FR3™ dielectric fluid can absorb water thus greatly increasing the life of the insulation paper immersed in it. In fact, a study based on tensile strength and degree of polymerization measurements has shown that Kraft paper immersed in Envirotemp™ FR3™ dielectric fluid lasts 5 to 8 times as long as paper in transformer oil derived from petroleum sources. This property combined with Envirotemp™ FR3™ dielectric fluid's superior thermal properties means a transformer can support higher hot spot temperature in its windings & support additional loading on transformer without compromising life.

Through the BEES® 4.0 lifecycle analysis, FR3 fluid has been shown to produce *56x less carbon emissions* than mineral oil and is essentially *carbon neutral*.

As now days, petroleum prices are volatile, there will be more and more interest in renewable sources for transformer dielectric coolants than the hydrocarbon oils and as FR3 fluid being derived from soybean seeds, their production and utilization is simple and cost effective. Overall, this can ensure sustainable development specially countries in BRICS with backward integration.

By going into industrial products like Envirotemp FR3 fluid, it creates a new demand stream that on average would tend to increase the price to the farmer. So far, the market for Envirotemp™ FR3™ dielectric fluid has been very encouraging.

Introduction

Fire safety, firewalls, deluge systems, and fluid containment are some of the fire protection requirements, users have to address while installing mineral oil filled transformers. Aging substation infrastructure, environmental protection, and resource sustainability are other growing issues.

Ester based alternate fluids are now available in market viz. Natural Esters which take over the limitations of conventional mineral oil in terms of biodegradability as it is made up of renewable sources,. Low fire point of mineral oil and consequent safety issues with transformer explosions and fires that can cause catastrophic damages.

The experience in India on using alternate environment friendly fluid is growing at accelerated speed., a good number of distribution transformers up to 66 kV have been retro filled with natural ester liquids. In case of power transformers, Gujrat Electric Transmission Company (GETCO), a state government owned company in India, has taken lead and used natural ester Envirotemp FR3 dielectric fluid in 2 Nos. 66 kV class 15 MVA transformers to have first-hand experience & now 200 plus substations in pipeline with Natural ester fluid filed transformers.

Case Study

Gujarat Energy Transmission Corporation Limited (GETCO), a state transmission utility of Gujarat India, is one of the growing transmission companies having more than 1350 substations and 50000 circuit km transmission lines. Transmission voltage within GETCO grid varies from 66 kV to 400 kV.

Moving forward on improving fire safety at urban substations and also to offer green solutions, GETCO identified two nos. 15 MVA 66/11.55 kV class power transformers from a lot of 184 Nos. manufactured at T&R, to be filled with natural ester liquids to gain field experience.

Electrical and constructional designs of mineral oil filled option of 15 MVA transformer was studied in all aspects and was found suitable for natural ester FR3 fluid (NE) application without any change in the existing design / methodology. .

Salient technical specifications of the copper wound transformer filled with natural ester Envirotemp FR3 dielectric fluid are as under:

Table I: Salient Technical specification of 15 MVA 66/11.55 KV transformer

Sr.No.	Technical Specification	Rating
1	Rated Power	15 MVA, Three Phase
2	Voltage Ratio	66/11.55 kV
3	Rated Frequency	50 Hz
4	Vector Group	Dyn11
5	% Impedance at rated tap	9.5 %
6	Voltage Regulation	+ 15 % to – 5.0 % in steps of 1.25% on HV for LV variation VFVV mode
7	Cooling Type	KNAN
8	Temperature Rise ºC	35 Oil, 45 Winding
9	BIL LI (kVp) One minute PF voltage (kVrms)	 HV - 350, LV - 90 HV - 140, LV - 30
10	Guaranteed losses	No Load loss : 9.50 kW Maximum Load loss : 51.0 kW Maximum

A. Design Review:

Following points were jointly discussed and deliberated before going for retro filling of subject transformers.

1) To avoid direct contact of NE with air, during transport, 100 mm nitrogen cushion shall be provided in the tank.

2) Due to different viscosity as compared to mineral oil, more impregnation & settling time was allowed.

3) Moisture content in NE before filling in tank shall be kept lower than 50 ppm, even though IEC 62770 allows for 200 ppm. This will keep dry new transformer in dry state for longer period.

4) The transformer shall be painted with Green strips of 300 mm at interval of 300 mm provided diagonally on existing paint of shade 631 of IS:5 on all surfaces to identify from distance & avoid any mixture in furring during top up if any.

5) Special instruction plate shall be provided on transformers in bold letters for use of NE oil.

6) In case of any deviation from specified values, the acceptance will be decided mutually based on applicable standards.

7) Basic liquid properties of NE shall be monitored as mentioned below.
   a. Before energizing.
   b. After 24 hours of energizing.
   c. After 7 days of energizing.
   d. After 30 days of energizing.
   e. Every month for 6 months.
   f. Bi-monthly after 6 months of energizing.

B. Testing Experience:

Both 15 MVA, 66 kV class transformers were subjected to all routine and type tests (viz. temperature rise and impulse test). As mentioned in various literatures due to inherent polar nature of ester liquids[1], significant differences were observed in winding tan delta and insulation resistance for both transformers. Comparison of insulation resistance and winding tan delta values with respect to mineral oil is given in figure 1 and 2 (20 Nos. same design mineral oil filled were compared with 2 units of natural ester liquid filled units).

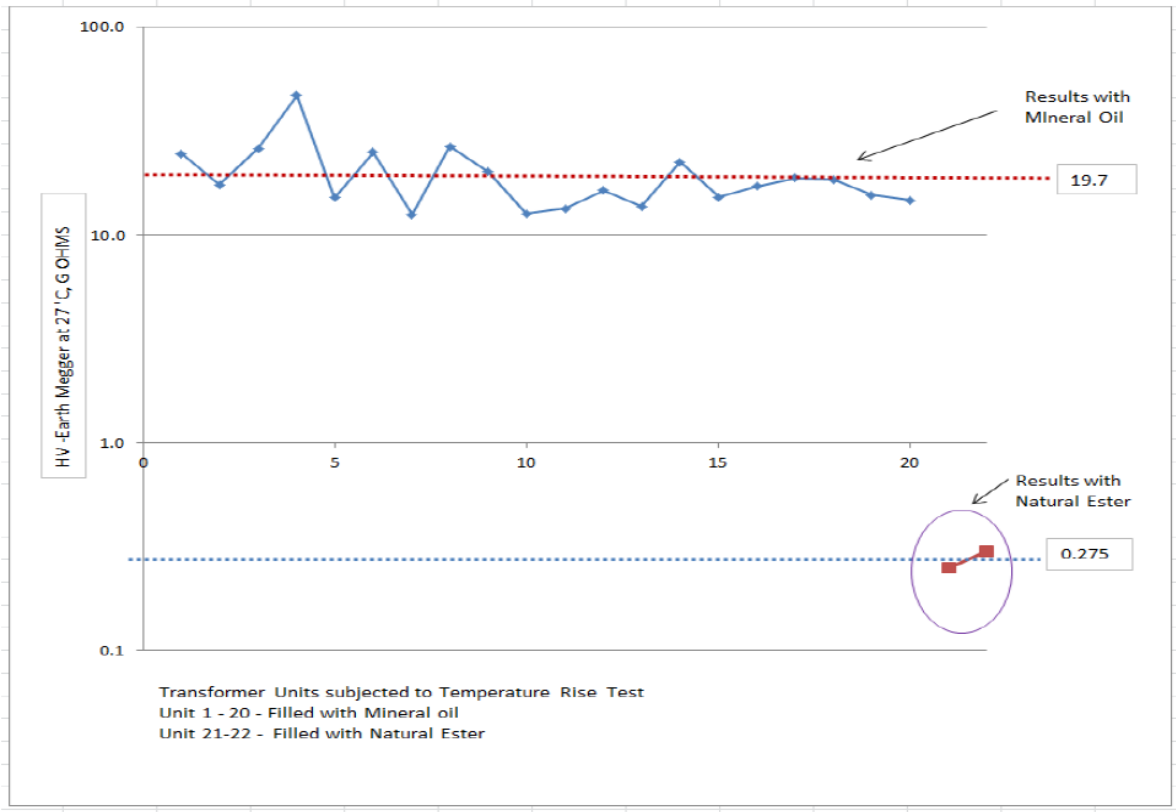


Figure 1: Comparison of insulation resistance values between identical designs of mineral oil and ester liquid filled transformers

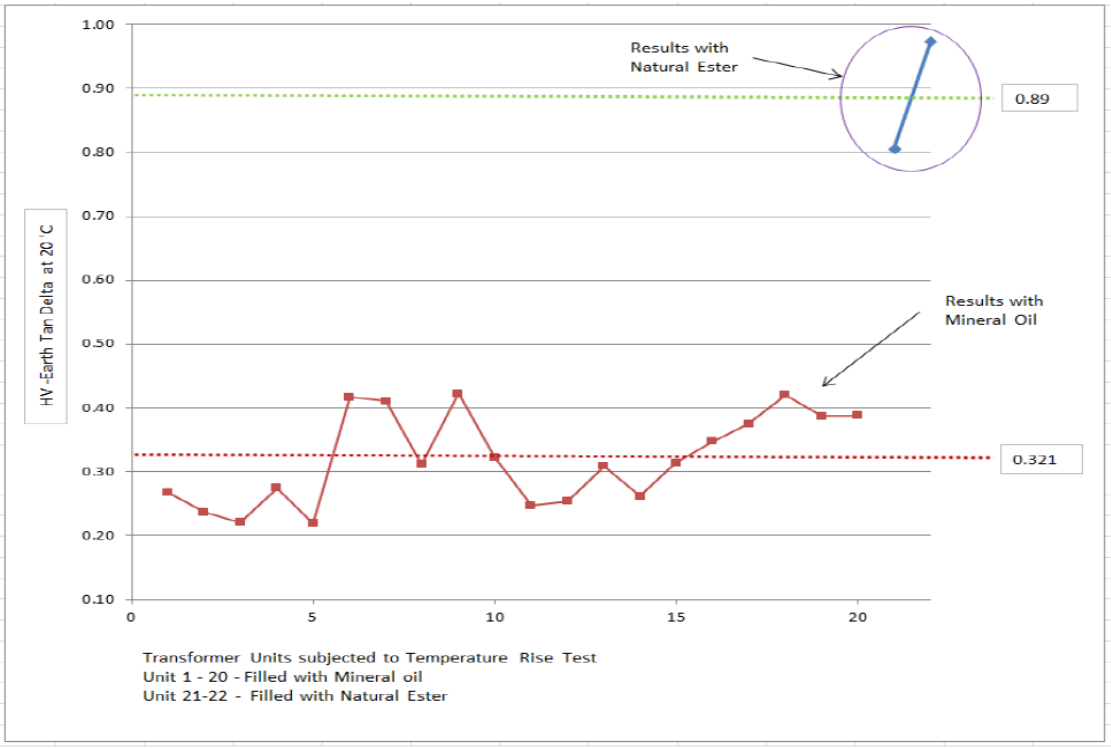


Figure 2: Comparison of winding tan delta values between identical designs of mineral oil and ester liquid filled transformers

While average insulation resistance value and tan delta value of 20 units of transformers filled with mineral oil are 19.7 G-Ohms and 0.00321, the corresponding average values of natural ester filled transformers are 0.275 G-Ohms and 0.0089. This observation was as expected based on insulation resistance and tangent delta performance of ester liquids.

Transformers with natural ester liquid passed all the dielectric tests satisfactorily. However, in temperature rise test % increase in top liquid temperature was of the order of 9.6%. Higher temperature rise is expected because of high viscosity of ester liquids. However, the temperature rises were still within the guaranteed temperature rises because of inherent margins available in mineral oil filled design.

C. Field Experience:

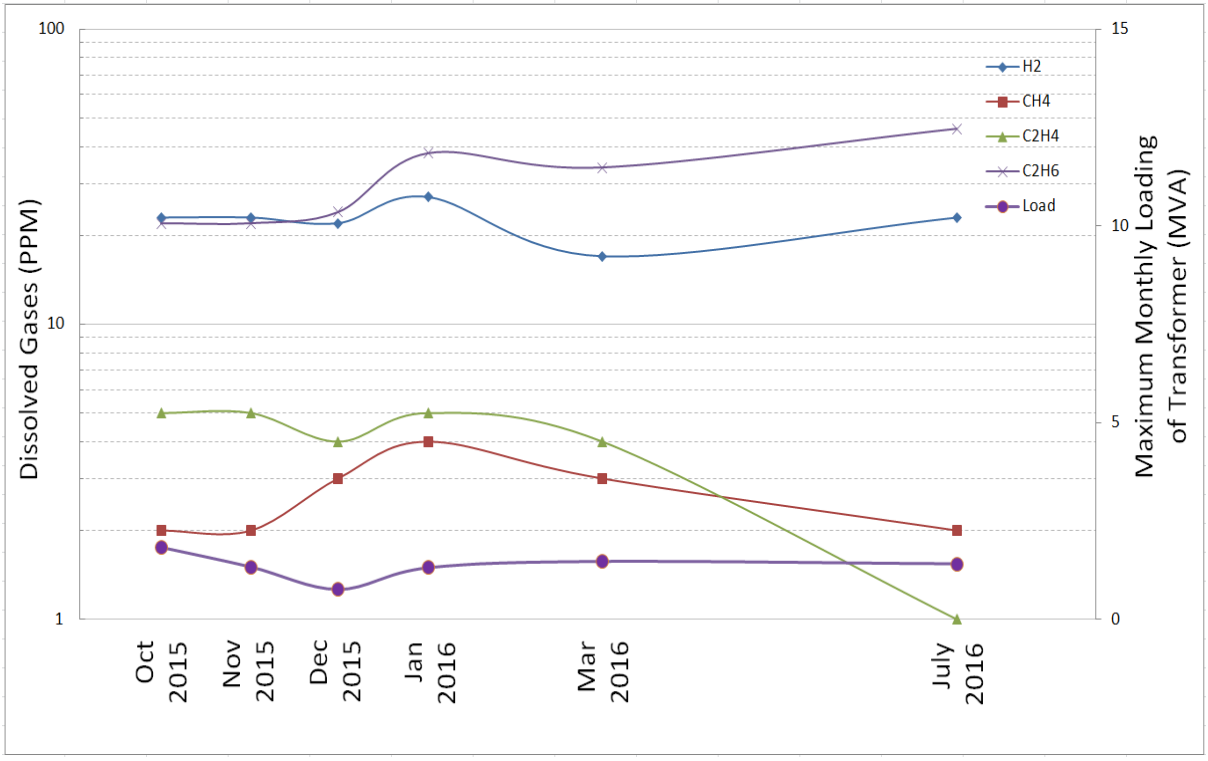
After completion of all routine and type tests, both 15 MVA transformers were dispatched to VESU substation of GETCO. Figure 3. shows 15 MVA green transformer under dispatch and in service.

Commissioning of both the transformers was done one by one by GETCO under supervision of T&R representative. All the required precautions were taken such that minimum exposure with air. The pre-commissioning checks and tests were carried out. The transformer was charged on 09.11.2015.

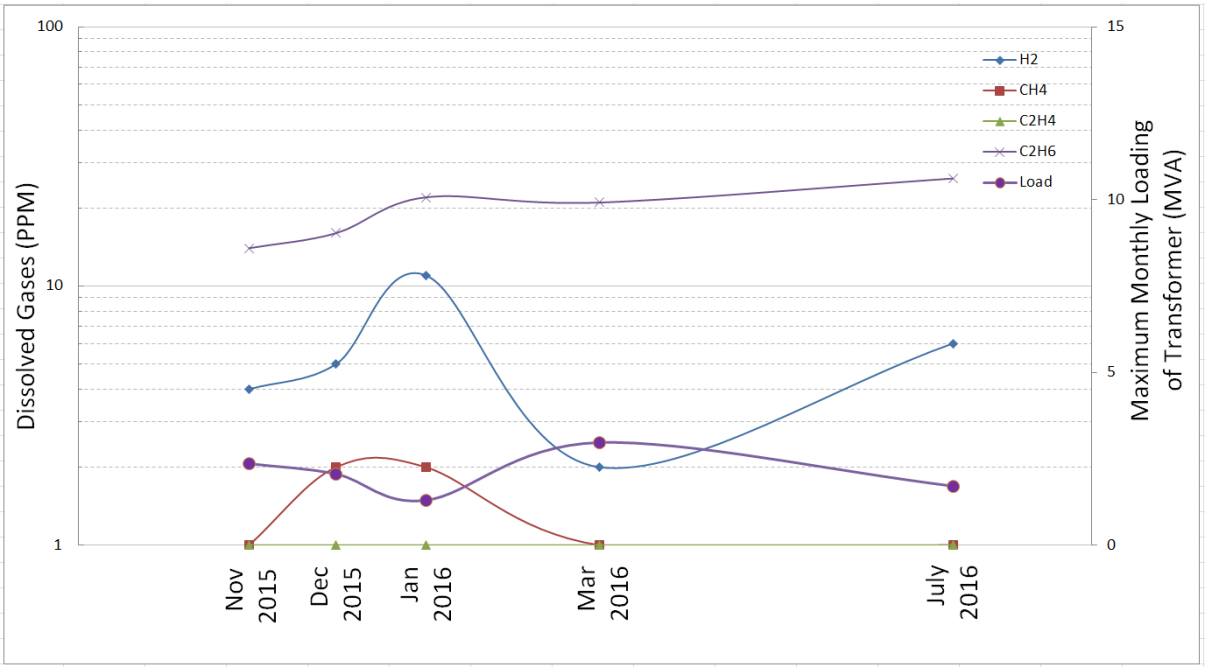
Over nine months in service, both the transformers have undergone periodic dissolved gas monitoring and other natural ester properties. Dissolved gas analysis was used to study the types of gases produced inside the transformer during its time in operation.

Figure 3. shows 15 MVA green transformer under dispatch and in service. 15 MVA Green transformer installed at 66 kV Vesu s/s

Graphical representation of key gases for both transformers with respect to loading conditions during this period is given in figure 5 (a) and (b). There was no generation of Acetylene (C2H2). As the loading conditions during the period under review were minimal, the maximum oil and winding temperature were of the order of 58 °C.



(a) Transformer 1 Sr. No. PC0101020



(b) Transformer 2 Sr. No. PC0101012

Figure 5 Graphical representations of periodic Oil DGA test results

Non-mineral oils appear to be more stray gassing type than mineral based oils. Gassing data from many transformers retro filled with Envirotemp FR3 liquids since 2001 have indicated significant difference with stray gassing in ester liquid as compared to mineral oil. Ethane (C_2H_6) gas formation can be attributed to the stray gassing of FR3, which normally is not expected from mineral oils. These are not considered a fault or a concern with the transformer and such experiences are presented in various platforms.

In addition to dissolved gas analysis, both transformers underwent tests for basic liquid properties. Such results after some nine months of operation are indicated in Table II.

Table II

Property	Reference value reported at receiving stage	Transformer 1 Sr. No. PC0101020	Transformer 2 Sr. No. PC0101012
Breakdown voltage (kV)	94	62	62
Water content (ppm)	41	54	67
Viscosity at 40 ℃ (mm_2/Sec)	27.34	27.47	27.36

As can be seen from table II, viscosity levels of the liquid for both transformers have shown a steady trend which indicates that the liquid is not affected with exposure to atmosphere.

Higher water content is also not a case of concern since BDV is within permissible values for this class of transformer & dielectric properties of NE do not detoriate as compared to mineral oil. Higher water content is due to high moisture retention property of ester liquids. GETCO has prepared specification for Ester liquids

CONCLUSION

Experience with use of Natural Ester (FR3) in 15 MVA 66 kV class transformers has been satisfactory. At works testing, in dielectric high voltage tests, transformer filled with this liquids with same design as for mineral oil filled type, did not give any problem. However, same temperature rises require about 4 to 10% increase in fins of radiator. Up to 66 kV, it is a kind of retro filling experience. This pilot project has laid down the future plan for GETCO to go in big way to adopt sustainable, green solution with safety & reliability in their network. Today 200plus ester filled transformers under installation, execution & commissioning.

Globally, transformers up to 420 kV class have been built using ester liquids & well proven but still individual customer will like to have their own studies before going in a mass implementation. Environmental demands and fire safety need more and more use of such fluids. It is intended to closely monitor these two transformers to help us understand long term behavior and experience for future, with respect to loading conditions.

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