Nanotechnology applications for electrical transformers

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Proposal

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Technical Details

Project Title :

Nanotechnology applications for electrical transformers

Domain : Advanced Materials

Theme : Materials Education (Nanomaterials, Biomaterials And Devices, Polymeric And Soft Materials, Glassy And Amorphous Materials, Bio-Inspired And Patterned Functional Materials)

Research Topic : Production of materials of high purity.,Biodiversity Conservation

Other Research Topic :

Aims and objective :

Nanoscience and nanotechnology applications have shown remarkable progress in several industrial fields, producing advance materials. Nowadays, there are a great number of technological developments and R&D projects regarding nanotechnology concepts to enhance performance and reliability of conventional materials. Electrical industry has taken advantage of these nanotechnology efforts looking for application in its components, such as in electrical transformers which are considered as key elements in the electricity network. This work includes a comprehensive literature review on the applications of nanotechnology concepts for transformers, especially investigations related to insulating materials, dielectric fluids, outdoor insulators, monitoring systems and other components. Latest up to date literature on the applications regarding nanomaterials for transformers will be reviewed and reported. In addition, opportunities for future research and a general overview of nano-applications in electrical transformers

Project Summary :

Nanoscale materials (or nanomaterials) contain nanoparticles or are developed using nanotechnology. Nanoparticles are commonly considered to be materials that have at least one dimension that is less than 100 nm. Nanoparticles can be distinguished according to their origin. They can occur naturally (e.g., from volcanic eruptions); they can be produced incidentally during other processes (e.g., from fuel combustion); and they can be manufactured intentionally. Manufactured nanomaterials can be classified according to their method of production.
Some are produced “from the top down,” as when a bulk material (e.g., gold, silicate) is reduced to a mass of nanoscale particles. Because of their very small size, these nanoscale metals, metal oxides, powders, and dusts have physical, chemical, magnetic, electrical, mechanical, and other properties that differ from those of the bulk materials from which they are derived. The second type of manufactured nanoparticles are built “from the bottom up,” atom-byatom or molecule-by-molecule. Engineered nanoparticles of this type are still relatively difficult and expensive to manufacture, but they have the potential to impact energy development and use, transportation, electronics, manufacturing, and other disciplines.

Keywords :

Power, Distribution
Nanotechnology
Electric transformers

Transformers
Engineering and manufacturing industries

Background/genesis and motivation :

Nanotechnologies have potential to be used in transformer industry in enhancing material properties which may lead to a compact design of transformer and reduced manufacturing cost.

Justification and novelty :

anoscience and nanotechnology applications have shown remarkable progress in several industrial fields, producing advance materials. Nowadays, there are a great number of technological developments and R&D projects regarding nanotechnology concepts to enhance performance and reliability of conventional materials. Electrical industry has taken advantage of these nanotechnology efforts looking for application in its components, such as in electrical transformers which are considered as key elements in the electricity network.

Plan of work :

Several types of nanoparticles to be selected and added into mineral oil. Breakdown voltage, streamer propagation velocity, oxidation stability, permittivity, electrical resistivity and dissipation factor were measured and studied. Results to be otained which shows that the dielectric properties of a modified liquid are strongly influenced by the type of the nanoparticles added. With the addition of one type of nanoparticles, the breakdown voltage of the liquid is much increased while the streamer propagation velocity is reduced. With the addition of another type of nanoparticles, the degree of scatter of breakdown data is improved, and thus the low probability value of breakdown is increased. The latter will increase the reliability of the insulation system or saying that there is a potential to increase the design values of the insulation system. A charging dynamic model is discussed. A trend has been seen from this study that nanofluids have potential for being used in transformer insulation liquid.

Important milestones and projected time to reach such targets :

A state-of-the-art review of nanotechnology alternatives for transformers will be included
Performance of materials used in transformers can be enhanced by nanoparticles.
Nanofluids, nano-insulation, nanostructured insulators are the main topics.
A general prospective of nanomaterials applications for transformers will be analyzed

Projected deliverables :

Nanotechnologies may
speed cleanup of soil and water contamination

Target beneficiary and impact :

the identified nanotechnology applications for pipelines involve material
coatings (insulation, corrosion, and multipurpose). Other potential applications include
nanosensors, which have the potential to minimize environmental damage by identifying
potential leaks before they spread, and oil spill remediation with nanomaterials, which may
minimize damage should a leak occur.This application is suitable for Industrialists in identifying the leakages easily and for Individuals to adapt for new technologies for simplicity and safe operation.

Budget Details

SNo.	Budget Heads	Amount (in Rs.)
1	Equipment	80,000
2	Manpower	15,000
3	Consumable	35,000
4	Travel	50,000
5	Contingency	10,000
6	Overhead	6,000
Grand Total (in Rs.)		**1,96,000**

Reference Material

1. Patent

Superparamagnetic iron cobalt ternary alloy and silica nanoparticles of high magnetic saturation and a magnetic core containing the nanoparticles, US20140375403A1

2. Paper

Electric Power Systems Research
Volume 143, February 2017, Pages 573-584
Electric Power Systems Research
Nanotechnology applications for electrical transformers—A review
Author links open overlay panelJ.E.ContrerasaE.A.RodriguezbJ.Taha-Tijerinac

3. Paper

Application of Nanotechnologies
in the Energy Sector, Hessian Ministry of Economy, Transport,
Urban and Regional Development
www.hessen-nanotech.de

Suggested Referee(s)

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PROFORMA FOR BIO-DATA (to be uploaded)

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3. Institution : MALLA REDDY ENGINEERING COLLEGE(AUTONOMOUS)

4. Date of Birth :07/08/1981

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6. Category Gen/SC/ST/OBC :General

7. Whether differently abled (Yes/No) :No

8. Academic Qualification (Undergraduate Onwards)

	Degree	Year	Subject	University/Institution	% of marks
1.	B.Tech	2002	EEE	B.V.R.I.T, Narsapur, Medak.	76
2.	M.Tech	2005	Control systems	JNTUCEA, Anantapur, A.P.	74
3.					
4.					

9. Ph.D thesis title, Guide's Name, Institute/Organization/University, Year of Award.

"Performance Evaluation and Energy management system for Hybrid Electric Vehicle", JNTUH, Hyderabad, 2016

10. Work experience (in chronological order).

S.No.	Positions held	Name of the Institute	From	To	Pay Scale
1	Professor and **Dean R&D**	MREC(A)	2009	2017	90,000/-
2	Sr.Asst.Prof	ATRI	2008	2009	35,000/-
3	Asst.Prof	GRIET	2007	2008	30,000/-
4	Asst.prof	BVRIT	2005	2007	25,300/-
5	Senior Research Engineer (R&D)	Future Tech Instruments	2002	2003	18,000/-

11. Professional Recognition/ Award/ Prize/ Certificate, Fellowship received by the applicant.

S.No	Name of Award	Awarding Agency	Year
1	Best paper presented in MRECW	MRECW	2015
2	Best paper presented in STACE, AEEE	IOAJ	2012

12. Publications *(List of papers published in SCI Journals, in year wise descending order).*

S.No	Title Name	Author's name	Journal Name	Volume No.	Issue No.	Impact Number	Citation Index	Year/Month of publication	Page Nos.
J-1-2009-JAN	Simulation and analysis of SVPWM based 2-level and 3-level inverters for direct torque of Induction motor	M. Lakshmi Swarupa(1), Dr. G. Tulasi Ram Das(2), Dr. P.V. Raj Gopal(3)	International Journal of Electronic Engineering Research	1	3			2009	929-933
J-2-2009-MAR	Energy management for parallel hybrid electric vehicle based on driving cycle	M. Lakshmi Swarupa(1), Dr. G. Tulasi Ram Das(2), Dr. P.V. Raj Gopal(3)	International Journal of Electronic Engineering Research	1	Number 3			2009/March	1,678 (3 Vols)
J-3-2012-JULY	Performance of energy storage system for parallel hybrid electric vehicles	M. Lakshmi Swarupa(1), Dr. G. Tulasi Ram Das(2), Dr. P.V. Raj Gopal(3)	International Journal of engineering research and development(peer reviewed journal)	1	11			ISSN:2278-067X, July 2012	49-51
J-4-2013-APR	Performance evaluation of parallel hybrid electric vehicle based on driving cycle	M. Lakshmi Swarupa(1),, Dr. P.V. Raj Gopal(2) ,Dr. G. Tulasi Ram Das(3)	Wulfenia Jounal	-	-			Selected	
J-5-2013-APR	Performance evaluation and energy management system for parallel hybrid electric vehicle	M. Lakshmi Swarupa(1), Dr. G. Tulasi Ram Das(2), Dr. P.V. Raj Gopal(3)	IJMER	-	-			Selected	
J-6-2013-APR	Measurement of Real time drive cycle for Indian roads and system-level modeling for PHEV using MATLAB	M. Lakshmi Swarupa(1), Dr. G. Tulasi Ram Das(2), Dr. P.V. Raj Gopal(3)	Int. Journal of Electrical Electronics and Telecommunication Engineering	44	1			ISSN: 2051-3240	1138-1145

15. List of Conferences:

S.No	Title Name	Author's name	Conference Name	Impact factor	Citation Index	Year/Month of publication	Page Nos.
C-1-2008-DEC	Fault prognosis for Electrical equipment for Battery operated vehicle	M. Lakshmi Swarupa(1), Dr. G. Tulasi Ram Das(2), Dr. P.V. Raj Gopal(3)	International Conference on Advanced Computing Technologies			26th – 27th December 2008	929-933
C-2-2012-JULY	Vector control scheme for induction motor using different controllers with and without the end effects	M. Lakshmi Swarupa(1), Dr. G. Tulasi Ram Das(2), Dr. P.V. Raj Gopal(3)	International conference on advances in electrical and electronics engineering, interscience research network(India)			22nd July 2012	59-66
C-3-2012-JULY	PMSM electric drive system simulation for parallel hybrid electric vehicle	M. Lakshmi Swarupa(1), Dr. G. Tulasi Ram Das(2), Dr. P.V. Raj Gopal(3)	International conference on software technology and computer engineering(Interscience research network, India)			22nd July 2012	42-48
C-4-2012-AUG	Design and simulation of battery charger for parallel hybrid electric vehicle	M. Lakshmi Swarupa(1), Dr. G. Tulasi Ram Das(2), Dr. P.V. Raj Gopal(3)	International conference on recent development in engineering and technology(IOAJ)			5th August 2012	90-95

16. Any other Information (maximum 500 words)

- Papers presented on high voltage engineering, HVDC, Embedded systems (RTOS), optimal energy flow control of an electric vehicle, microprocessors and controllers.
- Handled B.TECH projects like fire reformer by using 8051 controller, pipe leakage detection by using CAN bus architecture –8051controller, best of waste, little door guard, dimmer, conductance tester, smart switch etc.
- Designed "USB based Electric Vehicle"
- Presently working on **HYBRID ELETRIC VEHICLES – FUEL CELLS**.
- Guided M.Tech Project - 600 and B.Tech projects – 500
- Guided so many projects related to Electric vehicles

NANO TECHNOLOGY APPLICATIONS IN ELECTRICAL TRANSFORMERS

Pressure on transmission systems has resulted in longer lines and higher voltages and currents, necessitating new higher rated and more efficient power transformers. Loss reduction, costing, environmental and reliability issues for power transformers are all under pressure, with efforts to reduce manufacturing and operating costs while increasing reliability the prime concern of developers.

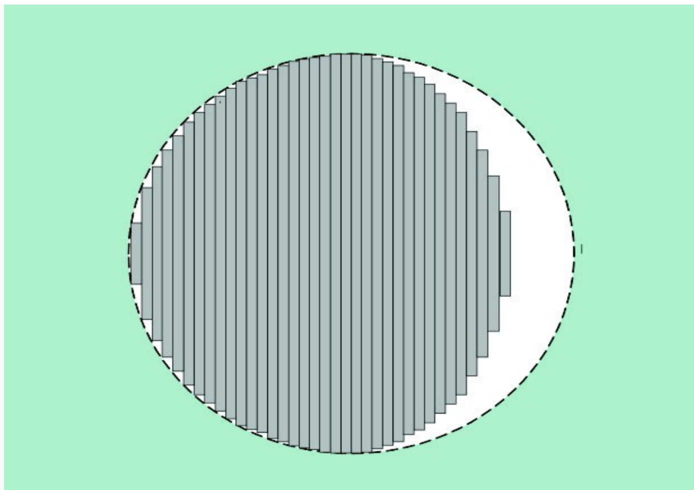


Fig. 1: Asymmetric core shapes for special purpose power transformers.

New developments focus primarily on the active components of the transformer, being mainly the core, windings, insulation and cooling systems.

Transformer core developments:

Material: Power transformers make use of grain orientated steel materials for the core. Developments are ongoing and moving towards even thinner material thickness (from 0,23 mm to 0,18 mm) to reduce losses. Laser scribing of decreases the eddy current losses by refining the magnetic domains in the steel. Stresses are introduced in the rolling and coating processes, which increase the losses in the material, by affecting the grain boundaries and domains. Coating is applied to reduce eddy currents. Laser scribing of lines in the direction of the grain orientation reduces the stresses and improves the grain boundaries.

Amorphous core material: Amorphous material has no grain structure and is only available in very narrow plates. Losses are claimed to be 30% of grain orientated steels. Price and size of material however limits the application to smaller transformers [2].

Item	Mitred (single step)	Multi step
Flux density in joint	2,7 T	2,0 T
Increase in flux above Nom.	58,8%	17,7%
Condition	Deep saturation	Below 2,03 T saturation level

Configuration

- Assymetric cores

Constructing the core from laminations allows the core shape to be varied from circular to assymetric shapes to accommodate size and space requirements without affecting the magnetic properties of the core (Fig. 1). This is of importance in special transformers such as those used in mobile substations.

- Mixed material – non uniform losses

Where losses vary in the transformer cores, different grades of steel are used for different parts to reduce costs, high quality low loss for high loss areas and cheaper lower grade for low loss areas.

- Overlap joints

Joints occur at the corners and intersection of limbs of the transformer core. Losses are higher as the flux path between elements is reduced and designs are aimed at reducing flux levels at joints. Single step lap provides a lower reluctance path for the flux and is the most commonly used method.

The multiple step lap (MSL) configuration, where overlap occurs at multiple different positions, has been developed to reduce reluctance even further. This leads to a higher manufacturing cost offset by savings in losses. The improvement possible with multiple step lap joints, for a transformer with nominal flux density of 1,7 T.

Environmental issues

Transformer noise is a prime problem, as mechanical vibrations at low frequencies are transmitted by concrete and other mechanical structures. The fundamental noise frequency is 100 Hz but may contain higher harmonics as well. Reduction of noise involves the following:

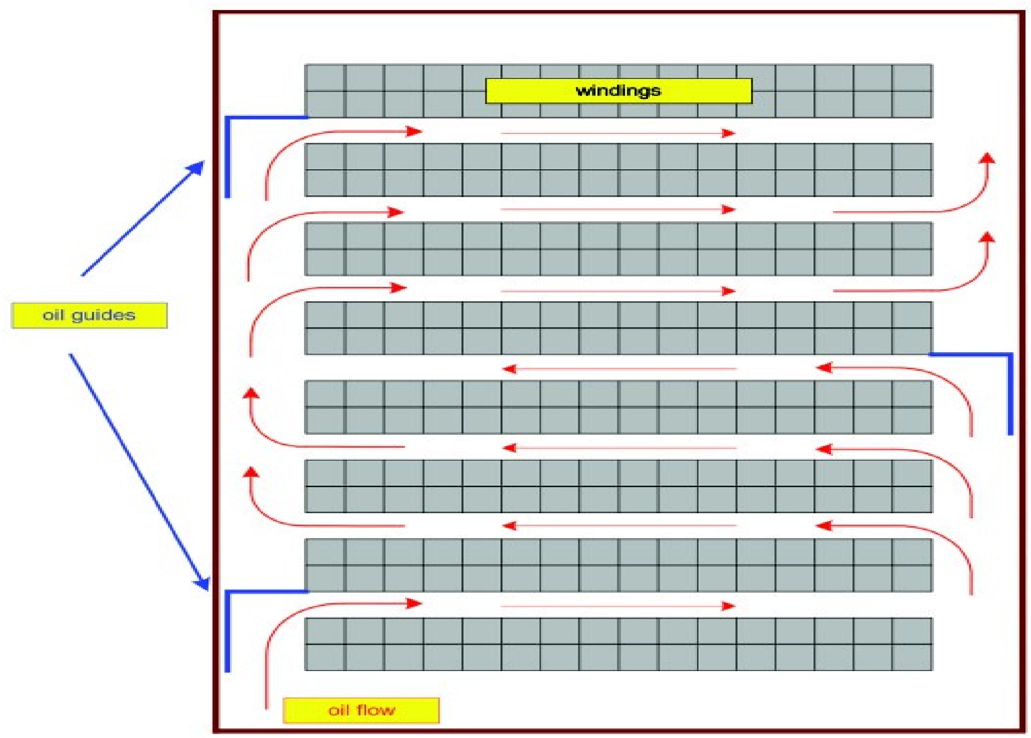
- Reduction of core flux density resulting in bigger cores
- Reduction in magnetostriction effects by choice of suitable core material
- Resonance analysis of both the core and the tank to determine natural mechanical resonant frequencies. These are often found to be close to the 100 Hz harmonic of the magnetisation current. Damping and stiffening of the tank or redesigning of the core to reduce resonance or moving the resonant frequency away from the magnetisation frequency

are proving as effective as changing materials. Advanced methods of analysing mechanical resonance are making it possible to reduce noise to acceptable levels.

Windings and conductor developments

Materials: copper-silver alloy

Operating pure copper at the temperatures encountered in a power transformer results in self annealing caused by crystal regrowth. This results in reduction of the strength obtained by hard drawing and reduces the short circuit (SC) withstand ability of the transformer. The addition of silver at a rate of 0,03 to 0,1% prevents self-annealing.



Oil guides control the circulation of oil within the windings (M Rycroft).

Conductors

Power transformers use flat enamelled copper of various profiles, depending on the winding type used. The conductors can be combined in bundles before winding. Bundled conductors can experience problems with circulating currents, which are due to stray flux from the cores and because of the different position of the outer and inner conductors in a bundle from the core. To reduce this, conductors in a bundle are transposed, inner to outer, at regular intervals. The product known as continuously transposed conductor, is supplieding this form to manufacturers (Fig. 4).

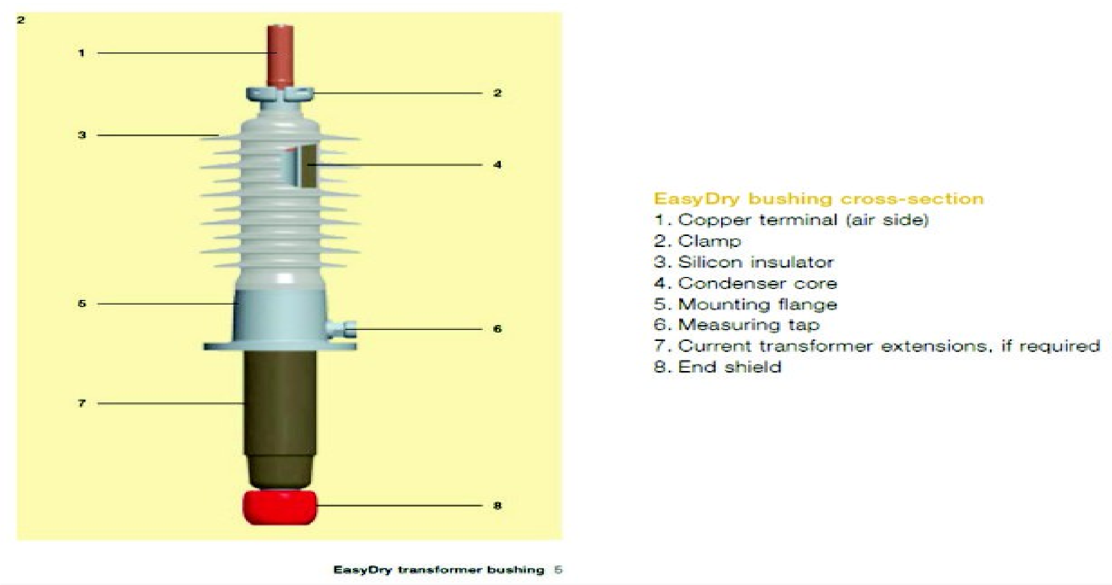
Expoxy bonding of conductor bundles

Conductor bundles are also required to have sufficient strength to withstand the forces present in the windings during short circuits, which could cause separation of a bundle of conductors. To achieve this, bundles are supplied with a high temperature epoxy coating which is cured during the assembly process. Coatings can be applied between conductor layers or on the bundle as a whole.

Insulation

Cellulose based insulation tape and boards are used in the windings of the transformer. Developments and trends with insulation:

- High temperature insulation: The lifetime of paper based insulation depends on temperature. With ongoing higher temperatures the development of high temperature paper insulation has become a necessity. Typical product in the elevated temperature range would be Nomex, a product produced by DuPont.
- High strength paper tape which allows tighter wrapping techniques to be employed is available on the market.
- Laminated pressboard which has been used in transformers where strength in insulation is required. It offers significantly better qualities such as consistent parameters. Laminated wood can contain irregularities which could lead to failures.



The ABB EasyDry RIS Bushing (ABB).

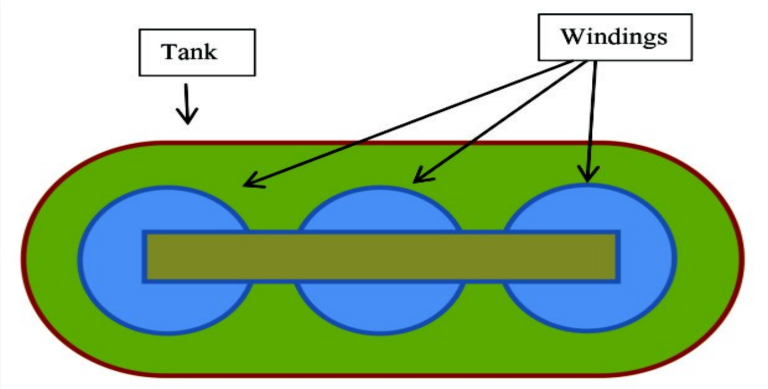
Oil insulation

- Natural esters

Natural esters such as vegetable oil are being tested and used increasingly in the power transformer market. These oils offer higher flash point ratings than mineral oil, and less dispersion on leakage, an important factor affecting the site safety design.

- Gas to liquid (GTL) oil

Synthetic transformer oils are a fairly new product in the transformer oil market. Manufactured from natural gas they have essentially zero sulphur and a very low aromatic and unsaturated content. Consequently, they offer superior additive response, improved resistance to degradation and better thermal properties, which can translate into increased transformer reliability and efficiency. The key benefit is consistent chemical composition and performance as they have a uniform molecular structure and low impurity levels, a base oil and an antioxidant. No other additives are used. A South African transformer user is apparently preparing to go ahead with a trial of DTL oil on one of its smaller power transformers.



Round transformer tank ends reduce oil requirements.

Cooling systems

Internal oil guides and cooling ducts

To be effective, cooling oil must flow freely through the core, and must be in close contact with sources of heat. To achieve this transformers are designed with oil flow ducts or paths in both the core and the windings. The size and placement of ducts will be determined by the performance requirements of the transformer and the external cooling system used. Oil guides are placed on the outer layer of the windings to divert vertical oil flow horizontally through the windings.

Static build up due to oil movement

In forced oil circulation systems static charges can build up due to the movement of oil across the insulation material surfaces. This is combated by adding ionic compounds to the oil.

External oil cooling systems make use of external radiators to cool the oil and are classified as follows:

- *ONAN (Oil natural air natural)*: Natural circulation used for both oil and air.
- *ONAF (Oil natural air forced)*: Natural circulation is used for oil and forced circulation (fans) for the air.
- *OFAF (Oil forced air forced)*: Oil circulation is forced by pumps and forced circulation is used for cooling air.
- *ODAF (Oil directed air forced)*: Forced circulation is used for the oil and in addition the oil flow is directed to follow a designed path through the core and windings. Forced cooling of air is used.

ODAF is a very effective method of cooling, which allows higher current densities in the windings to be used, resulting in less copper and smaller windings. In spite of additional costs of running the pumps, ODAF is proving very popular method of cooling in large power transformers, especially those with a high duty cycle, such as generator step-up (GSU) transformers. Developments are trending in the direction of greater use of ODAF in power transformers, as more knowledge on the design and performance of these systems becomes available. Reduction in copper however reduces the short circuit withstand capability.

External component developments

Bushings

Bushings are used to connect the active parts of the transformer to the transmission line and must perform as reliably as the transformer. There are a number of types in use.

- OIP (oil insulated paper): the oldest and most developed technology, available at ratings up to 1200 kV.
- RIP (resin impregnated paper): a dry type of bushing available at ratings up to 800 kV.
- RIS (resin impregnated synthetic): this is the latest development in bushings and models have cast-on silicon insulator sheds, which gives a superior performance. The synthetic material and filler are not hydroscopic and there is no deterioration in tan-delta over the lifetime, and hence reduced possibility of failure. This item is only available up to 170 kV at the moment, but manufacturers are considering a move up to 245 kV. The size is limited by the machinery required for manufacture, as the mould for the cast-on silicon is large and may be a limiting factor for manufacture. Any move to higher ratings will depend on demand from the market. The RIS bushing has the added advantage of storage without special requirements. The ABB EasyDry product is a typical example [5]

There is an apparent move by the industry away from oil impregnated bushings to dry type. Eskom specifies dry type for bushings up to 500 kV.

Tank design

Attention is being paid to the design of the transformer tank in an effort to reduce weight and materials used. An interesting development is the change from rectangular tank design to a shape having round ends, which makes sense as the coils are round (Fig. 7). Adopting this shape reduces the amount of oil required to fill the tank and also allows better control of the direction of oil flow. Manufacturing costs are however higher as the end plates have to be bent into a circular shape.

System developments

Mobile sub stations

The transformer is the largest weight and size component in a mobile substation and special designs are necessary to keep the whole structure within the size and weight limits of a standard trailer. Weight is reduced by using higher than normal current density in the coil windings, which reduces the size of the windings and the core. This results in higher temperatures and necessitates the use of high temperature insulation materials, such as Nomex, and higher capacity on the oil cooling system. Typically the size of transformer used in a substation would require ONAN cooling but in mobile substations ONAF is used to dissipate the extra heat. Asymmetrical or other special core configurations may be used to allow a narrower profile to be achieved.

In addition, the tank requires strengthening to withstand the rigours of a journey on a trailer without special suspension, and over a range of road surface quality, and higher strength steel may be used to achieve this without adding to the weight.

Transformers for renewable energy generators

Power transformers connecting renewable energy generators to the grid have to cater for a set of circumstances not found in conventional generators based on rotary machines. Both solar PV and wind use inverters to convert DC to AC at the grid frequency, which have their own peculiar set of behaviour. Because each inverter has a different profile, the transformer has to be designed specifically for each installation. Some of the special requirements are:

- High harmonics: Harmonics generated by the inverter cause higher eddy current losses and the transformer core has to be designed to take harmonics into account.
- Transients: Ramp rates and voltage control from renewable energy sources can be rapid and need to be accommodated.

- Interface with inverters: Short circuit performance of inverters is significantly different from rotating generators, and varies from supplier to supplier. The transformer has to be designed to cater for the specific inverter used.

Inrush current identification

Inrush current with power transformers is problematic as it is often mistaken by protection equipment for fault currents. A new technique which uses the second harmonic content of the inrush current to distinguish it from fault current is being developed.

Maintenance

Improved online monitoring equipment is making the change in maintenance routines from time based to condition based possible. A winding optical temperature monitor is a typical example that makes it possible to monitor the performance at an extended range of points in the winding.

The test philosophy is moving towards one of only testing annually if problems had been encountered previously, and if no problems were encountered at a previous test a longer interval is used. New tests for dissolved gases in oil such as methane and hydrogen, are being developed.

Tear down analysis of recovered transformers

Operators with fleets of transformers of similar design and age are taking to doing tear down analysis of retired (non-failed) transformers in order to build up data on the state of core materials and to estimate remaining lifetime of other transformers in the fleet. The exercise has yielded useful results.

Incoming testing and quality control

The failure of the cheapest item in a power transformer can cause failure of the whole unit, and thus it has become increasingly necessary to test and verify properties of incoming material to weed out failures before construction begins. PTT has acquired a unique set of test equipment which allows the properties of the critical and not so critical components to be verified.

Near future developments: nanotechnology

As with many other components and materials, nanotechnology is being considered as a means of improving performance of transformers. In the case of power transformers this is happening in the oil issue. Addition of nano particles to the oil has been proposed as a means of improving the heat transfer and resistivity. Use of nanotechnology to manufacture micro gas detectors, which can be placed permanently in the oil, is also being developed.

Oil modification

A report published in 2012 [3] states that the addition of nanoparticles at a concentration of up to 8% increased the heat transfer capabilities of mineral oil by up to 80%. The nano structure used was Hexagonal boron nitride (h-BN) particles, about 600 nm wide and up to five atomic layers thick. There was no change to the mechanical properties of the oil. No further news on this has been issued and it may only be a laboratory curiosity.

Micro gas sensors

Nano structures have proved capable of detecting and measuring gases dissolved in transformer oil such as hydrogen and methane, both of which are indicative of failure. The sensors have dimensions of the order of 1 mm2, which allows them to be placed permanently in the oil path and provides online sensing of these gases. Through nanotechnology, Applied Nanotech has created a palladium alloy nanoparticles-based sensor for the detection of hydrogen gas dissolved in power transformer oil [4]. The absorption of hydrogen by the palladium alloy nanoparticles results in changes in the sensor's physical, electrical and optical properties. The sensor, which was tested for different hydrogen concentrations at different temperatures in transformer oil, exhibited suitable sensitivity and short reaction time.

References

[1] Powertech Transformers: "Powering the future through knowledge sharing", Power transformer technology colloquium, 9 – 11 March 2015.

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