TRANSFORMERS + SUBSTATIONS

HANDBOOK: **2014**

Foreword

by Ian Jandrell

Once upon a time, the substation was 'the building over there', or the 'room in the basement'; and the transformer the 'thing with the tubes that hums'.

This has changed and 'Transformers + Substations Handbook: 2014' allows you to reacquaint yourself with one of the most important parts of any system, the substation and its content, and the transformer as the key device. This change relates as much to a utility, a building or a plant.

The change has been profound. The cynics amongst us may argue that the transformer is the device that drips oil all the time and the substation the building that had the explosion. This view is not far-fetched as the issue of maintenance has a specific poignancy in South Africa at the present time.

'Transformers + Substations Handbook: 2014' is a collection of targeted articles written by authors willing to share their knowledge. It combines some of the best thinking in terms of tutorial-type and experience-based material; it covers some of the latest thinking and it reviews important background theory.

Transformers are required to be more efficient than they ever were, and to operate reliably over increasingly long life spans. This implies attention to detail at the design and manufacturing stage, as well as consideration of the protection and monitoring schemes that will assist in ensuring longevity of the asset.

A further issue relates to the inclusion of the substation into the communications network, where information for the energy supply system is important not only for that system, but as part of the overall plant data system. Data used in energy control and protection has specific associated challenges and supportive network and technologies.

This handbook comes at a critical time in the development of the South and southern African economies. It comes at a time when the supply of energy has without doubt impacted on the potential growth of the economy. This speaks to the need to plan carefully when developing strategic objectives – but it also speaks to a fundamental failing at a number of levels. Whereas this can be understood, it is a lesson that must be learned and remembered.

The second issue that emerges is the tendency to suspect that, in attempting to solve this problem, we are biting off more than we can chew. However, that is not the case. The fact of the matter is that when you need to eat an elephant, you need a plan, you need the resources, and you need the structures … but you still do it bite by bite. Some would say carefully.

So energy has become the number one commodity on our plants. We need to revisit transformers and substations; and we need to integrate all the data from those systems into plant information systems.

I am sure this handbook will allow you to pause and consider where you own system is, and where, perhaps, it should be.

Ian

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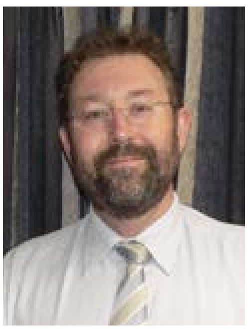

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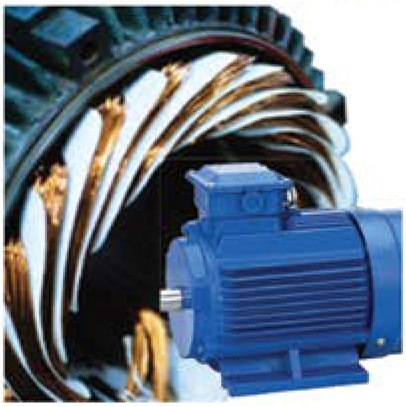

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Providing this is not Hollywood, transformers combine an electric and a magnetic circuit to form one of the most essential components on the ac network. Each element of the transformer is worthy of careful consideration.

Fundamentals of transformer design

By H du Preez, Consultant

1

A transformer is a static piece of equipment with a complicated electromagnetic circuit. The electrical energy is transferred from one electrical circuit to another through a magnetic field. In its simplest form, a transformer consists of two conducting coils having a mutual inductance.

The history of transformers goes back to the early 1880s and with the demand for electrical power increasing, large high voltage transformers have rapidly developed.

Transformers are amongst the most efficient machines. Being static devices, they have no moving components, therefore maintenance and life expectancy is long.

They are necessary components in electrical systems as diverse as distribution of multi-megawatt power from power stations to hand held radio transceivers operating at a fraction of a watt.

Transformers are the largest, heaviest and often the costliest of circuit components.

The geometry of the magnetic circuit is three dimensional; this property places a fundamental restraint on reducing transformer size. The properties of available material limit size and weight reduction.

High voltage transformers require specific clearances, and insulation type and thickness dictate the size of the unit.

Transformers are indispensable for voltage transformation in power applications. Their ability to isolate circuits and to alter earthing conventions can often not be matched in any other way.

Special designs are available to obtain isolated multi-phase supplies for six, 12, 24 and higher phase (pulse) rectification circuits.

Transformers are essentially single-application devices designed for specific requirements.

A well designed transformer is a rugged piece of equipment and, if used in the environment and application for which it was specifically designed, it will give many years of trouble-free service with minimal maintenance and attention. However, because transformers are static passive units they often lack attention and maintenance.

The basic principles for all transformers are the same; only the detail design will change and in this short article it is impossible to cover all possible winding configurations. The basic theory covers all types from small high frequency transformers using ferrite core, current transformers – typically a round wound core and a toroidal winding – to 800 kV power transformers.

There are no rules which dictate that either a spiral winding or disk winding has to be use on a particular design; the designer would have to make these decisions, as in the case of most electrical machine designs. There is no unique design for a particular transformer and there are many designs which could meet all the specifications. Some of these designs would be better than others but they would all function.

Basic theory

Electrical energy is transferred from one electrical circuit to another through a magnetic field. In its simplest form, a transformer consists of two conducting coils having a mutual inductance. In an ideal scenario, it is assumed that all the flux linked with the primary winding also links the secondary winding. This is impossible as magnetic flux cannot be confined; but it can be directed so that most of the flux meets this criterion. The small portion of flux that cannot be directed is known as leakage flux and will link one or other winding and/or component in the transformer. Voltage is proportional to the number of turns, current is inversely proportional to turns.

General types

The two fundamental types of transformers are the 'core' and 'shell' types: the winding circulating the iron core is the core-type while in the shell-type, the winding is largely encircled by the iron core. Both single and three phase transformers can be constructed in either type.

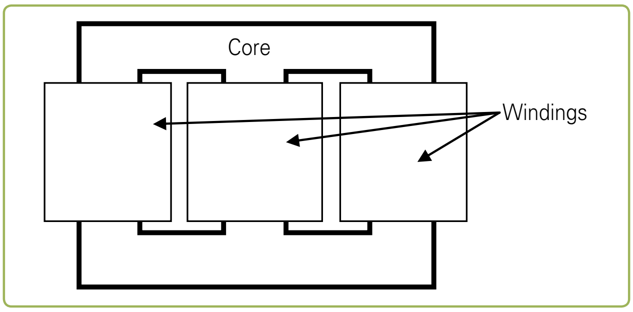

Figure 1: Core type transformer (3 phase).

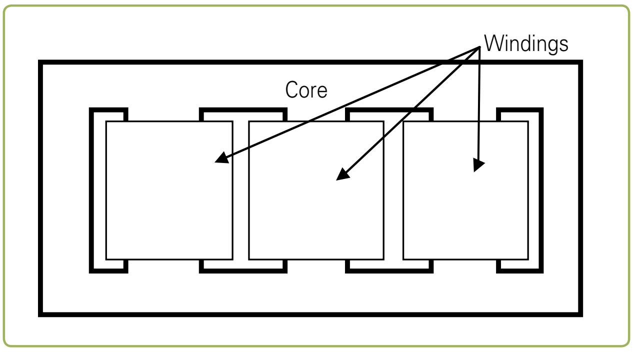

Figure 2: Shell-type transformer (3 phase).

Core construction

- Core steel laminations are manufactured specifically for transformers and motors but with a difference. Motor laminations are manufactured (stamped) from non-oriented lamination steel whereas transformer laminations are manufactured from grain oriented steel
- Flux flows with lower losses in the direction of rolling (grain oriented)

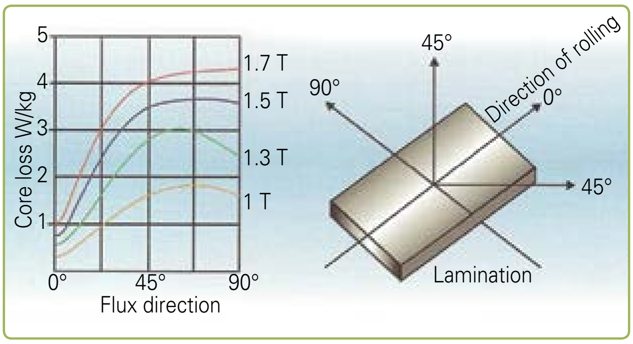

Figure 3: Losses in grain orientated lamination steel for various directions of magnetisation [1].

The purpose of the core steel is to provide a low reluctance path for the magnetic flux that links the primary and secondary windings.

Lamination steel is specifically designed to reduce losses in the steel. There are two main components to iron losses they are:

- Hysteresis losses
- Eddy current losses

Hysteresis is dependent on frequency, material and flux density. Eddy current is dependent on the square of the frequency and the square of the material thickness.

A number of different grades and types of lamination steel are available.

- Hot rolled steel
- High-permeability steel (0,025% Al cold rolled) (30 to 40%)
- Domain-refined steel (5 to 8%)
- Amorphous steel (80% Iron 20% Boron and Silicon) (33,33% improvement at knee point) (1,5 to 1,6 Tesla)

Core profile can be square, round (stepped), oval or rectangle. The joint can also take on many configurations (butt, overlap, mitred, etc).

Core-magnetic circuit

The magnetic flux density is measured in Tesla (Webers/m^2), and normal values for a transformer range between 1,6 and 1,8 Tesla.

How eddy currents are avoided in the core (eddy currents increase no-load losses and create hot-spots):

- The core steel laminations should be thin
- The core steels should be insulated from each other
- Smallest burrs possible in both slitting and cutting as these burrs create shorts across the laminations
- The core steel should have high resistivity

Joint between core laminations:

- In joints the magnetic flux 'jumps' to the adjacent laminations, with local saturation as a result
- Step-lap joints have a higher saturation limit compared with conventional joints. The magnetising current is lower for the step-lap in this area of the joint
- Mechanically, the step-lap joint is weaker than the conventional joint because of the smaller overlap
- It is important to keep the gap between the laminations as small as possible at the joints
- The clamping at the joint must be as strong as possible to reduce noise, increase strength and reduce gap losses

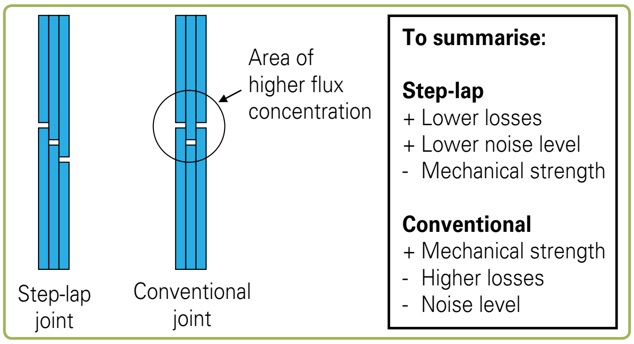

Figure 4: Lamination joints.

- The core construction can take on many forms but must be rigid and tightly clamped
- All clamping must be insulated to eliminate the possibility of circulating currents as a result of the main flux and or the leakage fluxes
- Clamping must not short-out the lamination; through bolts must be insulate

In its simplest form, a transformer consists of two conducting coils having a mutual inductance

Windings

Winding can be done in a number of configurations, namely concentric or sandwich types. In the concentric type the LV coil is generally wound against the core and the HV winding over the LV winding. In certain applications the HV is against the core and the LV is in on the outside. The sandwich type of winding is assembled with alternating low and high voltage winding.

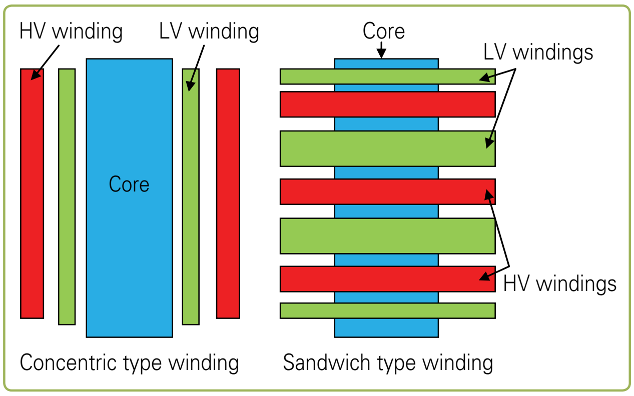

Figure 5: Winding types.

There are four types of coils used in transformer winding assemblies - cylindrical (*Figure 6*), bobbin (*Figure 7*), disc (*Figure 8*) and foil windings (*Figure 9*).

- Foil-type winding: Foil wound transformers generally have the LV wound using aluminium or copper foil over the full width of the winding; therefore with one turn per layer and the number of turns equal to the number of layers, the foil being wound with a suitable insulation is interleaved with the foil.

- Winding conductors may be copper or aluminium, and they may be in foil or sheet form, or of round or rectangular section
- For high powered transformers the low voltage winding may require a large cross-sectional area to be able to carry the required current. In this case, the use of stranded insulated conductors in parallel may be required to reduce the eddy current losses in the conductor. It may also be necessary to transpose the conductors, to reduce the circulating current within the winding. In large transformers continuously transposed conductors (CTC) may be used
- It is important when conductors are used in parallel that the lengths and configuration with respect to the core and each other are all the same otherwise circulating currents could result and there would be an uneven distribution of current in the parallel conductors
- Large cross sectional conductors also result in eddy currents and skin effect coming into play in the conductor, which increases losses and therefore localised heating


Figure 6: Cylindrical type winding.


Figure 7: Bobbin type winding.

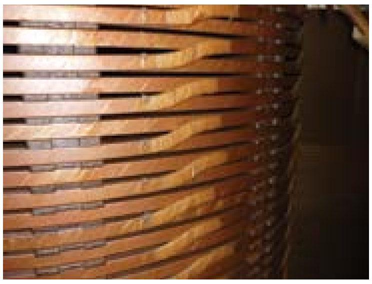
Figure 8: Disc-type winding.

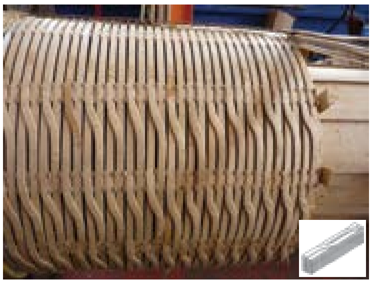
Figure 9: Twin parallel disk winding with continued transposition.

Coil insulation

Paper insulation on the conductor is the insulation generally used for oil-immersed transformers. Nomex, an aramid paper developed by Du Pont, is used extensively in the electrical industry and also in oil-immersed and dry type transformers.

The oil in a transformer serves two purposes; one to act as an insulator and the other, to act as a coolant medium. The paper used readily absorbs the oil to form a uniform insulation medium in the transformer.

Main insulation

In oil type transformers, pressboard and wood products are widely used as the operating temperature is limited by the oil and paper products used as insulation. In the case of core transformers, pressboard cylinders are used between the LV and core and between the HV and LV windings.

Dry type transformers would use 'Nomex' or 'Kapton' for conductor insulation and 'Nomex' or glass-based boards for packing and cylinders as the operating temperature would be much higher than oil types.

Conductor material

Generally copper is used for its mechanical properties and conductivity. Aluminium can, and has been used but its conductivity is much lower than copper and mechanically not as good. Aluminium has successfully been used in cast resin dry type transformers because the thermal expansion coefficient of the resin and aluminium are extremely close.

The transformer designer should weigh up the pros and cons of the particular application when deciding whether copper or aluminium is used as the conductor material - there is no fundamental rule. Generally, copper is preferred and used except where foil winding are employed.

Cooling

Dry type transformers rely on air circulation through and around the winding for cooling and can be naturally- or force-cooled with fans. The designer would have to design accordingly, bearing in mind that the operating temperature would be much higher and materials would have to be selected to suit the high operating temperature.

Oil-cooled transformers rely on the oil to cool the transformer and this is circulated through suitable radiators by natural convection or alternatively, pumped.

Common terminology used:
ONAN – Oil Natural Air Natural
ONAF – Oil Natural Air Forced (fans used to force air over radiators)
OFAN – Oil Forced (oil pumped through the transformer) Air Natural

Oil should have the following properties.

- Low viscosity
- High flash point
- Chemically stable and low impurity content
- High dielectric strength

Mineral oil has traditionally been used in transformers though vegetable oils are now available with properties that are claimed to be superior; notably high flash point with flame retardant properties owing to the high flash point.

One of the major problems with mineral oils is once they are ignited and burning, it is extremely difficult to get the fire under control, particularly in enclosed environments such as buildings or underground in the mines.

Fundamental transformer theory

$E = (2 \times \pi \times f \times N \times a \times \beta)/\sqrt{2} = 4.44 \times f \times N \times a \times \beta$
where:
f = frequency
N = number of turns
a = core area (m^2)
β = flux density in Tesla
Voltage transformation ratio = $N_{secondary}/N_{primary}$
Therefore $V_{secondary} = V_{primary} \times (N_{secondary}/N_{primary})$
Current transformation ratio = $N_{primary}/N_{secondary}$
And I secondary = $I_{secondary} \times (N_{primary}/N_{secondary})$
where N is the number of turns in the primary and secondary winding

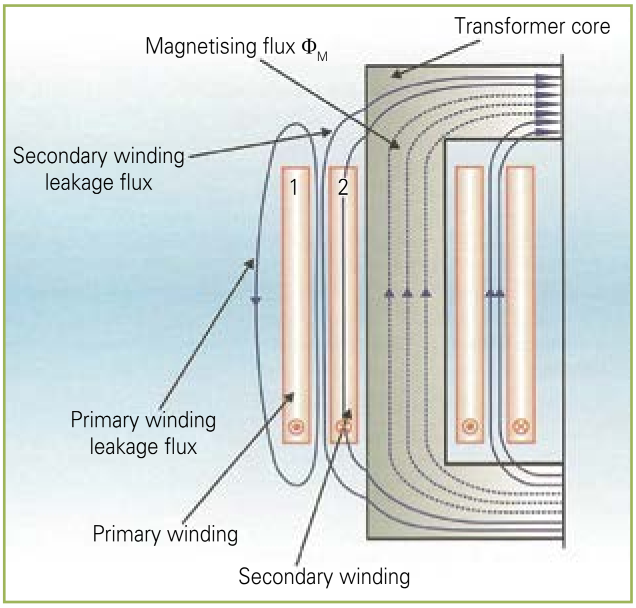

Figure 10: Magnetic flux distribution.

Figure 10 shows the main flux in a transformer including some leakage flux. The leakage though the tank is not shown. There will always be leakage flux in the transformer and into the tank. The leakage into the tank would generally be small in magnitude but would depend on the clearance and tank configuration and any screening.

Efficiency

The transformer is not called upon to convert electrical energy into mechanical energy or vice versa and consequently has no moving parts. The efficiency is generally high.

Efficiency % = $\{P_{output} / (P_{output} + P_{losses})\} \times 100$

The losses are confined to:

- Core losses: Eddy-current losses and hysteresis losses
- I^2 R losses: Owing to the heating of the conductors due to the passage of current

- Stray losses: Owing to stray magnetic fields causing eddy current in the conductors or in the surrounding metal, eg tank
- Dielectric losses: In the insulating materials, particularly in the oil and solid insulation of high voltage transformers

Regulation

The voltage regulation is defined for any given load current as the arithmetic difference between the secondary no-load voltage E_2 and the load voltage V_2 expressed as a fraction of the no-load voltage.

Regulation % = $\{(E_2 - V_2)/E_2\} \times 100$

No-load losses

On no-load the secondary circuit is open and, consequently, the primary current is I_o only. The $I^2 R$ losses owing to this are negligible. (At full load the $I^2 R$ losses would be approximately 1% or less and since the no-load current is of the order of one twentieth of the full load current the $I^2 R$ losses would be 1/400 x 1% = one four hundredths of a percent.)

Consequently, the power input on no-load is concerned with the core and dielectric loss, the latter being negligible except in very high voltage transformers.

The no-load losses measured on open circuit secondary represent the core and dielectric losses; the dielectric losses are generally negligible compared to the iron losses.

Copper losses ($I^2 R$ losses)

As the voltage has to be reduced to a very low value if the secondary terminals are short-circuited, the current in the secondary could be full load current while the secondary voltage would be zero because of the short-circuit.

The primary voltage would be small and the flux F would likewise be small. At full load the input voltage would be 0,05 to 0,1 of the rated voltage.

The core loss is approximately proportional to the square of the flux and would be very small. Therefore, the core losses would be negligible.

Transformer connections

In three phase transformers there are five types of winding connections. The choice of connection depends on the function of the transformer in an integrated power system.

Star-star connection

This connection is used where the phase relationship is required to remain the same and earths are required in both sides. It is mainly used in small transformers and large transmission transformers. The transformers are frequently equipped with an additional set of winding connected in delta to suppress any triplen harmonics.

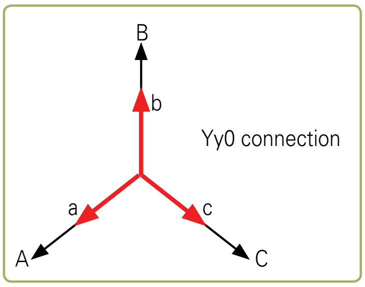

Figure 11: Star-star vector diagram.

Delta-star connection

Dy11, Dy1 and Dy5 are commonly used configurations enabling the secondary to be earthed directly or through a suitably sized resistor. The delta winding inherently suppresses any triplen harmonics, that may occur in the magnetising current and distort the voltage. The numerical number associated with the configuration indicates the phase angle relationship.

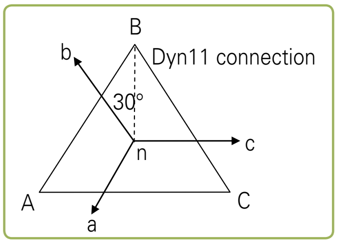

Figure 12: Delta-star vector diagram.

Star-delta connection

Essentially used in situations where the secondary is not to be earthed and cannot be used where single phase voltage is required, such as domestic or small light industry connected to the secondary supply. Again, the connection can accommodate various vector phase angle relationships.

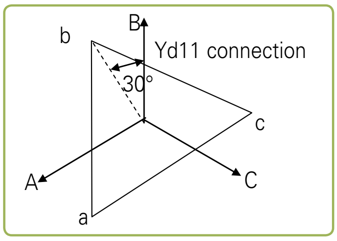

Figure 13: Star-delta vector diagram.

Auto-wound transformers

Auto wound transformers share a common star point and thus a common earth and the systems are not isolated from each other. Auto-transformers comprise two windings; series and common. Auto-transformers are typically used as high voltage system interconnecting transformers and in reduced voltage starting systems for large motors.

Zig-zag connection

This configuration is typically used where a specific phase angle shift is required, for example, in multiphase rectifier transformers and where it is necessary to have a positive sequence impedance higher than the zero sequence impedance.

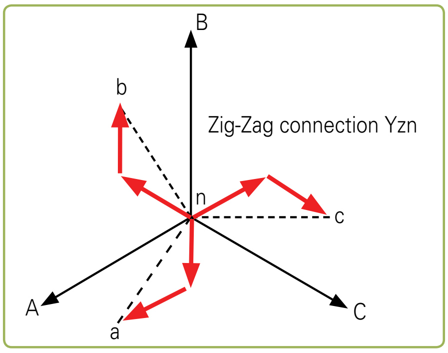

Figure 14: Star zig zag vector diagram.

Conclusion

The subject matter on transformer design is extensive and this article briefly outlines some theory and factors to be considered in the design.

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[1] Przybysz P, Transformer Fundamentals. Eskom publication.

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From the perspective of the utility, transformer efficiency has become one of the more important considerations. However, the fundamentals of how the machine is built are critical. The mechanical, switching and insulating systems are described.

1

Power transformers - design and manufacture

By S Mtetwa, Eskom

This article discusses the important parameters that should be incorporated in the design and manufacturing of transformers in order to achieve more efficiency, environmental acceptability, and low fire risk.

The transformer has always been a major and expensive component in the power system. In growing economies and electrification projects around the world, transformers are very much in demand and their prices continue to increase, with the lead times to source them following the same pattern.

It is always desired that a return on investment be realised on transformers because they require a significant capital investment. In many cases, transformers fail before they reach their expected life span. Studies show that most transformers fail around midlife (appraisal) with the known leading causes of the failures being windings, tap changers and bushings in decreasing order. The main questions then are: What is being done, or can be done, in order to achieve the expected life span from a transformer and how is the issue of the leading causes of failures being addressed?

Transformer owners need to face the reality that a transformer life management practice that will enable the utility to safely, economically, and with a high degree of reliability and availability, utilise its transformers for their entire, expected life span, does not start when the transformer lands on the intended site. The stages prior to the delivery of a transformer are critical and require serious attention.

The life cycle of a transformer can be summarised as:

- Identification
- Specification
- Design
- Design review
- Manufacture
- Test
- Transport
- Install
- Commission
- Operate
- Maintain
- Retire or dispose of

From this, one can see that prior to switching for operation there have been many life cycle stages in making a transformer that will last a certain period, from a few milliseconds to a number of years.

In this discussion of the critical issues of the design and manufacture of a transformer, other aspects or stages of the life cycle are touched on in less detail. This information applies to different types of transformers but is more applicable to oil-filled power transformers (generator step-up, network coupling transformers and distribution sizes).

Identification

The first stage is to identify what transformer is required. This should be determined by the network planners. It involves deciding on the power rating of a transformer, taking into consideration the future demand growth. The primary and secondary (and tertiary, if applicable) voltages of the transformer are decided at this stage.

Specification

A transformer specification document is an important document required to start the journey of acquiring a transformer that will be robust for the network environment in which it will operate. The purchaser is the one who best understands the network and the environment which must be made known to the manufacturer through the specification document. This makes it important for each transformer user to have a specification that is relevant to his network needs and operating environment. Adoption of specifications from other users, especially those with different climate parameters and operating regimes, must be done with care. If this is not carefully considered, it may present the negative effects of either under-specifying or gold-plating the requirements. It is in the specification document that maintenance, safety and risk requirements are clearly defined.

Design

The design is the responsibility of the transformer manufacturer, based on the specifications provided. The manufacturer has to ensure that the design complies with the specification provided by the purchaser in terms of functionality, electrical parameters, choice of material (when specified, eg insulation-type) and, most of all, withstanding the operational conditions detailed in the specification document. When the manufacturer is satisfied the client's requirement has been met and his design is ready, he can engage with the client concerning the design.

Design review

A design review, in a planned exercise, ensures that there is a common understanding of the applicable standards and specification requirements to provide an opportunity for the purchaser to scrutinise the design and ensure that the requirements have been met. The purpose is not to take away from the manufacturer the responsibility of designing and manufacturing a unit that is fit for purpose. Since purchasers often have limited knowledge of the subject of design, they usually employ experts in transformer design. The expert has to be somebody with vast first-hand experience of design and this is hard to find. Many good transformer designers work for companies and cannot be expected to interrogate the designs of their competitors – hence the need for an independent body.

The exercise offers the manufacturer an opportunity to see if he has correctly interpreted the specification and if he can further optimise the design to be more robust, economical, or both. This will require a utility engineer or representative that is familiar with the network and

other aspects, such as the operations and maintenance regimes of the business. The interest between the two parties, although from different points of view, is common – a transformer that will be fit for purpose. The manufacturer wants this for his reputation and the purchaser wants this for reliability and productivity in his business.

The important point is what items are looked at during the design review meeting and what the options are. The following important points should be discussed during the design review stage of the transformer's life in order to ensure that both parties are clear about the expected product and the associated capabilities and limitations. The materials for transformer construction should not be procured before the design review is done and concluded, because the design may be completely changed during the review meeting.

Electrical characteristics and requirements of the network or system

These will include system frequency (including its variations), voltages (both nominal and maximum continuous), short-circuit fault levels and duration of short-circuit. The agreements regarding lightning impulse, switching impulse and other withstand capabilities that are considered important are agreed, taking into consideration the geographical locations. Voltage regulation requirements and performance are part of the discussion and it must be clear whether such regulation is done on-load or off-circuit. Many purchasers now have requirements regarding Geo-magnetic Induced Currents (GIC), which are solar storms. The parties should discuss this as well as how the withstand capability will be demonstrated before the transformer is dispatched to the purchaser. The total harmonic distortion and values for each harmonic should be assessed.

The purchaser must be involved in the stages prior to installation of the transformer to ensure that quality is built into the product.

Transformer components

Both the major components and the auxiliary components are important. The discussion around the major components should cover:

Core

The type (shell or core), grade of material, surface insulation, cross sectional areas, number of limbs, flux densities, core clamping, cooling ducts, core grounding, thermal performance, core joints (step lap, mitred, butt, etc), and all other core related items. The inrush current characteristics should be reviewed.

Windings/coils

Each winding of the transformer should be reviewed, and the manufacturer should have supplied detailed information so that all parties understand the physical arrangement of active parts. Such a description will include, but not be limited to, the type of winding (helical or disc – interleaved or inter-shielded), number of turns per phase, conductor dimensions and construction (Continuously Transposed Conductor (CTC), twin, triple, etc), current densities, insulation level, magnetic length, electrical length, winding sizing forces, weight, conductor yield strength for forces, tapping leads arrangement for regulating windings, etc.

It is also important to look at how the insulation system is built around the conductors and verify the performance of that insulation

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against the stresses that will prevail during factory testing and in service. The manufacturer will also state what type or grade of insulating paper is used. The options available for purchasers include netted CTC, normal Kraft paper, thermally upgraded paper, and the conductors themselves may be enamelled or not, depending on the purchaser's needs and the type of conductor. All these are to be clearly specified and discussed during the design review meeting.

Tap changers

The tap changers should not be the limiting component for the transformer performance; they must be able to withstand all the transformer loading and testing conditions and stresses. For on-load tap changers, the purchaser can specify vacuum or oil technology. Vacuum technology is becoming the technology of choice owing to its advantage of minor to no maintenance requirements. The positioning of the tap changer in the electrical circuit is also an important part of the review to achieve either constant or variable flux regulation. Tap changers can be located on neutral end or line end.

Bushings

Dry technology (Resin Impregnated Paper (RIP)) of bushings has matured up to voltages of 550 kVac and 800 kVdc and is still in its infancy stage and being developed for higher voltages. RIP is preferred to Oil Impregnated Paper (OIP) bushings because it is maintenance-free and has a low fire risk and a fail safe mode. The types and makes of bushings should be discussed during the review meeting. Composite Insulator Sheds (CIS) technology is preferred to the traditional porcelain one as it is more robust, especially against vandalism.

Other requirements

Other requirements will include insulation design. The review will involve looking at dielectric stresses for normal and abnormal conditions, power frequency, and during transients. The insulating technology can be gas (eg SF_6), oil (mineral, natural or synthetic ester), or other materials like Nomex for dry type transformers. The insulation system should be selected and designed, taking into consideration the thermal stresses that will be encountered in service.

Thermal design ie, temperature rises, are to be reviewed taking into consideration different loading requirements, selected insulation materials, and what is specified in the standards. Glass fibre optic sensors can be considered for more precise measurement of the hot-spot temperatures and, if specified, the positioning should be discussed during the review.

Short-circuit withstand discussion is important to determine the ability of the transformer to withstand the faults expected on the purchaser's network. Today's tools and knowledge allow for optimised designs of the conductor insulation (improved space factor) to avoid spongy windings owing to significant amounts of insulation in the axial dimensions. It is important to check this during a design review; in fact, all aspects related to short-circuit must be reviewed, ie materials, thermal behaviour, mechanical behaviour (or stresses), and should be considered at the same time. The ability of a transformer to withstand short-circuit stresses should be verified by calculations, tests, or both.

Sound levels as per IEC 60076-10 [1], seismic requirements, cooling requirements (for oil filled transformers: ONAN, OFAF, and ODAF [O – Oil, A – Air, N – Natural, F – Forced, D – Directed] are popular cooling modes), losses (which are important for network efficiency) and tender evaluation (loss evaluation for total cost of ownership) are other important requirements. For the losses, the manufacturer will provide the calculated total service losses, and these will the guaranteed values that will be checked during factory testing. The purchaser may apply penalties if these are exceeded, depending on the contractual agreements.

Figure 1: Transformer being tested at the factory.

Manufacture

This is another critical stage in the transformer life cycle. A well designed transformer can fail to perform to the expected level just because of the way it was manufactured. The design engineer needs to ensure that during the design stage, the production engineers (eg the winders) are consulted to make sure that the design is executable and that the production staff is clear of the criticality of certain activities related to that particular design.

Purchasers have intervention points during the construction of the transformer in order to satisfy themselves that quality is being built into the product they are purchasing. Some shortfalls in quality cannot be picked up during the factory high voltage testing stage, and in-process inspections are vital. The points to check during the manufacture of transformers include, but are not limited to, the following:

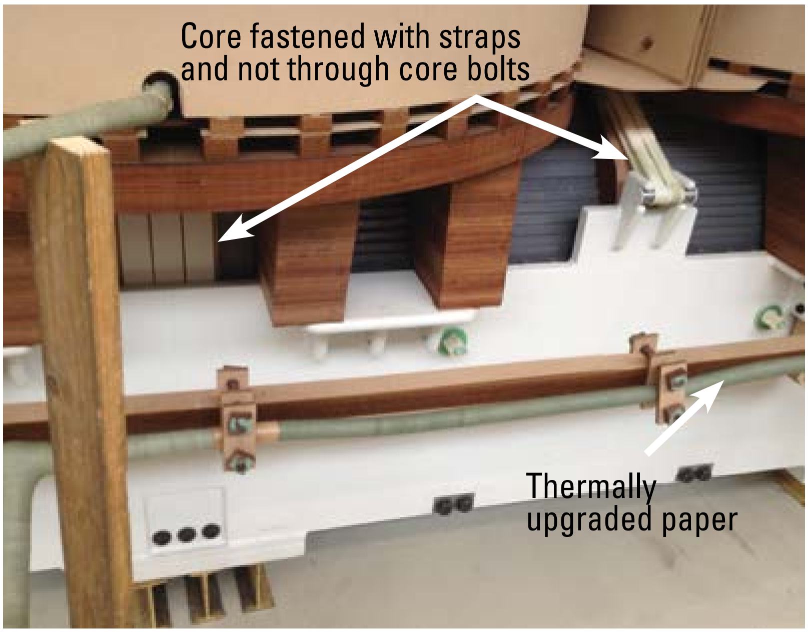

Figure 2: Transformer in-process inspection.

Materials

Check that the materials procured for the transformer comply with the agreements of the design review and specification. An example of this is checking whether or not the conductors are insulated with a thermally upgraded paper, depending on what was agreed. Check that the core steel grade is correct, etc.

Core

Verify that clamping is done correctly (using straps or through bolts). Through core bolts are not favoured anymore, especially on large transformers because of the failure mode they have demonstrated in the past. Straps are preferred. Check that burrs do not exceed set quality limits, which are normally 0,02 mm. There should be no core snaking or any form of damage, and one should verify the core duct (the number and size) against the design.

Coils

For coils it is important to check the dimensions of the conductors and the insulation used. In certain cases the conductors are to be enamelled (eg when specified or in CTCs) and this must be verified. The manufacturer will have adequate quality checks for these; however, witnessing the processing of the coils is important for the purchaser as well. Drying of the coils is important and cannot be avoided; however, every time this is done some paper life is lost.

Assembling, drying, oil and testing

The assembling techniques for transformers are improving in terms of available tools and equipment. Some factories will have fully automated core cutting and stacking; however, better methods using human resources still exist. Platforms for better construction, which enable the production staff to keep to the design dimensions, are available and being improved. Drying methods are continually improving and advanced vapour phase ovens are available that provide optimum drying without severe loss of paper life. Vapour phase technology (heat and vacuum) is superior to the traditional ovens using hot air or kerosene, the latter has been found to contribute to the problem of corrosive sulphur in the insulating oils. The oil specified, especially for transformers that will be highly loaded and are in critical circuits, must be non-corrosive. The additives in the oils must be known and understood. Classic utilities will have proper oil specifications and quality control on the oils coming into their pool. Both inhibited and uninhibited oils are used. The Poly-Chlorinated Biphenyl (PCB) oils are no longer accepted on new units. Green oils (environmentally friendly) are preferred nowadays, but should be selected from the start as dielectric requirements are different for mineral oils. Finally, the transformer will be tested according to IEC 60076 [1] requirements and these are clearly specified in parts two and three of this standard.

Conclusion

Transformers are a critical component of a power system and continue to be in demand. There is a strong drive for transformers that last to expected life so that capital funds can be used for network growth rather than replacement projects. The design and manufacture of transformers have a significant role to play to achieve this. Good specification documents, good relationships and collaboration between the purchaser and the manufacturer will make this possible, to the benefit of both. There are various new technologies that can enhance the life of the transformer and make it robust, and these must be integrated into the specification documents. The purchaser must be involved in the stages prior to installation of the transformer, to ensure that quality is built into the product.

Acknowledgement

The author thanks Khayakazi Dioka for reviewing this article.

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[3] Cigré Technical Brochure No.529. Guidelines for conducting design reviews for power transformers.

1

We should never forget that copper remains an important and expensive component of a transformer. However, losses within the machine have an associated cost and it is useful to understand the trade-off between the initial cost of the copper versus the cost of the losses over the lifetime of the machine.

Proper transformer sizing and copper windings

By E Swanepoel, Copper Development Association Africa (CDAA)

As the electrification of Africa continues, choosing the right component is critical if the result is to be cost effective and efficient.

Transformers are essential for the transmission, distribution and utilisation of electrical energy. They are used in virtually every commercial and industrial building, from the service transformer that reduces distribution voltage to a more usable voltage for buildings to step-down transformers that serve individual floors, to small transformers for individual equipment. Transformers can be expected to operate for 20 to 30 years or more.

Over such a long life span, the operating cost of a transformer can greatly exceed its initial price, so selection of the right transformer for economic performance involves examining the unit's capacity (size) and efficiency. In this context, efficiency means looking at the core steel and the winding material.

Transformer losses

In simplest terms, transformer losses comprise core losses (also called no-load losses) and coil losses (called load losses).

Core losses originate in the steel core of the transformer and are caused by the magnetising current needed to energise the core. They are constant, irrespective of the load on the transformer, hence the term 'no-load'. They continue to waste energy as long as the transformer is energised. No-load losses vary depending on the size (kVA) of the transformer and the core steel selected; hence the emphasis on proper sizing.

Coil losses, or load losses, originate in the primary and secondary coils of the transformer and are a result of the resistance of the winding material. This is where the selection of copper windings can make a difference.

Proper sizing

Transformers are sometimes installed in advance of occupancy, so the engineer does not necessarily know the load that will be placed on the unit. As the installer is often not the party paying the electricity bill, there can be a tendency to oversize the transformer capacity relative to the load it will see. Since the no-load loss is a function of the kVA capacity of the transformer, careful selection of transformer capacity, appropriate to its intended task, will ensure the lowest core loss.

Energy Star (TP-1) transformers may not be efficient enough

Energy Star, an international standard for energy efficient consumer products, originated in the USA where it was created in 1992 by the Environmental Protection Agency and the Department of Energy. Since then, Australia, Canada, Japan, New Zealand, Taiwan and the European Union have adopted the programme. Devices carrying the Energy Star service mark generally use 20 to 30% less energy than required by federal standards.

The Energy Star label is applied to transformers that meet a certain minimum standard for efficiency, known as the National Electrical Manufacturers Association (NEMA) TP-1 [1]. This standard is intended to promote the manufacture and use of energy efficient transformers by establishing minimum efficiency standards, albeit with certain built-in assumptions. It contains a simplified method for evaluating the initial cost of transformers along with the costs of core and load losses. It also presents tables of minimum transformer efficiencies based on kVA size, voltages and liquid or dry-type.

Unfortunately, there is nothing particularly efficient or cutting-edge about transformers that meet TP-1. Yes, they are an improvement on so-called 'standard' transformers, which are still made and sold widely. However, many transformers are available from various manufacturers that exceed the efficiency levels of TP-1, and can provide a faster payback of their purchase price.

The efficiency standards in NEMA TP-1 [1] are based on certain assumptions that may result in the selection of less-than-optimally efficient transformers. One key assumption is that low voltage (600 V class), dry-type (typical commercial or industrial) transformers are loaded at 35% of their nameplate rating. For medium voltage and liquid-filled transformers, the assumed loading is 50% of the nameplate rating. Another underlying part of the economic rationale for the standard is an assumed electricity cost of six cents (US) per kWh (which is equivalent to 62 cents per kWh in South Africa).

These assumptions could be inaccurate for industrial and commercial users, who can often more accurately predict their load requirements and who may be paying more or less than six cents per kWh, particularly at peak times. In fact, recommended loading for economic sizing of a transformer is typically around 75% of nameplate; a 35% load, if constant, means the transformer is oversized and wasting core loss as well as being higher priced.

The operating cost of a transformer, over its long life span, can greatly exceed its initial price, so the selection must include examining the unit's capacity and efficiency.

Copper windings

Table 1 compares a 'standard efficiency' 75 kVA transformer to an aluminium-wound TP-1 model, a copper-wound TP-1 model and a 'premium efficiency' copper-wound unit, at various loading levels. As shown, choosing a more efficient, copper-wound transformer that exceeds the minimum efficiencies of TP-1 (and Energy Star) can pay back its price premium in as little as one year.

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	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	StdAl	TP-1 Al	TP-1 Cu	Prem Cu	Std Al	TP-1 Al	TP-1 Cu	Prem Cu	Std Al	TP-1 Al	TP-1 Cu	Prem Cu	Std Al	TP-1 Al	TP-1 Cu	Prem Cu
% of name plate load	100	100	100	100	75	75	75	75	50	50	50	50	35	35	35	35
Core loss (W)	375	350	320	190	375	350	320	190	375	350	320	190	375	350	320	190
Conductor loss	2829	1874	1670	993	1591	1054	940	559	707	469	418	248	1591	176	157	113
Total loss (W)	3204	2224	1990	1183	1966	1404	1260	749	1082	819	738	438	1966	526	477	303
Efficiency loss (%)	95.9	97.12	97.42	98.45	96.62	97.56		98.69	97.19	97.86	98.07	98.84	96.62	98.04	98.04	98.86
Transformer cost ($)	1366 (R13463)	1979 (R19505)	2064 (R20343)	3214 (R31678)	1336 (R13463)	1979 (R19505)	2064 (R20343)	3214 (R31678)	1336 (R13463)	1979 (R19505)	2064 (R20343)	3214 (R31678)	1336 (R13463)	1979 (R19505)	2064 (R20343)	3214 (R31678)
Comparison: Additional cost compared with standard unit ($)		643 (R6337)	728 (R7175)	1878 (R18510)		643 (R6337)	728 (R7175)	1878 (R18510)		643 (R6337)	728 (R7175)	1878 (R18510)		643 (R6337)	728 (R7175)	1878 (R18510)
Energy cost/ year ($)	1964 (R19364)	1363 (R13441)	1220 (R12030)	725 (R7149)	1205 (R11882)	8 60 (R848561)	772 (R7615)	459 (R4526)	663 (R6539)	502 (R4949)	452 (R4460)	268 (R2647)	1205 (R11882)	322 (R3179)	292 (R2882)	185 (R1831)
Annual energy cost saving compared with standard unit ($)		600 (R5923)	744 (R7337)	1239 (R12214)		344 (R3396)	432 (R4267)	746 (R7355)		161 (R1589)	210 (R2079)	394 (R3448)		69 (R688)	99 (R985)	206 (2036)
Payback period (years)		1.07	0.98	1.52		1.87	1.68	2.52		3.99	3.45	4.76		9.20	7.29	9.09

Table 1 - courtesy: Olsun Electrics, Richmond, IL.

- Al (Aluminium)
- Cu (Copper)
- Std (Standard)
- Prem (Premium)

Notes:

- Standard and Aluminium TP-1 units are 150°C rise, Copper TP 1 unit is 115°C rise, Premium unit is 80°C rise.
- Loss values at 100%, 75% and 50% nameplate load are at reference temperature
- Loss values at 35% nameplate load are at 75°C in accordance with TP-1
- Energy cost assumed to be $0,07/kWh
- Conversions from US$ to ZAR - 18 July 2013

Table 1: Payback time comparison for 75 kVA dry-type transformers.

Noteworthy is the fact that the TP-1 (Energy Star) efficiency, copper-wound unit, loaded at 75% of its nameplate capacity (column 7), saves over US $88 (ZAR 867) a year compared with an aluminium-wound TP-1 model (column 6), but costs only US $85 (ZAR 837) more initially. At only 50% loading, the copper TP-1 unit (column 11) saves about US $50 (ZAR 492) a year compared with the same aluminium unit (column 10). No-load loss is reduced from 350 to 320 watts because the greater conductivity of copper windings allows a smaller core to be used, so energy continues to be saved, even at light loading levels.

For greater savings, the premium efficiency, copper-wound unit saves over US $401 (ZAR 3 952) a year at 75% loading (column 8), compared with the aluminium TP-1 model (column 6), and only costs an additional US $1 235 (ZAR 12 172).

Minimising owning cost

Whenever possible, compare competing transformer models by asking for the load and no-load losses in watts and look at the total cost of ownership. Given their life span, buying a unit based only on its initial cost is uneconomical and foolish.

Transformer life cycle cost takes into account the initial transformer cost and also the cost to operate and maintain the transformer over its life. This requires that the Total Owning Cost (TOC) be calculated over the life span of the transformer. With this method, it is possible to calculate the real economic choice between competing models. A basic version of the TOC formula would be: *TOC = initial cost of transformer + cost of the no-load losses + cost of the load losses*

No-load losses are constant whenever the transformer is energised. Specifying copper windings can minimise both the load loss and the no-load loss, by allowing for a smaller core. If the load is known or can be predicted, choose a transformer that will be loaded to about 75% of its nameplate rating. Oversizing the unit increases the no-load losses, as well as the purchase price, unnecessarily.

If the actual losses in watts are not available, and you are seeking the transformer with the lowest losses, choose a transformer with 80°C rise, with M6 steel grade core or better, and copper windings.

Conclusion

Transformers remain a fundamental part of electrical distribution systems. The correct sizing for the load they are expected to carry and the material used in their internal windings can dramatically impact their life time and cost. It is worth reiterating that the recommended loading for economic sizing of a transformer is typically around 75% of nameplate and a premium efficiency, copper-wound, unit will result in significant savings in the long run.

Reference

[1] NEMA TP 1: 2002. Guide for determining energy efficiency for distribution transformers.

Higher reliability makes copper the lower-cost material over the life of the transformer

Why are some transformers copper-wound while others use aluminium? Is it simply a matter of cost? Or are there more compelling reasons? Copper is a superior electrical conductor. Aluminium's conductivity is about 62% that of copper when measured on a volume basis. Aluminium does offer lighter weight, because of the metals large density difference

- Copper keeps the size of completed units small enough to transport easily.
- The smaller size of copper transformers saves core steel, as well as structural elements including the tank, oil, cooling equipment and other accessories.
- Manufacturing savings and the fact that coils and conductors comprise less than 10% of the cost of the finished transformer minimize the effect of price differences between copper and aluminium.
- Copper is stronger than aluminium and, therefore, withstands stresses imposed by fault currents better than aluminium. Because the coil is stronger and less likely to deform, transformer life is extended and lifecycle maintenance costs are reduced.
- Copper's better connectivity means that connections inside the unit stay tight, reducing maintenance and prolonging life.

Copper is the obvious choice for all transformers.

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The reconsideration of how best to generate electrical energy has seen an increase in the number of alternative energy supply systems – including wind farms. Wind turbine transformers, of course, have a completely different operating environment from standard power transformers.

1

Design and material selection of wind turbine generator transformers

By C Carelsen, M Hlatshwayo, J Haarhoff and G Stanford, Powertech Transformers

It is important to consider the different operating conditions and influences – as well as the different electrical, mechanical and material requirements – to which wind turbine generator transformers are subjected, compared to distribution and power transformers. All should be taken into account when designing a wind turbine generator transformer for optimal performance and cost.

Wind turbine generator transformers are subject to different operating conditions from distribution and power transformers. In the electrical design, there are different fast transients, harmonics and non-sinusoidal loadings, and different loading factors that need to be considered. From a mechanical design perspective, the dynamic load and losses result in a different drive for the design and testing criteria. These changes, in turn, bring about the need to re-examine the materials used, such as the insulation paper for thermal hot-spots, cooling oil for environmental reasons, or the core steel to optimise losses.

Design considerations

Electrical design

The operating conditions of wind step-up transformers are distinct from those of distribution and power transformers. Their designs should be such that they withstand amongst others: very fast transients, harmonics and non-sinusoidal current loading, loading factors and frequency variations [1, 3]. This section explores electrical design considerations when taking into account a few of these aspects.

Very fast transients

Wind generator step-up transformers are installed in network layouts consisting of cables that are connected to the breaker. During the switching process, very fast transients yield a rise time that is approximately 50 times shorter than that of a conventional full wave lightning impulse test (FWLI). These transient characteristics influence the voltage withstand of the internal insulation of the transformer. The reason for this phenomenon is given as: 'In systems with oil insulated transformers and reactors, transients are about 10 times slower due to a 10 times larger stray capacitance' [2].

The study in [2] found that the turn-to-turn voltage withstand reduces significantly with reduced rise time. A reduction as low as 0,4 pu of the turn-to-turn voltage withstand was recorded. In a separate investigation [4], it was concluded that in the case of oil, the breakdown voltage influence is 12% and 35 - 40% lower for impulses of front times 0,7 µs and 0,044 µs respectively, compared with that of the 1,2 µs full wave lightning impulse. Transformer internal insulation structures should be designed to withstand these very fast transients.

Harmonics and non-sinusoidal loading

Transformers for wind applications will frequently be subjected to non-sinusoidal load currents and harmonics. IEC 60076-16 [1] highlights this risk and specifies that customers shall provide the harmonic spectrum. The effect on transformer load losses is widely reported in literature. A detailed calculation of the K-factors that amplify the individual loss components appears in [5]. The reduction of the conductor sizes is a commonly applied effort to reduce the winding eddy losses. Subsequently, the cooling design should take into account increased winding losses and winding hot-spot rise. However, the overall temperature rise is not exactly proportional to total winding losses [6]. Similarly, the stray losses in metal parts will be enhanced according to the K-factor [8]. Stray loss reduction techniques should be applied, including increased yoke distances, tank shunts and copper shielding.

Dynamic loading factors

The speed of wind determines the output of the wind turbines; consequently the average loading factor of 35% is common [9]. The low level of transformer loading will directly impact on the requirements for the no-load losses. The low no-load losses required become even more stringent to reduce running or long term costs of the units. This inherently affects the selection of the core material that is used for the transformer. The varying load also affects the thermal performance of the metal part structures in a transformer and should be considered at the design stages to prevent localised hot-spot heating.

From the factors described, it is clear that a slightly different set of design considerations is necessary for wind generator step-up transformers. The International Electrotechnical Committee (IEC) provides important considerations to assist customers and Original Equipment Manufacturers (OEMs) to specify, design and manufacture more durable transformers.

Mechanical design

Structural considerations

Transformer performance, as prescribed by global standards and customer specifications, can only be achieved if there is perfect harmony between the electrical and mechanical designs. The mechanical design complements the electrical design by means of design concept and material choices, to achieve the most cost effective design to suit customer specifications, and reduce the carbon footprint (losses).

Any architectural marvel is only as good as its foundation; with transformer design the foundation is laid by the magnetic core clamping structure. The clamping structure limits core lamination vibration,

so the noise impact on
the environment is reduced, and is exclusively
responsible for maintaining winding clamping forces. These structures must be well designed and constructed in order to withstand short-circuit forces resulting from abnormal service conditions without permanent deformation. Guaranteed losses as specified are achieved through the strategic use of non-magnetic material or special geometry, as this reduces possible financial penalties on the manufacturer and ensures the supply of a profitable asset to the customer.

Cooling influence and selection

With modern transformer life expectancies, it is essential to cool the windings sufficiently and effectively enough to ensure hot-spot temperatures below customer specified values. Research has shown a mechanical half-life breakdown in pulp cellulous insulation for every 6 - 7ºC increase above the designed hot-spot temperature, which could

Wind turbine generator transformers are subject to different operating conditions from distribution and power transformers.

lead to a breakdown in the insulation electrical stress withstand capability, and failures. Cooling can be achieved by various cooling methods ie ONAN (Oil Natural Air Natural), ONAF (Oil Natural Air Forced) and OFAF (Oil Forced Air Forced). Wind turbine step up transformers are usually specified with a rating equal to the generator [23] and therefore do not normally operate at full load, resulting in a potential long insulation lifetime. However, the higher localised losses at full load, due to the harmonics introduced by the wind turbine generator [23], need to be taken into account at the design and testing phases.

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Winding connections

Other important factors of the mechanical design are the winding connections or joints. The cable area choice is based on the current carrying capability of the material used and the effect of the insulation thickness on the cooling efficiency and the cable orientation when routed in a bundle of cables, ie horizontal or vertical. The dielectric clearances between winding leads and winding leads to earth are driven by the Design Insulation Levels (DILs), the cable diameters and the insulation thicknesses. The structure containing the cables should be designed with short-circuit, manufacturing and transport forces in mind.

Material requirements and selection

Transformer specifications such as IEC 60076 [10, 11 ,12 ,13, 14, 15, 16], usually omit specific material requirements, focusing rather on design and performance. Wise selection of materials can improve the design of the transformer in terms of performance and cost. The different materials that may be selected must be reviewed and the benefits of each selection weighed up with respect to the application in the transformer and the performance influences from the wind turbine generator.

With harmonics being present, the focus on conductor and insulation techniques and quality compliance, with specifications such as [17, 18, 19] is important. In all probability, the area of the conductors will be increased and insulation will be increased one class.

With the possibility that cooling could be a challenge in wind towers, it may be necessary to consider aramid [20] and ester oil-based [21] insulation systems. The added advantage of the ester oil is reduced risk in an oil spill.

The local humidity and possible high salinity of the tower may mean that polymeric open bushings or cable connections should be specified in accordance with the correct pollution class defined in IEC 60815 [22]. Bushings or cable terminations should, as a minimum, pass simulated salt fog testing, but should preferably pass long term natural ageing.

The losses for wind turbine transformers should be as low as possible. The two focus areas of materials are core steel, which affects the no-load loss, and conductors, which affect the load losses. For low loss cores, thinner domain refined core material is often used to reduce magnetic losses. The method for reducing load losses is to reduce the resistance of the conductor by increasing the active conductor area and reducing the dimensions that drive the eddy losses down. As this can be a costly exercise with copper conductors, aluminium could be considered as a cheaper alternative. Aluminium windings will generally be bigger than copper owing to the difference in density so conductor saving will need to be balanced against the extra costs needed owing to the dimensional growth of the tank and oil needed for the larger tank. The fact that the transformer may need to fit inside a tower may limit its size and may mean that copper has to be used.

Conclusion

Wind turbine generator transformers have different operating conditions from distribution and power transformers. The subsequent effects on the electrical and mechanical design have to be taken into account, and wise material selection can improve the cost and performance of the design. There are various techniques in the design and application of standard and alternative material selections to ensure a resilient transformer in the application of wind turbine electricity generation.

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1

Where there is a power transformer, you will find a Buchholz relay. It remains one of the most important protection devices, monitoring oil and gas levels within the machine. A Buchholz relay trip generally indicates that a potentially catastrophic situation has been avoided.

Invented in 1921 by Max Buchholz, Buchholz relay technology gained prominence worldwide and became an industry standard in South Africa.

Buchholz relays in South Africa

By P De Matos, Allbro

1

After basic thermal protection and pressure relief devices, Buchholz relays are traditionally the most commonly used protection devices on oil-filled distribution and power transformers.

Categorised as Asset Protection Devices (APD), Buchholz relays are used in oil-filled power and distribution transformers. Usually installed in the pipework between the main transformer tank and conservator, Buchholz relays perform three primary functions as protection devices:

- Monitoring gas build-up caused by the degradation or decomposition of the solid/liquid insulation owing to overheating or arcing
- Monitoring oil surge caused by arcing or short-circuit conditions in the transformer
- Monitoring oil loss in the conservator

During normal transformer operating conditions, the Buchholz relay is filled with oil when installed in the pipework between the main tank and the conservator.

The gas build-up operation occurs when gas is generated in the transformer; it rises up through the pipework towards the conservator and collects in the upper section of the relay. This causes the oil level to drop and the top float to trigger an alarm switch. Further gas accumulation causes the oil level in the relay to drop until the lower float triggers a trip switch.

The oil surge operation of the relay is caused by an arcing or short-circuit in the transformer. This forces oil up through the pipework towards the conservator. The relay is fitted with a paddle, which is set to trip at oil velocities of above 1 ms.

The last operation of the relay relates to oil loss and will only take effect once all the oil in the conservator is depleted. This operation is similar to the gas build-up condition. The oil level drops in the upper section of the relay and the top float triggers an alarm switch. Further oil loss drops the level in the relay until the lower float triggers a trip switch.

The construction of the Buchholz relay is an assembly of two machined aluminium alloy castings. The main body of the relay is fitted with tempered glass inspection windows. An oil sampling plug is located at the bottom of the main body. The top cover carries the frame which contains the moving parts of the relay. These comprise the two floats and their relevant switches, rated at 400 Vac/6 A.

The cover also carries a gas discharge valve with G1/8" in male thread, a valve for pneumatically testing the alarm and insulation circuits, a Press-to-Test (PTT) rod for mechanically tripping the alarm and the insulation circuits. It also carries the terminal box which, as standard, contains four numbered M6 terminals and one earth terminal.

South African transformer manufacturers subscribe to British specifications and the dimensions of the Buchholz relays and flanging arrangements are limited to British standards. Three standard sizes are used, ie 25 mm, 50 mm and 75 mm. In Imperial terms manufacturers refer to 1, 2 or 3 inch devices. These sizes generally refer to, and govern, the inner diameter of the pipework that is connected to the devices.

Looking at the installation of the relay, certain procedures should be adhered to, in order to ensure the correct operation of the unit. Each unit has a red arrow clearly painted on the lid which must point to the conservator. The international recommended inclination of the relay pipework is between 2,5° and 5° to the horizontal, rising up from the tank, through the relay, towards the conservator. To ensure the correct flow of gases and oil, the pipe from the transformer to the relay must exit the transformer at its highest point.

The length of the pipe between the relay and the conservator should be at least five times the diameter of the pipe. Similarly, the length of the pipe between the tank and the relay should be at least three times the diameter of the pipe. Finally, to ensure that the relay operates correctly, the relay must be filled with oil. In other words, the height of the relay's breather valve must be lower than the minimum level of oil in the conservator.

Each unit is individually tested and the test results are recorded on a certificate that is supplied with the relay. Several routine tests are performed to ensure the correct performance and operation of the relays. A hydraulic seal test is performed at 2,5 bar for four minutes to check for any possible leaks. The correct operating sequence of the alarm and trip switches is verified by the PTT rod. By pressing the rod, the alarm switch must activate first and then the trip switch.

Conclusion

The gas build-up (or loss of oil) function is tested by slowly introducing air into the gas sampling valve and recording at which volume the alarm and then the trip switches are activated. The current Eskom specified values are shown in the *Tables 1* and *2*.

Oil content of transformer	Relay nominal size	Alarm gas volumes
1 000 litres	25 mm	150 ± 50 cm
1 001 – 10 000 litres	50 mm	300 ± 50 cm
10 000 litres	75 mm	400 ± 100 cm

Table 1: Alarm signalling volumes.

Oil content of transformer	Relay nominal size	Trip gas volumes	Trip oil flow rate
1 000 litres	25 mm	300 ± 502 cm	1 000 ± 150 mm/s
1 001 – 10 000 litres	50 mm	700 ± 502 cm	1 000 ± 150 mm/s
10 000 – 50 000 litres	75 mm	800 ± 1002 cm	1 000 ± 150 mm/s
50 000 litres	75 mm	800 ± 1002 cm	2000 ± 200 mm/s

Table 2: Trip signalling requirements.

The final routine tests are the 60 s, 2 kV RMS at 50 Hz electrical withstand tests, applied in turn between each electrically independent circuit and the casing of the device, and between the separate independent electrical circuits.

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132 kV, 350 MVA, 2500 mm² Milliken Cable

CBI electric
african cables

CBI-electric: african cables is a fully SABS and ISO accredited market leader in the supply, design and manufacturing of electric power cables. CBI is the first in Sub-Saharan Africa to design, manufacture and type-test underground High Voltage (HV) cable systems with large conductors up to 2500mm², capable of delivering 350MVA from a single circuit.

Why HV cables with large conductor sizes?

As the first local designer and manufacturer of SABS IEC 60840 type tested HV cables and cable systems that range from 44kV to 132kV with 300mm² to 2 500mm² conductor sizes, copper or aluminium and by extending the conductor range to include 1 200mm², 1 600mm², 2 000mm² and 2 500mm², in accordance with IEC60228 and SANS1411-1, CBI is now able to offer HV cables and cable systems that can distribute maximum power ratings up to 350MVA from a single circuit. This enables the Electrical Distribution Industry to meet increased power demands at reduced costs.

What is a Milliken segmental large conductor?

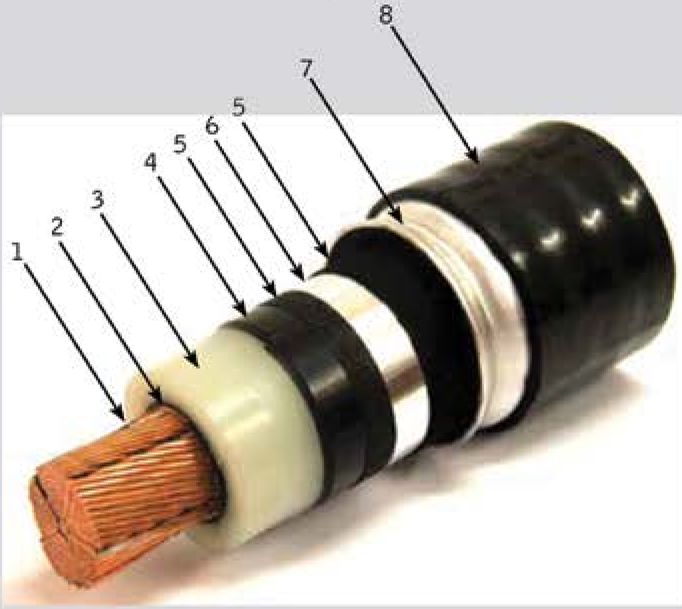
A Milliken conductor is described as a stranded conductor comprising an assembly of shaped stranded conductors, lightly insulated from each other. The design and construction is such that it reduces the AC resistance of large conductors, consequently increasing the current rating. In the case of the 2 500mm² copper, AC resistance is typically reduced by 18% which directly improves the current rating by approximately 7%.

CBI-electric: african cables offers Milliken segmental conductors from 1 200mm² to 2 500mm² in non-water blocked and water blocked versions with a SABS IEC 60840 water penetration type test certification.

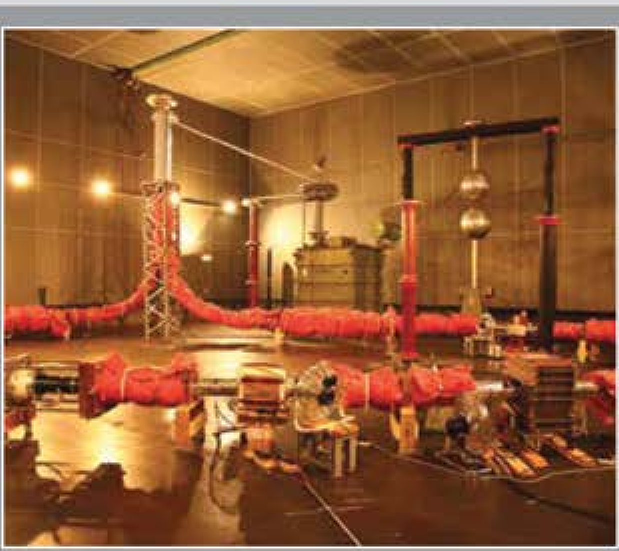
What is HV cable construction?

The conductor screen, insulation and insulation screen is extruded simultaneously over the conductor in a Triple Extrusion Process using a single cross-head employing the CBI-electric: african cables new Continuous Catenary Vulcanising (CCV) line with a Dry Cure Dry Cool Cross linking Technology. This assures perfect bonding of the semi-conducting layers with the insulation in order to eliminate chances of micro void formation. In-line state of the art X-Ray units and an advanced control system ensure that radial insulation thicknesses and concentricity according to design and specifications are continuously achieved during the extrusion.

To restrict the longitudinal penetration of water along the cable, special water blocking tapes are added to the design ensuring that water travel will never exceed 3m from the entry point. The Corrugated Seamless Aluminium (CSA) sheath offers superior mechanical protection to the cable core and is able to conduct high earth fault ratings. Being seamless and impermeable, it is a perfect radial barrier to moisture ingress. To protect the CSA from electrochemical or galvanic corrosion, it is covered by Linear Low Density Polyethylene (LLDPE) outer sheath or serving.



1. 2 500mm² Copper Milliken water blocked conductor
2. Semi-conducting conductor screen
3. XLPE insulation 132kV
4. Semi-conducting insulation screen
5. Water blocking tape layer
6. Aluminium foil metallic screen
7. Corrugated Seamless Aluminium metallic sheath
8. Linear Low Density Polyethylene outer sheath



Why is it important for a Type Test to be conducted?

Type tests are tests that are carried out on a cable system before it can be supplied to the electrical industry and are essential to demonstrate the satisfactory performance characteristics of the cable and cable system, confirming reliability and longevity. A cable system includes both cable and accessories (terminations and joints). A type test also confirms the electrical stress performance of the cable and accessories as designed.

Type tests are conducted at our 300kV Type Test laboratory under the witnessing and strict control of SABS inspectors. Electrical type testing includes a mechanical bend test, partial discharge measurements, a tan delta test, current with voltage load cycles for 20 days, lightning impulse tests and a voltage withstand test. The non electrical type testing includes all the intensive material tests on the insulation and sheathing materials, as well as the conductor resistance measurement, physical construction and dimension checks. A water penetration type test is also conducted.

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Why not simply specify your substation and have it delivered to site? Fabricating the entire substation off-site has numerous advantages – one of them being the working conditions under which the system is built. This allows rapid deployment of substations to remote sites and even across borders.

2

Mobile substations – the sensible alternative

By W Jackson, Efficient Power

A combination of heavy engineering thinking and substation integration breaks the shackles of the conventional approach to the building of substations - offering true, cost-effective off-site turnkey solutions for large electrical plants.

Why is it that we persist with the construction of brick and mortar substation buildings and transformer bays, often in hostile and remote locations? Conventional thinking is constrained by the idea that the only substitutes for brick buildings are shipping containers. This could not be further from the truth.

Having spent a large portion of my career at the tail end of projects trying to compensate and correct for delays caused by poor interfacing and the sequential reliance on other disciplines, I needed a fundamental change to the traditional electrical and control and instrumentation (C&I) execution strategy. My approach was to do as much work as possible off-site, but the primary barrier to this method was designing and developing mega mobile housings that met the criteria of all the specialised equipment installed in them, followed by the logistics of getting these buildings to site.

The answer came while I was stuck behind a 12 m wide, 50 ton Komatsu 960 iron ore bucket destined for the Sishen Mine just outside Kathu (in South Africa's northern Cape province). It dawned on me that if a load nearly five times wider than an ISO (International Standards Organisation) shipping container could find its way from the West Rand of Johannesburg to the Northern Cape, my logistical issues were not as daunting as I had envisaged. As it turned out, the very company that fabricated the bucket held the key to this mobile building problem and unlocked massive positive spin-offs for the project of which I was part.

Not working on site - advantages

Having come off the back of a challenging mega iron ore project, my team and I were given the blank canvas of a greenfields project to re-define the electrical and C&I execution strategies. Armed with lessons from the shortcomings of the previous project, we were determined to change the sequential reliance on other disciplines. Our primary objective was to reduce our exposure to site-based inefficiencies and poor productivity.

The Achilles-heel was the brick and mortar building as this was the starting point for all site-based work. That traditional first concrete pour condemned every other aspect of the electrical and C&I installation to serving a two to three year sentence on site. There are a number of fundamental issues with site-based work, site-based health and safety policies, site access, poor productivity and the logistics associated with the remoteness of most site work.

Health and safety

In a world where health and safety has rightly become the number one priority on site, all other aspects of projects have had to accommodate its requirements, resulting in increases in construction time and costs. The reason for health and safety having become so onerous is that large construction sites are, by nature, hostile and hazardous environments. Health and safety policies accommodate all disciplines and all circumstances, which makes them extensive, cumbersome and complicated. The obvious solution would be to find a way of doing as much work as possible off-site, in purpose-built facilities where there are substantially fewer hazards, making health and safety far easier to manage.

Access to site

Access to site and access to work are becoming bigger and bigger issues. The process of getting personnel and equipment onto sites is extremely expensive and time-consuming. A number of companies recommend that contractors allow at least two months to obtain the relevant safety files, site personnel medicals, inductions and equipment certification before any work is carried out. With so many different types of specialised equipment needed within substations or Motor Control Centres (MCCs), a large number of equally specialised personnel is required to install, test, integrate and commission this equipment. If the substations or MCC buildings are built on site, all this follow-on

work has to be carried out in the remote, harsh and difficult conditions that site-based work demands.

Access to work

By its nature, site-based work is sequential; there is no real way of completing a particular task until all the items preceding that task have been completed. This often involves numerous other disciplines with battery limits that are seldom clearly defined or understood and interfacing that is difficult to manage. A classic example of this is the civil contractor having to build a substation or MCC. Within the scheme of the civil contractor's responsibilities, these buildings are often low priority and there is little understanding of the complexity of the equipment the buildings will house. Another of my professional concerns is a disregard for the specification for medium voltage switchgear floor tolerances; these are seldom met, making for difficult electrical installations.

Remote locations

A final problem with site-based work is that it often takes place in remote locations and there is an attendant cost. To install all electrical and C&I equipment in buildings on site, the equipment – and the personnel responsible for installing it – must travel to site, access the site and stay near the site. This has time and monetary implications resulting in extortionate Provisional and General (P&G) costs, numerous delays and logistical nightmares for any project manager or engineer.

The reality is that site-based work is expensive, unproductive and always takes longer than expected.

Why so much on-site work?

So why do we continue to do so much work on site? Why are we not building and commissioning electrical and C&I equipment for site in our main business centres, thereby removing our exposure to site-based issues and risks? The obvious answer to this is the size of the buildings that are often required to house electrical and C&I equipment. Convention says that we are constrained by standard transport loads, which means we persist with brick buildings.

Customised mega mobile buildings

We have been building simple mobile substations for many years, but it has largely been for the wrong reasons and in the wrong types of mobile structures. They have been makeshift or temporary solutions and have not embraced what is possible if the off-site philosophy is

truly followed. ISO shipping containers are for transporting goods at sea or, at a stretch, for temporary site offices, but not for substations.

Complete off-site fabrication needs companies with facilities and skills to design and fabricate customised mega mobile buildings that out-perform traditional substations and MCCs in every sphere. Once fabricated, the mobile building needs to be equipped, test-integrated and have every possible piece of equipment commissioned in the same facility so that the building leaves for site 100% operational, 'from mouse to motor'. This approach makes it possible to have a substation with MV switchgear, an MCC and a C&I room fully operational within a week of arriving on site. This completely changes the extent of site-based commissioning. If off-site thinking is carried out correctly, the saving to the project can be orders of magnitude greater than the total cost of the buildings themselves.

Truly off-site approach

The solution lies in the unusual marriage between electrical and C&I requirements and heavy engineering thinking offered by the company that built the Komatsu 960 bucket I was stuck behind on that trip to Kathu. The company, Efficient Engineering, has been building massive equipment and buildings for sites around the world for the past 40 years. The company is not constrained by what convention would say is a large load for transport. It is this 'nothing is too big to make or move' when it comes to building bespoke mega structures for land transportation that unlocks the electrical and C&I engineers' ability to have total control of their aspects of the project. Importantly, this approach allows for a parallel construction path, removing the majority of the sequential reliance on site-based execution.

The key is to have buildings that are custom built around the equipment they will house and not to try to force or squeeze equipment into a standard building container. Clearances should not be compromised and every combination of equipment requires a bespoke solution. When challenging convention, the alternative should be superior, and cost and time effective.

Custom designed base frames

The heart of these buildings is the custom designed base frames that are made to match the equipment to be installed in them, and accommodate the deflection criteria of MV switchgear and their tolerances for floor levelness. The buildings are designed for over thirty years of service and have a track record to back this up. Specific attention is given to explosion venting, fire detection and suppression. Lux simulations are done for each room to ensure that statuary lux levels are met or exceeded. Rooms are positively pressurised and HVAC systems are designed around the heat outputs of the equipment installed in the buildings.

The thermal performance of the buildings is designed to be superior to that of brick and mortar, with the possibility of passive buildings (no net heating or cooling requirements) being dependent on the primary equipment installed. The pre-fitted walkway hand rails and stairs are part of the standard offering with the option of self-lifting buildings that remove the need for site cranes.

The most important benefit is that all electrical and C&I installation and commissioning can be carried out in large business centres rather than in hostile site environments.

Mega mining project

The following costs are based on the rounded numbers from a mega mining project on which I was the lead engineer. The project's basic approved budget for the electrical and C&I delivery was a little over R500 M with a provision for R11 M for substations and MCC buildings (only 2% of the budget). By making use of large custom modular buildings built off-site and moved to site post-installation and commissioning of all equipment internal to the buildings, the overspend on the 'traditional brick' building budget was a little over R3 M.

However, by removing the requirement for any of the electrical and C&I contractors to travel to site to install, integrate, test and commission the more than R100 M worth of equipment designed for those buildings, there was saving in the total budget of more than R80 M. This was mainly through the removal of almost all of the associated P&G, reduction in commissioning time and not spending any of the contingency budgets. Perhaps, more significantly, the project was operational five months ahead of schedule. The early delivery alone realised more than 1,4 million tons of additional iron ore for the mine and early closure of the construction site. This had financial benefits for the company that exceeded R1 billion. I ask again, why is it we persist with working on site when there are other simpler, more cost effective solutions that merely require a logical mindshift?

Conclusion

The question arises once again - why is it that we persist with working on site when there are other simpler and significantly more cost effective solutions that merely require a logical mindshift?

Acknowledgement

The author wishes to acknowledge the contribution of his team – Francois Booyens, Kevin van Blommestein, Percy Nxumalo and William Visagie – to the development and success of the Off Site Philosophy, as well as the valuable input from the teams of Kumba C&I, Hatch SSP and BVI SSP.

GIS systems are known for their production of Very Fast Transient Overvoltages (VFTOs). Whereas GIS systems offer many advantages, power transformers installed in those systems must be specifically designed to deal with theses steep-formatted waves and the associated overvoltages. Particular care must be paid to the insulation system and testing of the machine.

2

Very Fast Transient Overvoltages on power transformers

By G Semiano, WEG Equipamentos Eletricos SA

The design consideration of two high voltage transformers connected to a GIS system, taking the VFTO characteristics into account.

Of all design elements in a power transformer, the insulation system is one of the most important. Its function is to dielectrically insulate the winding, ensuring that no discharge occurs during the field operation of the transformer.

The electric field distribution that may occur in the insulation system of power transformers connected to a GIS system is not covered in the IEEE and IEC standards. These standards only refer to the traditional methodology of connecting a transformer to the power grid and do not consider the special conditions when connected to a GIS system.

In verifying the transformer insulation during the final tests, the standards are a guide to executing tests of applied voltage, induced voltage, lightning impulse and switching impulse, depending on the equipment characteristics [1, 2]. Each test has its own purpose and all dielectric tests complement each other. While the tests of applied voltage and induced voltage are requirements for industrial frequency (low frequency), the tests of lightning impulse and switching impulse are required for high frequency and apply high voltage (HV) gradients to the windings.

On the induced voltage test, the voltage gradient distributes equally along the winding; while on the impulse test, the voltage initially distributes in one function of the winding capacitances and applied waveform characteristics in the frequency domain.

If the initial voltage distribution is different from the voltage determined by the low frequency inductive coupling, the associated energy of the high frequency impulse will oscillate between these two distribution characteristics. This leads to internal winding voltage oscillations, based on its eigenfrequencies, which may reach twice the value of the applied voltage during the impulse test.

The presence of overvoltages on the GIS system is a result of the operation of the switching devices. It is also clear in situations where there are disruptions to ground inside the gas. The frequencies that show up in these cases are higher than in an ordinary system. The VFTO is a phenomenon of which the main characteristics are the occurrence of very fast front waves that consist of a high frequency spectrum. There is no standard for the values involved, but analysis of the available literature shows that the events have microsecond waves, frequencies of kHz up to MHz and typical amplitudes of 1,5 pu to 2,5 pu [3, 4, 5].

Simulations

During the design stage, in order to define all the dielectric distances and insulation materials, it is necessary to analyse and simulate the electric field along the transformer winding for the voltage and frequency values [6, 7, 8]. For low frequencies, the results may be analytically verified through simple mathematical calculations involving voltages and dielectric distances. However, in high frequency, the transformer is a complex circuit of leakage and mutual inductances, capacitances and resistances, presenting a great number of resonance frequencies. If a transient with sufficient energy excitates one of these resonance frequencies, the amplification of the internal voltage and the possibility of a dielectric breakdown is inevitable. It is possible to change the winding voltage distribution during high frequency tests through the use of different winding built models (eg interleaved windings). In this way, the design has to be done in a manner that permits a more linear voltage distribution in order to reduce the transient's HV energy that will occur during the tests and operation.

The design procedure will require detailed prior modelling of the winding and simulations using specific mathematical tools and software.

Lightning impulse simulation

Usually, in lightning impulse simulations, where the predominant frequency is between 0,1 and 5 MHz, a simplified model of the winding is sufficient for the analysis (see *Figure 1*).

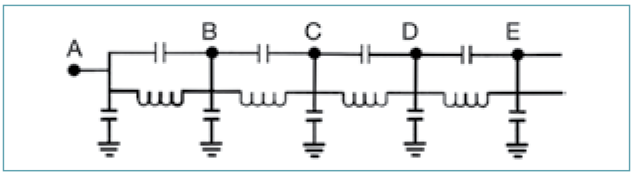


Figure 1: Simplified model of the winding.

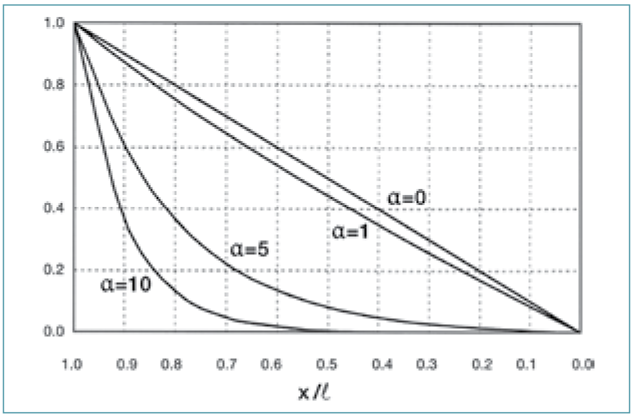


Figure 2: Example of voltage distribution along the winding, considering its capacitance.

For the transformer dielectric design, it is undesirable to have a high intensity electric field at the first discs of the winding. Since all this is likely to occur in the case of VFTO, the design should consider a circuit model with a high level of detail for the winding, in order to evaluate

with great accuracy the voltage in all critical points. The characteristics of the transformer response for ordinary lightning impulse and chopped waves (not involving VFT voltages) are shown in *Figures 3* and *4* and offer a simple analysis that most software employed in review of equipment design is able to handle.

Figures 5 and *6* show the response of the transformer under a chopped wave impulse test. *Figure 6* defines the response at a specific point of the winding. This view is only achievable with specific software.

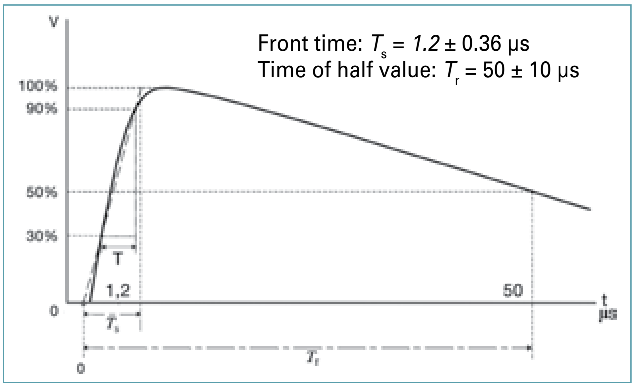


Figure 3: Standard lightning impulse wave.

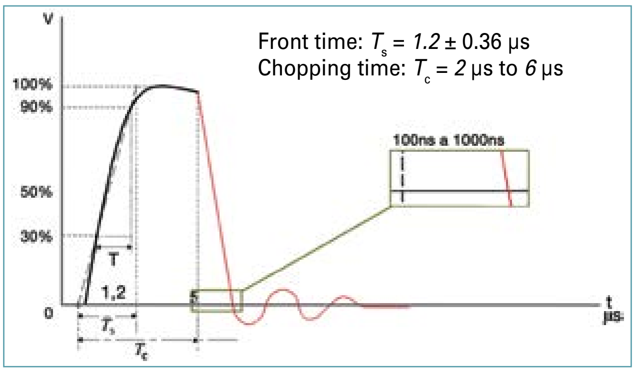


Figure 4: Standard chopped impulse wave.

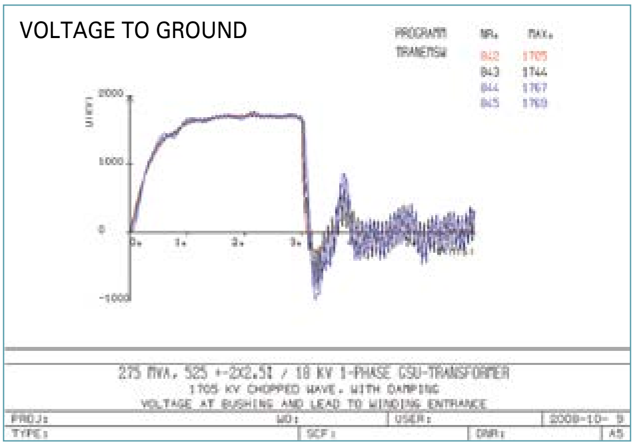


Figure 5: Simulation – chopped wave on the air.

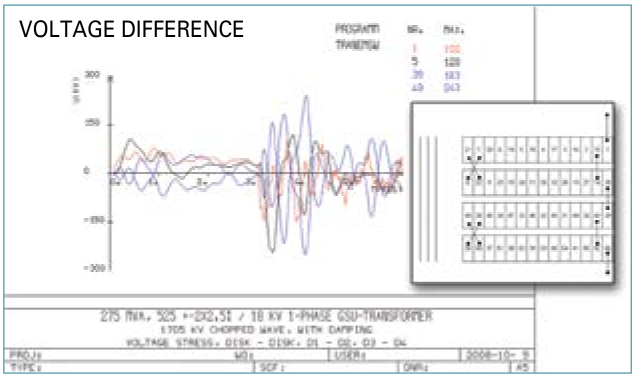


Figure 6: Simulation – chopped wave impulse on the air: difference between disc 1 and 2 2 (n°49 = points 45 and 40).

2

VFTO simulations

In the case of VFTO simulations, where the prevalent frequency is between 30 and 100 MHz, a more detailed winding model is necessary. This modelling represents only the first discs of the winding, since the voltage distribution is concentrated at the beginning of the winding (see *Figure 7*). The model to be analysed is reduced to ensure a more detailed analysis of the most important regions.

The simulations that are executed take into account the detailed model of the first discs where the characteristics of the phenomenon must be reproduced with as much accuracy as possible. The waveform of the VFTO (see *Figure 9*) reflects the measurements executed on the GIS system.

The input wave shape for the VFTO simulations considers the reduced time for chop (2 μs) and, mostly, the fast fall time duration (10 ns) that represents the most critical condition for the transformer dielectric insulation. Some simulation results of VFTO on the transformer under study can be seen in *Figure 10*.

Figures 10 and *11* represent simulation examples based on winding points being analysed. To analyse the adaptation of the dimensions and the dielectric arrangement adopted for the winding, an accurate analysis has been done of the different points for each winding.

Comparing *Figures 5* and *10*, it can be noted that the oscillation after the chop in the gas is much higher than in the air. Comparing *Figures 6* and *11* it can be seen that the voltage at the first discs is much higher than when chop occurs in the air.

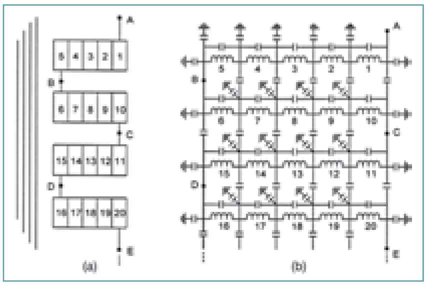


Figure 7: Detailed model of the first discs of a continuous disc winding.

Figure 8: Model of the first discs of the interleaved winding of the transformer under study.

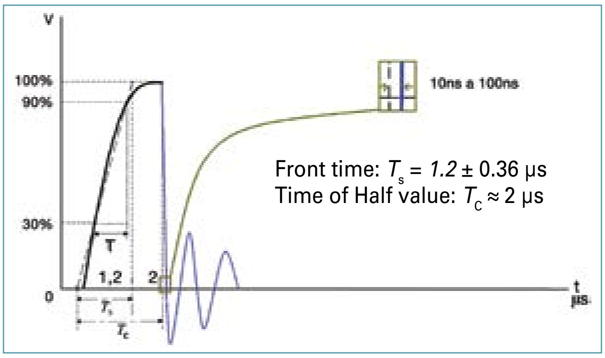


Figure 9: VFTO wave shape for the GIS system.

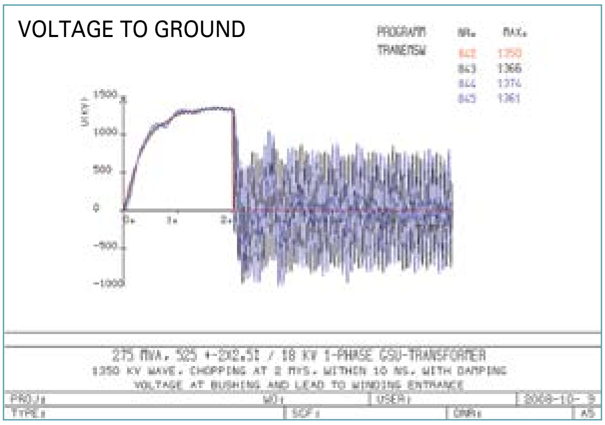


Figure 10: Simulation of VFTO response.

VFTO test

The most critical aspect of this analysis is the practical evaluation of the transformer under the VFTOs. A specific laboratory test device has been developed to execute the chop in the gas (see section on 'chopping device') and to do complementary tests in order to prove the final performance of the transformer. Another important consideration is the fact that the HV bushing is reduced once the transformer is connected to the bar through the SF_6 bushing. This constructive characteristic requires the installation of an appropriate bushing for this test: adapting the original condition of the transformer from insulation oil-gas to gas-air, which represents one of the most critical items of the test system. *Figure 12* indicates the transformer with the original bushing and the transformer prepared for the test.

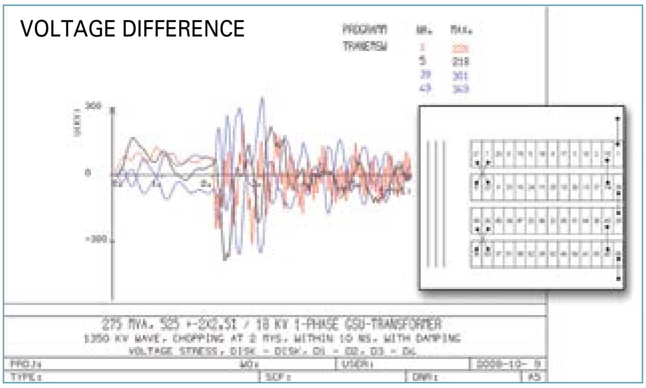


Figure 11: Simulation of VFTO: difference of voltage between disc 3 and disc 4 (n°49 = points 45 and 40).

The practical tests in the laboratory are critical and absolutely new in the final evaluation of power transformers under VFTO during the manufacturing process. They are, therefore, without any standard reference and a preliminary guide for application of the VFTO was established (voltage levels and chop time) as follows:

- Maximum overvoltage: 2 pu
- Maximum transient, peak to peak: 1 350 kV
- Front of the wave: 10 – 50 ns

The following sequence of dielectric tests was applied to the power transformer to make the final evaluation of the previous design, and the reliability of the equipment could be tested in the as-built condition.

Chopping device

The execution of a VFTO test implies the development of a chopped system that makes it possible to obtain the special waves necessary for input of the HV winding into the transformer, in a compartment filled with gas to simulate exactly the operational conditions in a GIS system. The chopped device (see *Figure 14*) consists of a compartment filled with SF_6 located on the base of the transformer bushing.

The chopping device presented is compounded by a chopped system assembled internally with SF_6 gas under high pressure (600 kPa). The device allows external regulation of the gap in SF_6 to obtain the desired chopped waveform. Characteristics of the waveform are shown in *Figure 15*, based on the distance regulation of the electrodes gap on SF_6 (internal to the projected device). The gap distance regulation permits an adjustment in the cut-off time of the applied transformer waveform.

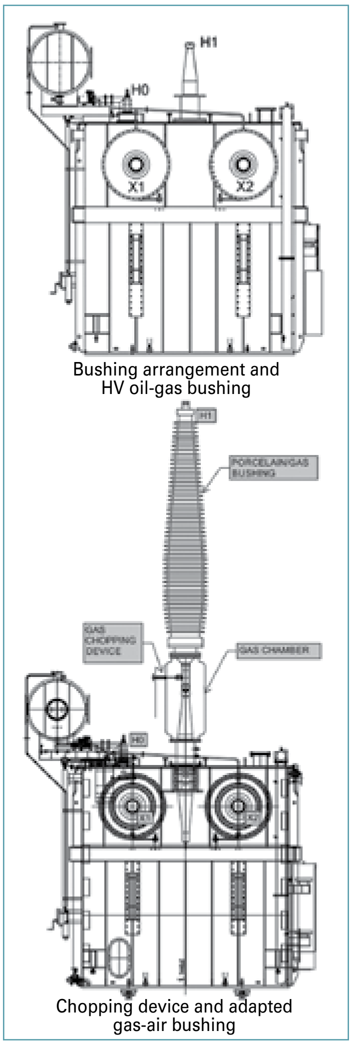


Figure 12: Transformer prepared for test.

The first time this test device was tested, it was completely independent of the transformer for two reasons:

- Calibration of cut-off time for a large range of the tested voltage

Nominal voltage (kV)	525/ √ 3 ± 2 x 2,5% – 18		
Withstand voltage (kV)	AT (H1)	HO	BT (X1, X2)
Applied voltage	34	34	50
Short-duration induced	680	consequent	
Long-duration induced (U1/U2)	550/476	consequent	
Lightning impulse – full wave	1 550	110	150
– chopped wave	1 705	–	165
Switching impulse	1 300	consequent	

Figure 13: Dielectric characteristics of the transformer.

Induced voltage with partial discharges measurement	1,5 x Rated voltage – 476 kV during 1 h
Lightning impulse before VFTO H1	1 reduced wave – 930 kV
	1 full wave – 1 550 kV
	1 reduced air chopped wave -1 023 kV
	2 full air chopped waves – 1 705 kV
	2 full waves – 1 550 kV
	1 reduced wave – 930 kV
VFTO H1	3 gas chopped waves 900 kV
	3 gas chopped waves 1 100 kV
	3 gas chopped waves 1 350 kV
Lightning impulse after VFTO H1	1 reduced wave – 930 kV
	1 full wave – 1 550 kV
	1 reduced air chopped wave -1 023 kV
	2 full air chopped waves – 1 705 kV
	2 full waves – 1 550 kV
	1 reduced wave – 930 kV
Switching impulse H1	1 reduced waves –780 kV
	3 full waves –1 300 kV
	1 reduced wave –780 kV
Lightning impulse H0	1 reduced waves – 66 kV
	3 full waves – 110 kV
	1 reduced wave – 66 kV
Lightning impulse	1 reduced wave – 90 kV
X1	1 full wave – 150 kV
	1 reduced air chopped wave -99 kV
	2 full air chopped waves -165 kV
	2 full waves – 150 kV
	1 reduced wave – 90 kV
Applied voltage	34 kV during 1min
Induced voltage with partial discharges measurement	1,5 x Rated voltage – 476 kV during 6 h

Table 1: Dielectric tests sequence.

- Evaluation of porcelain bushing and test system for certification of the adequacy of all environmental conditions before connecting the device to the transformer under test

The VFTO test was performed with an atmospheric impulse test common circuit with the chopped device inserted in the test circuit. The cut-off time was calibrated according to *Figures 15* and *16*.

The purpose of this test is to obtain the cut-off time of the SF_6 with as accurate a precision as possible. With the assurance of a cut-off on

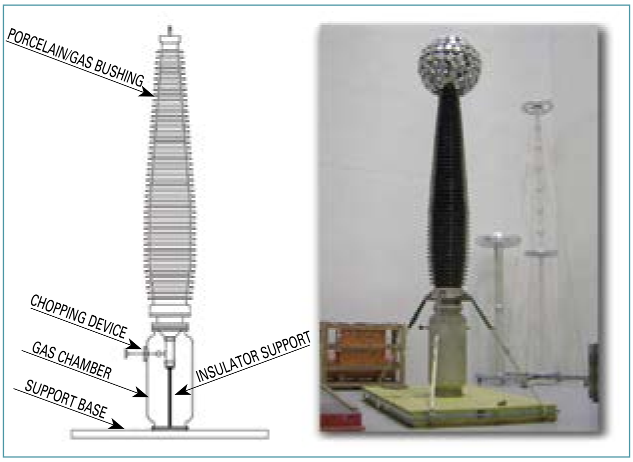


Figure 14: Chopping device on gas.

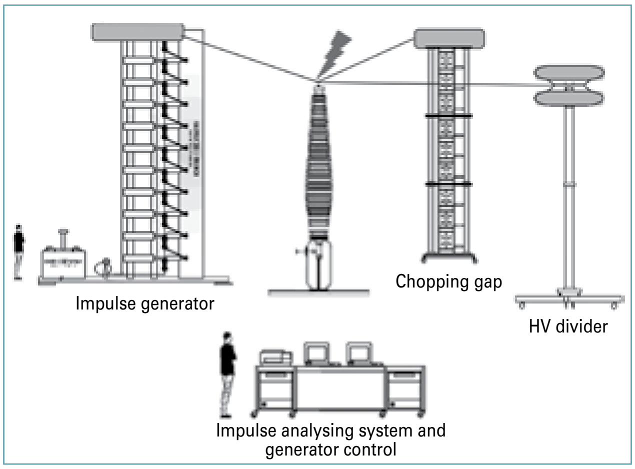


Figure 15: Chopping device on the gas calibration circuit.

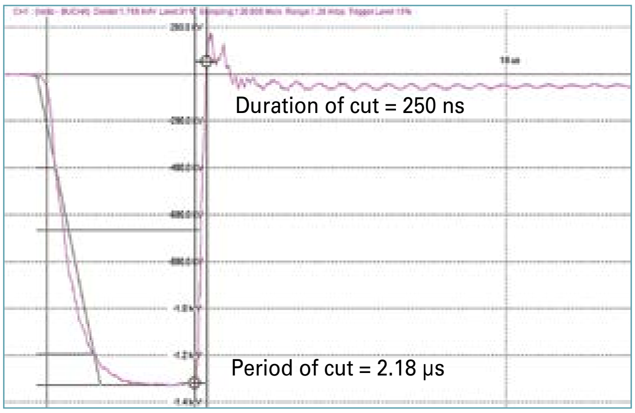


Figure 16: Waveform measured during the calibration of chopping device on gas.

gas in an extremely short time and the generation of correlated freak of insulation request on high intensity, it was established that the measure of cut-off time would be performed on the top of porcelain bushings (see details of chopped points of the wave and details of measurements in *Figures 14* and *15*).

Therefore, as the chop occurred inside the gas chamber and the waveform was measured on top of the bushing, there was a delay of about 250 ns between the real chopped waveform and the measured waveform.

VFTO application to transformers

After calibrating the chopped device and certifying that the set supported VFTO applications in an independent manner, the device was assembled in the transformer according to *Figures 17* and *18*. That is the beginning of the test sequence presented in *Table 1*.

During the application of full and chopped waves of an ordinary lightning impulse test, the gap of the chopped device on gas is kept open so as not to permit the chop on the gas. When VFTO applications are required, the gap of the chopped device on air is completely opened while the gap on gas (inside the chopped device) is set according to the previous calibration.

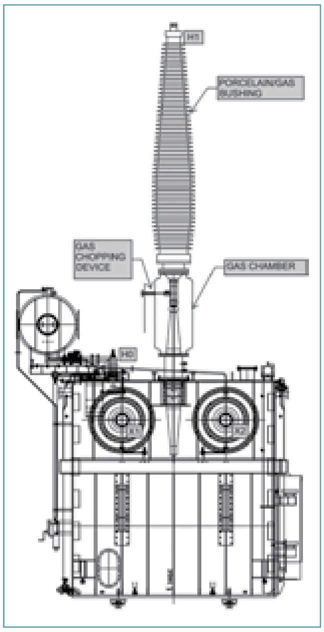


Figure 17: Transformer assembled with chopping device and porcelain bushing.

Measure analysis

It is important to address the differences in the voltage levels applied during the impulse test and VFTO. In the impulse test, the voltage levels are higher than those submitted during transformer operation in the field (between 10 and 30% higher, being limited by the surge arrestors) and have a probabilistic characterisation to allow the analysis of the insulation. In VFTO tests, the voltage levels used represent exactly those submitted by the equipment during normal operation in the field.

Since this test had never been performed before, for final reception of transformers and since there is no standard guide to analyse the supportability of VFTO, one of the ways to evaluate was by observation of behaviour of the transformer during the test: evaluating possible direct disruptions to ground and comparing the results of standard lightning impulse tests performed before and after the VFTO applications.

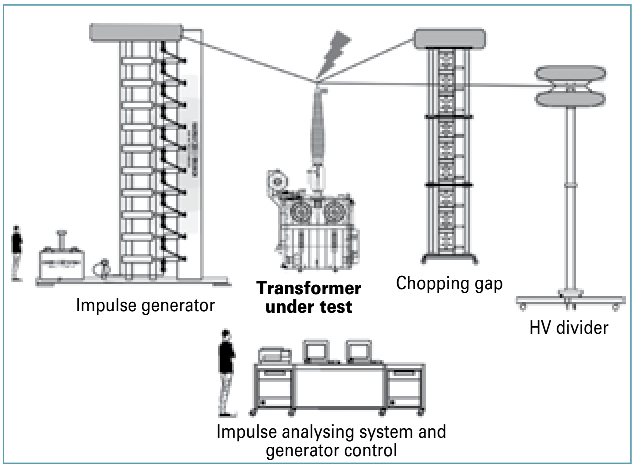


Figure 18: Transformer prepared for lightning impulse test, switching and VFTO.

Comparison of VFTO with the standard waves of lightning impulse

In the comparison shown in *Figure 20*, the frequency of oscillation after the chop which converges fully with software simulations can be seen.

It is possible to check the reduction of the cut-off when performed on gas. It is important to point out that the measure point for one or other condition of wave is the same and was placed at porcelain bushing extremity. However, as the chop happened in a gas enclosure system, the real time of the chop is much earlier than the time reported by the measurement. This means that it will be a significant increase in the frequency of this transient applied to the transformer.

Figure 22 shows the increase on current levels owing to the chop on gas of a waveform of 1 300 kV when compared with a chop on air of a waveform of 1 705 kV. It can be observed that, although the voltage level of the gas chopped wave is 23% lower, the current after the chop is 185% higher than that chopped on air.

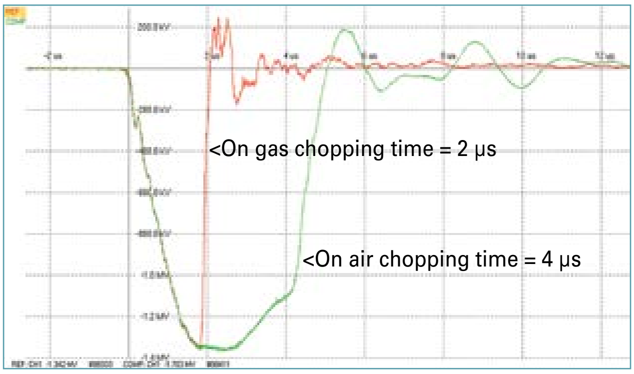


Figure 19: Comparison voltage – lightning impulse chopped on gas (1 350 kV) and chopped on air (1 705 kV).

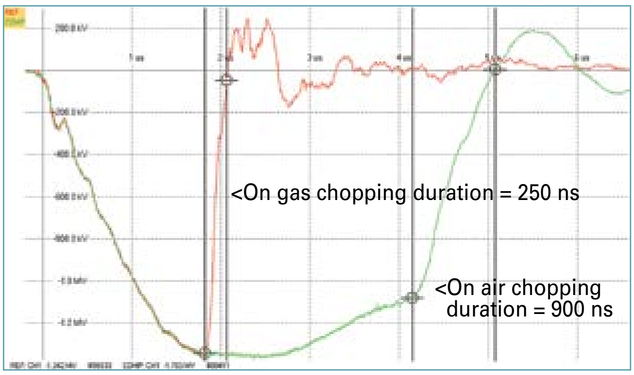


Figure 20: Comparison voltage – lightning impulse chopped on gas (1 350 kV) and chopped on air (1 705 kV).

NTSA presents two unique relays for **TRANSFORMER PROTECTION.**

NTSA
DEFINED POWER PROTECTION

Transformer Inrush currents considerably age transformers and expensive rewinding and reconstruction of the transformer are commonplace.

The TRIM relay offers a unique solution. TRIM selects the optimum closing time so that the breaker closes exactly at the intersection of the phase voltage AND the remanent magnetism in each phase. The relay calculates the remanent magnetism in each phase and selects the optimum breaker closing time for each of the 3 phases.

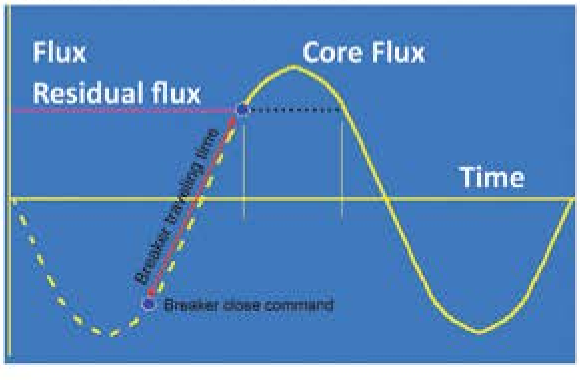
The relay can be set up remotely and can be read remotely. It has state of the art fault and event recorders. The relay is certified to IEC 61870 standards and as such can interface with various other relays of this standard.

The second relay named AZT is a transformer back up protection relay which can be used as an autonomous relay or as back up protection addressing transformer burnout situations

The relay is typically located in the transformer marshalling kiosk. It charges itself up via the VT/CT of the transformer and stores the energy to trip the breaker in case of unmaintained or faulty batteries or protection relay failure or in case of copper theft preventing the trip command. The relay has its own IDMT settings and trips the breaker when the other traditional elements fail.

Many transformers were saved from burnout this way. In many European countries this relay is mandatory to protect the environment from the smoke of a burning transformer and to protect against the explosion danger in buildings and dense residential situations.

Optimal controlled closing



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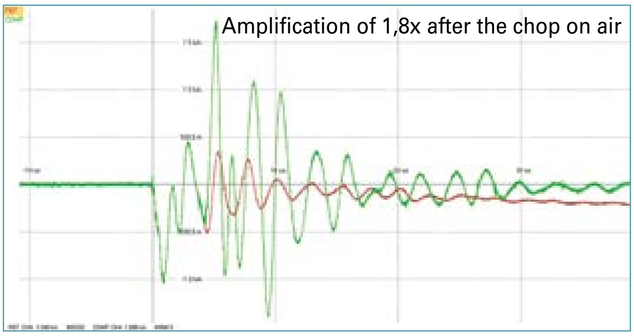

Figure 21: Comparison of the full wave current without chop x on air chopped.

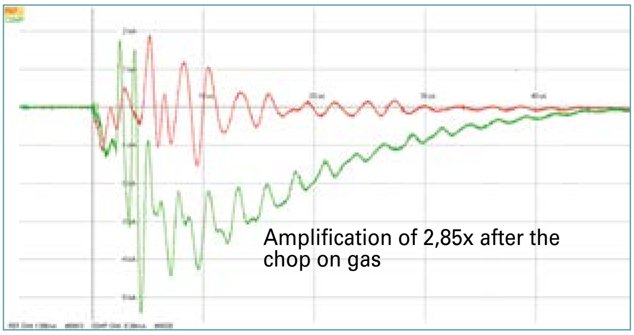

Figure 22: Comparison of chopped wave on air current x chopped on gas (VFTO).

Conclusion

Transformers connected to a GIS system are exposed to VFTO and have to be prepared in order to perform under these conditions. Simulations and experience show that the VFTO is more critical to the transformer design than to the standard chopped lightning impulse waveforms. Although the duration of VFT is extremely short, its amplitude and frequencies have the capacity to compromise, irreversibly, the conditions of insulation of the equipment.

Identification of the transient characteristics that may occur at the GIS is extremely important for the optimal design of the transformer. However, the determination of transient characteristics on the electric system is outside the scope of this research and readers are directed to the references which show the measures and simulations that may be performed to predict this behaviour.

Manufacturers must be informed of the characteristics of the transients of a specific power system so these can be taken into account in the design of the equipment. These requests must be considered not only in the design of the electrical insulation, but also at the internal configuration of each transformer.

The practical, final tests prove the capability of transformers in the VFTO presented by customer's power system. But, to obtain a general standard consideration of the VFT waveforms, more studies of the literature must be undertaken.

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[2] IEC 60076: Power Transformers.
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When a transformer fails, it can be spectacular. For repair and refurbishment, it is generally necessary to remove it from site, which is a costly exercise. New protection devices play an important role in extending transformer life – and limiting the stresses.

2

Innovative transformer protection relays

By R Billiet, NTSA

Important factors to be taken into account to avoid transformer failure.

Transformers are critical to the operation of industrial plants and residential complexes. When a transformer fails, users are frequently faced with long replacement time intervals and massive replacement bills. A few important factors need to be taken into account to avoid transformer failure:

- Transport cost to the transformer repair factory
- Repair or rewinding of the transformer
- Transport cost to the original position
- Reconnection
- Commissioning of the repaired transformer

When a transformer fails, the factory or the residence has to find alternative energy from other sources, such as generators. This translates into high and unforeseen expenses that are not always covered by insurance. Sometimes, there are no other options and the electricity cannot be restored. It is thus very important to maintain the transformers properly and one must, therefore, be aware of some intrinsic facts about transformers and, in particular, the need for protection devices to extend their useful life cycle.

This article considers two protection relays that will extend the life of a transformer.

Two protection relays

The first is the Transformer Inrush Limiter Relay (TRIM) which extends the life of transformers by protecting them from transients emanating from frequent switching effects, under conditions such as load shedding.

The second is the AZT relay for 'unmanned' or remote transformers where maintenance is challenging because of under-qualified staff or the effects of 'copper theft'.

In these situations, the relay switches off the main breaker when the normal substation protection is unable to fulfil this role. This will avert the transformer burn-out that normally happens when the protection is impaired and the transformer is feeding into an earth fault or overcurrent. The back-up relay can also stand on its own and operate as the main relay protection in this case.

Both relays are operational in many European countries including Germany, Austria, and Hungary. In certain countries, the back-up relay is mandatory because of environmental or safety regulations.

Transformer Inrush Limited Relay

Transformer inrush is defined as the currents that are generated when a transformer breaker energises a transformer at an instant where the residual flux in the transformer is not matched in all the phases. But it remains a field which is often ill understood. Some solutions have been mooted, such as switching at the zero crossing time, but Eskom [1] does not support this. Other solutions invoke the use of double harmonic blocking (which is achieved when a breaker has been programmed not to trip when harmonic currents would normally trip the current) but in this instance, all that is achieved is that the breaker will be closed during the inrush event and the full inrush current will go through the transformer without any mitigation.

When transformers are switched off and on again an inrush current is inevitable. This causes a series of mechanical stresses to the core of the transformer that are damaging in the short term, depending on the size of the transformer. The windings around the core will likewise be affected and will experience severe stressing. The danger is that the copper or aluminium could become elongated and this is conducive to the eventual formation of hot-spots in the windings in the long term. The paper insulation of the windings will also be affected and, because the winding is stressed, pieces of paper may loosen and fall into the oil. The wedges around the core and pieces of wood or plastic may likewise fall into the oil. The cumulative effect of this is the possible clogging up of the cooling ducts in the transformer, creating hot-spots that will seriously affect the transformer lifespan. Should the LV breaker be closed during the inrush current, it will probably create damage in the downstream plant and could play havoc with electronic loads such as computers and negatively influence the lifespan of chokes, capacitors, UPSs, VSDs, rectifiers and the like. The inrush current creates a host of negative effects and it is important to reduce these.

A study undertaken by Eskom, published in 2008 [1], shows that switching the transformer at zero or maximum voltage will result in some form of inrush current. Any residual magnetism remaining in the core after de-energising the transformer will influence inrush currents as it can drive the core into saturation when energising the transformer. This can become a problem with more modern circuit breakers, ie non-oil filled breakers.

The influence of inrush current phenomena is directly proportional to the MVA size of the transformer. The bigger the transformer, the larger the effects will be. Magnetic improvements in core steel and thinner core steel improve transformer efficiencies and lower the Eddy currents, but increase inrush current effects.

How to eliminate the effects

The key is to try to eliminate the remnant magnetism in the transformer core. Theoretically, this can be achieved by opening the transformer and reducing to zero the remnant magnetism by heating the core, by repeated chocks to the core, by nuclear radiation or by using a magnet with the opposed magnetic field. All these are non-workable solutions. The problem was posed to Budapest University's Dr Petri Kornel, who solved it by pointing out that there are no inrush current effects at the point where the breaker closes at the intersection of the residual flux in the core with 50 or 60 Hz voltage. The challenge is to determine these parameters with a precision of approximately 2 ms. This can be achieved with a protection relay called the TRIM. The said intersection is shown in *Figure 1* - as is a view of the TRIM relay in *Figure 2*.

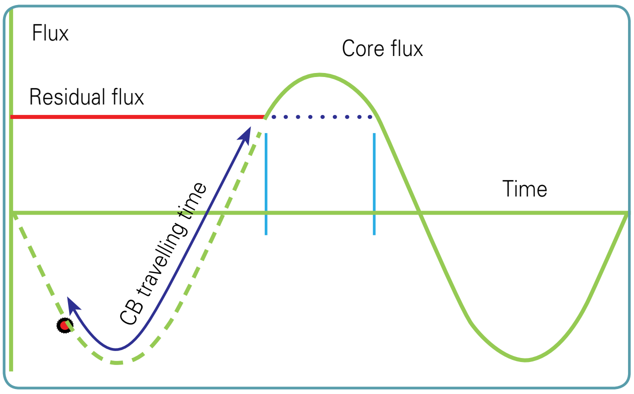


Figure 1: Intersection of the residual flux in the core.

Figure 2: TRIM relay.

Commissioning

Commissioning is relatively easy. The transformer is energised and the breaker operation time is simultaneously recorded and stored in the relay. The transformer is switched off and the vanishing voltage is recorded in three phases and stored in the relay. The integral of the flux is the value of the remnant magnetism in each phase.Therefore, it can be determined when the breaker needs to close so that the conditions mentioned are met for zero inrush current effects. The TRIM is a modern relay to IEC 61870 [2] standards so can interface with other relays of this generation. The relay can be set up and read remotely. The parameters for settings up include: vector group, on/off/bypass, single- or three-pole operation, breaker lag type, voltage correction parameters. The relay ensures that the transformer life span is extended because the negative effects of inrush current are virtually eliminated. At the same time, it is possible to determine, via the built-in fault and event recorders, the correct operation of the relay. This is ideal for remote transformers and transformers where low-technical operators are present.

Autonomous back-up relay - AZT

The simple autonomous back-up relay is another useful transformer protection device.

This is a relatively low cost solution and has the benefit of being versatile as a relay in a system or as a standalone relay. When the traditional control systems are unable to operate, the relay will clear the overcurrent or earth fault and save the transformer from overheating with subsequent explosion and burn-out, which are bad for the environment and worse, could lead to loss of life.

In unmanned or remote substations the following situations are quite common:

- Batteries are not maintained or are poorly maintained or sized incorrectly
- Protection relays are set excessively high to limit the number of call-outs
- Copper from control cables or earthing is stolen

When a transformer fails, users are frequently faced with long replacement time intervals and massive replacement bill.

Figure 3: The low cost and versatile AZT relay.

Each of these situations can lead to transformer burn-out, with the subsequent consequence of environmental damage or the danger of transformer explosion. In several European countries this relay is mandatory, especially for indoor oil transformers and transformers in dense residential areas.

Protection relays are typically situated in the transformer marshalling kiosk and connected to the voltage transformers of the transformer to be protected. In this way the relays store enough energy in the built-in capacitors to be able to trip the breaker when normal conditions of the substation breaker are no longer met. This can occur in any of the situations that have been outlined.

The relay is set 5% above optimal conditions in the substation. Under normal operational conditions the substation will clear the fault. However, under adverse conditions the relay will clear the fault and alarm the situation to the substation or remote operator. This will avert transformer burn-out and the associated effects on the environment and people.

Conclusion

TRIM and AZT relays are useful devices for protecting transformers from the damages caused by transformer inrush and the devastating effects of transformer burn-out. The main benefit to users will be in the confidence that the plant will remain operative and that massive unforeseen costs of lost production are minimised while safety of staff is greatly increased.

References

[1] The impact of load shedding on sub transmission plant. 2009. Eskom. EN09020001.
[2] IEC 61850: 2002. Design of electrical substation automation

Whether a question of insulation coordination for an EHV network, lightning protection for a MV substation, or surge protection on an LV network, lightning poses a risk.

2

Lightning protection – where it matters most

By A Barwise, DEHN Protection South Africa

A reliable power distribution grid is essential for reliable power supply. Protection measures for substations and transformer stations, as well as safe working conditions, are essential.

High voltage systems (between 110 000 V and 420 000 V) transport large amounts of energy over great distances and are thus the backbone of power transmission. In this context, uninterrupted supply is a top priority.

Due to the increasingly distributed supply of renewable energies, higher requirements are placed on the availability of medium-voltage systems. Voltages from 1 000 V to 30 000 V are used for medium-sized transmission lines up to about 100 km. This so-called medium-voltage (MV) is transformed down from high-voltage in substations. To ensure uninterrupted supply, substations and overhead line networks must be maintained.

System failure and surges on the low-voltage (LV) side pose high risks for the connected loads. To be able to use electrical energy in households, it must be transformed down from medium to LV in centrally located transformer stations, before it is distributed to the loads. In this context, it must be observed that voltages up to 1 000 V are termed 'low-voltage'. To prevent interruption and failure of the electrical energy supply, maintenance and repair work must be performed on the installation.

Although these installations and networks frequently need to be disconnected for maintenance and repair, which includes disconnecting, re-connecting and verifying that the installation is dead, it is important to remember that at the moment of disconnecting and reconnecting the system is still live. To prevent accidents, tested high-quality products are indispensable.

To minimise the number of fatal electrical accidents, it is mandatory to observe the five safety rules according to EN 50110-1 [1] when working on electrical installations:

- Disconnect completely
- Secure against re-connection
- Verify that the installation is dead
- Carry out earthing and short-circuiting
- Provide protection against adjacent live parts

Protecting personnel in the event of an arc fault

Every day, electrical work is carried out all over the world. The risk that technical defects, maloperation, pollution or foreign matter in the installation can cause arc faults cannot be excluded.

An arc flash is part of an arc fault, a type of electrical explosion that results from a low-impedance connection to ground or another voltage phase in an electrical system. The light and heat produced from an arc flash, when supplied with sufficient electrical energy, can cause substantial damage or harm, fire or injury. An arc fault is the most catastrophic event that can occur in an electrical enclosure, with temperatures that can exceed 10 000°C at the arc terminal. The massive energy released in the fault rapidly vaporises the metal conductors involved, blasting molten metal and expanding plasma outward with extraordinary force. The result of the violent event can cause the destruction of equipment involved, fire, and injury, not only to an electrical worker but also to bystanders.

There are many methods of protecting personnel from arc flash hazards. These include wearing arc flash personal protective equipment (PPE) or modifying the design and configuration of electrical equipment. The best way to remove the hazards of an arc flash is to de-energise electrical equipment when interacting with it, although de-energising electrical equipment is itself an arc flash hazard.

The installation of a modular arc fault protection system for low-voltage distribution boards in transformer stations will protect persons from the effects of an arc fault during live working. The arc fault protection system detects arc faults in an installation and immediately causes a short-circuit, which trips the upstream overcurrent protective devices. Consequently, the incident energy is considerably reduced and the thermal effects of the arc fault significantly limited.

With recent increased awareness of the dangers of arc flash, tremendous progress has been made in protecting workers against the heat energy associated with arc flash, with a major area of improvement being the steps taken to get workers into safer clothing

Arc-fault-tested personal protective equipment consists of a safety helmet with face shield for electricians, protective gloves and a protective suit, which will safeguard against thermal effects. After safety helmets and protective gloves, protective suits and jackets constitute the third most important component for reducing the risk of arc flash injury while working on electrical installations. Whilst the materials used must provide maximum protection and excellent wearing comfort, it is important that they do not continue to burn after the extinction of an arc and also that they do not release any toxic or corrosive elements.

Lightning protection systems for substations and transformer stations

The National Oceanic and Atmospheric Administration (NOAA) reports that, in any single second, there are over 2 000 thunderstorms occurring around the globe. Lightning protection systems protect structures, including substations, from fire or mechanical destruction, and persons in the buildings from injury or even death. A lightning protection system comprises external and internal protection.

The external lightning protection system is made up of three elements, ie air termination, down conductors and grounding systems. The functions of the external lightning protection are: to channel direct lightning strikes into an air termination system; the safe conduction of the lightning current to the earth by means of a down-conductor system; and the distribution of the lightning current in the earth via an earth-termination system. The function of internal lightning protection is to prevent hazardous sparking inside the building or structure. This is achieved by means of equipotential bonding or a safety distance between the components of the lightning protection system and other conductive elements inside the building or structure.

Surge and lightning protection for electrical and electronic systems

A lightning protection system, according to International Electrotechnical Commission (IEC) 62305-3, protects persons and material assets of value in the buildings. It does not protect the electrical and electronic systems, but it is precisely such systems – in the form of building management, telecommunications, control and security systems – that are rapidly becoming common in all areas of residential and functional buildings. Whilst owners or operators place high demands on the permanent availability and reliability of these systems, few developers seem to appreciate the fact that they are critically susceptible to externally and internally generated voltage transients and surges, especially those produced by lightning.

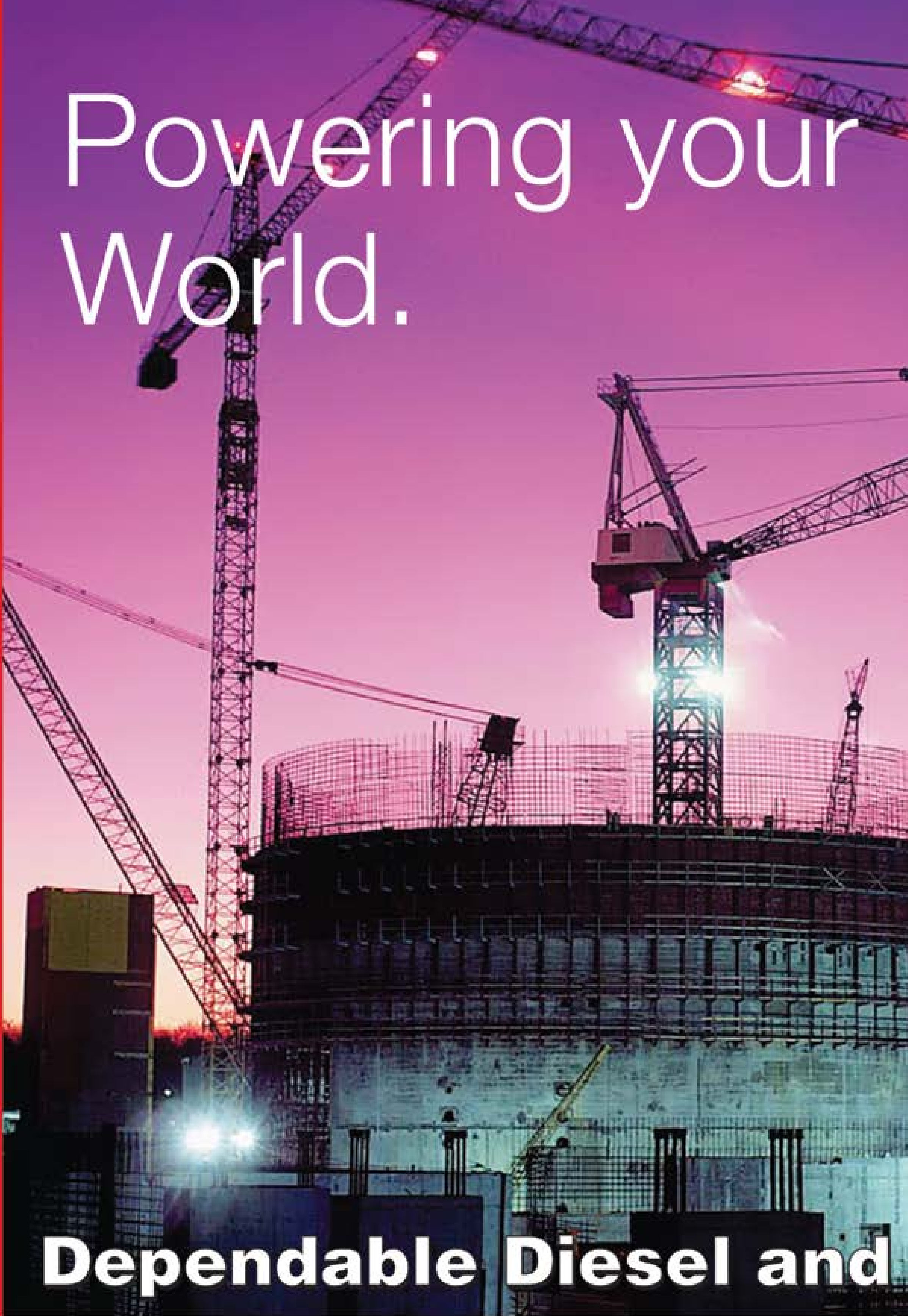
To ensure uninterrupted supply, substations and overhead line networks must be maintained.

Lightning up to a kilometre away can cause damage to sensitive electrical and electronic equipment. At these distances, the induced voltages can be as high as 200 V per metre of cable, which is more than enough to cause damage to equipment. Even equipment connected via cabling within a building can be damaged as a result of the high electromagnetic induction that occurs under lightning conditions.

Lightning damage falls into two main categories; primary and secondary effects.

Primary effects are those resulting from direct lightning strikes, which are a major cause of fire, instant destruction of property, electrocution injury and death. Even though it is one of the most common natural phenomena known to man, there has been no practical method developed to prevent lightning strikes or to avoid damage caused by a direct hit.

The most prevalent technology for dealing with lightning is to divert the strike energy to a properly grounded lightning rod or cabling system. The external lightning protection on a building is only there to act as a preferential point of strike and offers a controlled discharge path to earth, thus preventing structural damage to the building. A common misconception is that if the building has external lightning protection, or if there is a high mast in the area, the equipment will not be damaged. It must be borne in mind that a single earth-termination system for all the various electrical



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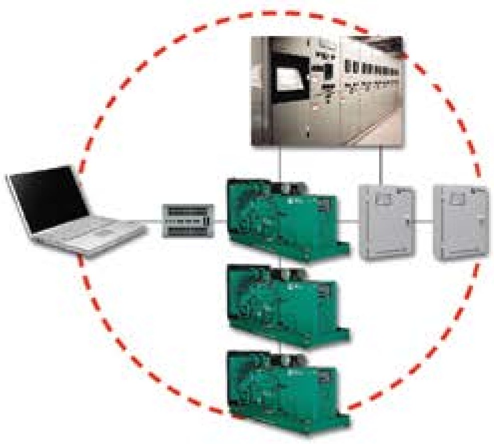

systems is preferable. This earth-termination system must be connected to the equipotential bonding (MEBB – Main Equipotential Bonding Bar).

Secondary effects are approximately a thousand times more likely to occur than primary effects. These are the damage caused to sensitive electronic devices, electrical networks and systems. Approximately 24 out of 100 cases of damage to electronic equipment are caused by surges. Plus, with the advent of Surface Mount Technology (SMT), sensitivity to lightning and overvoltage damage has increased exponentially.

Lightning does not have to strike a facility directly to do real damage. Protection currently in place may be fine for normal surges caused by load switching and utility transients, but will not be effective against lightning. It may even put system equipment at greater risk by providing a pathway through sensitive equipment.

Electronic equipment can be protected from the potentially destructive effects of high-voltage transients. Protective devices, known by a variety of names (including lightning barriers, surge arrestors, lightning protection units and so on) are available. The correct names, accepted internationally, are Surge Protection Device (SPD), or Transient Voltage Surge Suppressor (TVSS). These terms are used to describe electrical devices typically installed in power distribution panels, process control systems, communications systems and other heavy-duty industrial systems, for the purpose of protecting against electrical surges and spikes, including those caused by lightning.

Surge protection devices should ideally operate instantaneously to divert a surge current to ground with no residual common-mode voltage presented at the equipment terminals. Once the surge current has subsided, the SPD should automatically restore normal operation and reset to a state ready to receive the next surge. Ideally, the SPD/TVSS should be built within a corrosion-resistant stainless steel threaded pipe.

Conclusion

Today, microprocessors and integrated circuits are hard at work processing digital data, controlling critical systems and communicating information through ever-expanding global networks. These now common components have dramatically lowered system costs while increasing the power and flexibility of modern electronic systems in a manner unimaginable just a few years ago. Whilst our buildings are protected, the guarding of these sensitive devices is often overlooked. The devices are critical to the running of our homes and businesses and also incredibly susceptible to both externally and internally generated voltage transients and surges, especially those produced by lightning.

According to the International Social Security Association and national regulations in the country of use, arc fault protection shall be taken into account for risk assessment. If there is an arc fault risk, employers must ensure that suitable PPE is provided to their employees and that it is used. PPE must be tested and approved by an accredited certification body.

Reference

[1] EN 50110-1: 2013. Operation of electrical installations. General requirements.

Best practice safety principles

The following steps illustrate the five best practice safety principles:

1 Disconnect completely
- Insulating and switching sticks along with the use of fuse tongs
- Personal protective equipment (arc suits and accessories) is needed when disconnecting that which is deemed 'live'

2 Secure against re-connection
- Protection against re-connection.
- Lock-out systems for circuit breakers

3 Verify that the installation is dead
- Voltage detection through state-of-the-art voltage detectors
- Phase comparison through state-of-the-art phase comparators

4 Carry out earthing and short-circuiting
- High-voltage and low-voltage installations: All parts, which are to be worked on, must be earthed and short-circuited
- Earthing and short-circuiting equipment or devices must first be connected to the earthing point
- Earthing and short-circuiting equipment or devices must be visible from the work location

5 Provide protection against adjacent live parts
- Protection against adjacent live parts must be provided by insulating protective shutters
- Tested protective shutters are customised for different types of switchgear installations
- Insulated rubber mats for insulating the operating location from 1 000 V up to 50 kV
- Use of insulation gloves to protect against live parts

Skipping any element of an electric safety rule can have tragic consequences. Following all of them rigorously should be a fundamental business directive for both employer and employee.

Modern technologies allow detailed information about the condition of machines to be made available at your plant. One area that has developed rapidly is that of transformer winding temperature measurement.

2

Transformer winding temperature determination

By JN Bérubé and J Aubin, Neoptix and W McDermid, Manitoba Hydro

Fibre optic sensors have improved to the point where direct measurement of winding temperature is becoming the preferred method for measuring this critical parameter.

When a new transformer is put into service, a temperature rise test is done to evaluate the average winding temperature and ensure that it is within industry standards. However, temperature of windings is not uniform, and the real limiting factor is the hottest portion of the winding, called the hot-spot. The hot-spot is located near the top of the winding, and thus not accessible for measurement using conventional methods.

The loading capability of power transformers is limited mainly by winding temperature. It has been the practice to assess this temperature from a measurement of oil temperature at the top of the tank, with an added value calculated from load current and winding characteristics. With more frequent occurrences of overloading, it has been found that this simplified approach is not suitable for several types of overload and transformer design. In an attempt to close this gap, IEEE and IEC loading guides are being revised with more sophisticated models aiming at a better representation of oil temperature inside the winding, and consideration of variations in winding resistance, oil viscosity and oil inertia. Still, direct measurement of winding temperature with fibre optic sensors provides a definitive advantage over a value calculated from uncertain parameters provided by the manufacturer and uncertain equations characterising the cooling pattern.

The temperature of paper insulation dictates the transformer ageing. With time and heat, the paper loses its tensile strength and elasticity. Eventually, it becomes brittle and cannot support forces because of short-circuits and normal transformer vibrations. This process is irreversible.

Monitoring hot-spot temperatures

Efforts have been made to monitor hot-spot temperatures in order to take advantage of the cool ambient temperatures, which extend transformer life while offering emergency overloading margins and exploiting market opportunities. The rated hot-spot temperature of modern insulation paper is 110°C. Each increase of 7°C doubles the ageing acceleration factor. In addition, water trapped in the paper runs the risk of forming bubbles at higher temperatures, creating a threat for insulation breakdown. With all this in play, it is no wonder transformer owners attempt to monitor hot-spot temperature with the best tools available.

Recent IEEE and IEC works have shown that the conventional equations used to evaluate hot-spot temperatures are inadequate. Indeed, these models are based on a number of assumptions that have been shown to be incorrect. The changes proposed in the IEEE and IEC loading guides indicate that the hot-spot evaluation methods previously known were inadequate for an accurate assessment of winding hot-spot temperatures. The wide use of computers allows for sophisticated calculation methods, but has demonstrated that the quest to monitor winding hot-spot temperature is not trivial, and raises further doubts about the number of additional values that need to be collected to run the calculation. It is no surprise then that the recommended practice for the direct measurement of winding temperature for critical transformers is via fibre optic sensors.

Recent developments in technology

For nearly 30 years, fibre optic temperature sensors have been available for measurement in high voltage transformers. The first units were fragile and needed delicate handling during manufacture. In the past 10 years, though, significant developments have taken place to improve their ruggedness and facilitate connection through the tank wall. The fibre optic probe on the authors' company's T/Guard system consists of a 200-micron glass fibre sheathed with a permeable protection Teflon tube. This probe is designed to endure manufacturing conditions, including kerosene desorption, and long-term immersion in transformer oil. The temperature-sensing element is based on the proven GaAs technology. An original algorithm is used to extract temperature information, providing accurate and reproducible measurements, even when probes are interchanged.

The most popular installation method is to insert the sensor in the spacer between successive disks. This avoids the delicate task of breaking and restoring the conductor insulation. As the spacer prevents oil circulation at this location, the temperature gradient in the spacer is small. This is illustrated in *Figures 1* where we compare temperatures from two sensors in contact with the winding and one inserted in the spacer below the same winding disk. It can be seen that the temperature measured in the spacer is higher than the measured conductor temperature. The installation of the fibre optic probe and the handling

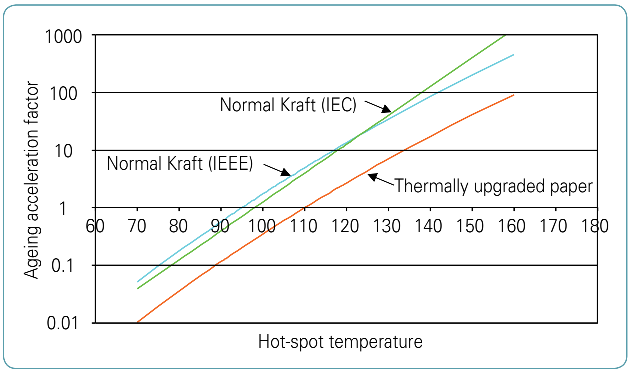

Figure 1: Effect of temperature on paper ageing rate.

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- Available with 4, 6, 8, 10, 12 or 16 channels

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- Heating element is built into the thermometer probe allowing for quick and easy installation
- Bi-metal measurement with resettable maximum pointer
- Up to 2 user adjustable switches (contacts) for control and alarms
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- Models designed for use in oil or gas space
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of the long fibres during the manufacturing process to avoid sharp bends that could break the fibre, are challenging tasks.

Among the improvements introduced are the temporary spooling of the fibre and the simplified through-wall connection. With these, the survival rate of fibre optic sensors is approaching 100%.

Overloading capability

Power transformers have inherent overloading margins. The rated capacity of a unit is basically the load that will result in internal temperatures not exceeding the limits set by industry standard. Loads that exceed the nameplate rating involve some risk and accelerated ageing. It is generally recognised that the risks associated with overloading can be significantly reduced if transformer conditions are closely monitored throughout the overload period. Monitoring of hot-spot temperature and dissolved gas-in-oil and furan-in-oil offer support to the operator when the transformer faces overload conditions.

On-line monitoring of winding temperature can provide a dynamic evaluation of insulation degradation and the relative loss of life can be converted into cost. The cost attributed to loss of life needs to be subtracted from the apparent benefits achieved from the extra load.

Conclusion

Fibre optic sensors have significantly improved to the point that direct measurement of winding temperature is becoming the preferred method for measuring this critical parameter. Compatibility of the fragile fibre optic sensor with the transformer factory environment was a problem in the past but has been resolved with sturdy fibre jackets, proper spooling of sensor during factory work, and simplified throughwall connection.

Fibre optic sensors have reached maturity for application in power transformers and should become a standard feature for new transformers. Immediate knowledge of winding hot-spot temperature provides the necessary confidence to carry through overload occurrences and helps reap the full benefit from this asset.

On-line monitoring of winding temperature can provide a dynamic evaluation of insulation degradation and the relative loss of life can be converted into cost.

Feedthrough fibre optic plate, with protection box.

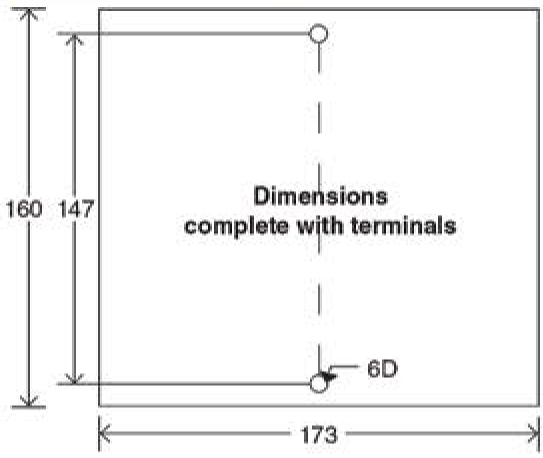
TWR: Transformer Watchdog Relay

FEATURES

- Each of the 6 trip sources has its own indicator blinking 2-3 days without power
- Continuous monitoring of earth bond integrity by measuring the resistance between transformer star point (Neutral) and Earth
- The Earth Fault current is calculated from two independent measurements: the resistance of the Neutral Earthing Resistor (NER) and the 50Hz voltage across it
- Four independent isolated inputs for 110V from other contacts can cause instantaneous closing of the N/O solid state output
- Separate non-volatile LED-indication for each function
- Trip times and levels for resistance and Earth Fault current can be pre-set for discrimination
- Separate LED indication for high/low-resistance trip and high earth-fault condition
- Separate LED indication for each independent input
- LED indications continue for days after power is lost
- Earth Fault current trip level and delay can be doubled by internal jumpers
- Totally solid state and shock-proof

OPERATION

- A short burst of limited current and duration is applied to the local earth bond approximately once per second
- During this burst the voltage response at the earth bond is measured and interpreted as resistance in Ohms. This is compared to an upper and optionally lower limit
- When the pre-set resistance limit is exceeded a solid state N/O output is activated after a pre-set delay of 5 sec (default)
- The output stays activated for up to 5 sec to allow sluggish breakers to operate
- When any of the red LEDs is flashing and power is restored it will continue flashing for approximately 5 sec after a healthy condition is detected
- The green LED only lights up while the unit is powered and in the following ways:
  - Solid Green LED = Healthy Earth Connection
  - Fast Blink Green LED = Faulty Earth Wire or excessive Earth Fault current is detected
  - Slow Blink Green LED = System Voltage Faulty



SPECIFICATION

Supply:
110Vac, single-phase 50Hz burden: approx. 3VA
Available in alternative voltages

Excitation:
3 pulses, 0.75msec at 200mA max every second
Continuous leakage: less than 1mA
Neutral – Earth max. voltage: 320V continuous

Resistance measurement:
Range: 0 – 150Ω, preferred trip settings: 27Ω, 63Ω
Measurement resolution: 1Ω
Accuracy: ±3Ω or ±5%
Default trip delay: 7 sec

Earth Fault current measurement (assuming NER=27Ω):
Range: 1 – 20A, default trip setting = 2A
Measurement resolution 300mA
Default trip delay: 2 sec

Trip delay for any of the four discrete inputs: 100msec
Internal watchdog to trip the output on internal failure: 0.5 sec

Trip output:
N/O solid state contact
Nominal switching voltage: 110 – 525Vac, 50 – 60Hz
Current rating: 3A continuous, 15A for 0.2 sec
Max.voltage between open contacts before clampdown: 600Vac
Normally open, leakage: approximately 3.5mA at 525V, 50Hz
Dielectric strength between contacts and Neutral reference: 2500Vac

Operating temperature range:
-5 to +70°C, Storage temperature range: -40 to +85°C

Overall dimensions:
160 x 173 x 60mm

Optional SCADA communication module:
Product-specific data is available on request

Contact: John Warwick
Cell: 083 230 1610
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Your substation and energy network rely on digital data – as does your control system. This implies the need for general familiarity with data communications in a power system context, and for the recognition of how critical energy system data has become. Reliable communications systems are essential.

3

Ethernet in utilities for critical communications networks

By T Craven, H3iSquared

This article examines some of the functionality available in the Ethernet and TCP/IP standards and how they can be properly used to cater for critical data.

Ethernet evolves constantly and has become the *de facto* standard for communications networks in utility environments. However, proper understanding, planning and configuration are required in order to use Ethernet for mission critical communications. Without correct configuration, Ethernet may not cater for the low latency and high reliability required for critical data transmission.

Traffic control

When creating or maintaining a distributed network that services hundreds of devices, it is important to control the traffic. When a shared physical network is being used for everything from corporate accounting to control and automation, the network must be correctly planned and configured to ensure that critical traffic is never impeded by non-critical traffic or bottlenecks.

Various mechanisms exist for traffic control, including VLANs (Virtual Local Area Networks), CoS (Class of Service) and multicast control. The most commonly implemented of these is VLANs; however, taking the time and effort to implement all three will lead to a more stable and reliable network, especially for critical data exchange. VLANs allow us to logically separate devices using the same physical hardware.

There are three types of VLANs available:

- ***Layer 1 VLANs:*** Generally, when people speak about VLANs, they are referring to Layer 1 VLANs. These involve separating devices based on the physical port they plug into on the network.
- ***Layer 2 VLANs:*** Layer 2 VLANs involve setting up MAC (Media Access Control) tables on the networking devices, which allow data to be controlled based on the source/destination MAC addresses. These types of VLANs are seldom implemented, as they require a large amount of commissioning and maintenance whenever a new device is added or an existing device is changed.
- ***Layer 3 VLANs:*** More commonly known as subnetting, Layer 3 VLANs involve placing devices in different IP (Internet Protocol) subnets. Unicast (one-to-one) communications will not be able to traverse subnets without a router. However, broadcasts (one-to-all) and multicast (one-to-many) messages will traverse subnets, and even if a broadcast/multicast is not destined for a device, that device is still obliged to open the packet in order to determine that it can be discarded. This uses up processing power and time in end-network devices and can lead to traffic being delayed or even lost, if buffers overflow.

The recommended way to implement VLANs on a critical network is to use a combination of Layer 1 and Layer 3 VLANs. This involves assigning a different subnet to each VLAN, which allows users to route required traffic across VLANs, while segmenting the VLANs logically so that broadcasts and multicasts will never be sent between VLANs.

When creating or maintaining a distributed network that services hundreds of devices, it is important to control the traffic.

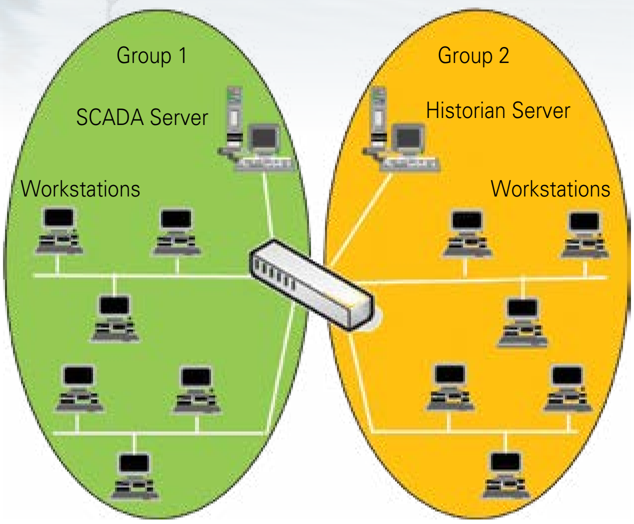


Figure 1: Layer 1 VLAN implementation.

The next type of traffic control that is often neglected but can lead to greatly increased stability and decreased latency for critical data is CoS configurations that tell the switches how to queue the traffic they are sending. There are different CoS levels available depending on the switch manufacturer (commonly Normal, Medium, High or Critical) and each packet is assigned to one of these levels by one of the following means:

- Priority field in the 802.1Q tag: an additional tag added to the packet that can be used for VLANs as well as priority (or both simultaneously)
- DSCP (Differentiated Services Code Point): another tag that can be added to a packet, similar to the 802.1Q tag]
- Default CoS assigned to the physical port on the switch
- CoS based on the packet's source/ destination MAC address

Once the switch has determined the CoS of a packet, it will decide how to queue that packet for transmission out of the switch. There are two methods of queuing, Strict-or-Starve and Weighted Fair Queuing (WFQ). WFQ allows users to assign different ratios to the transmission queue. For instance, a queuing ratio of 2:1 could be set, which would mean two medium packets are sent for each normal packet, two high priority packets for each medium priority packet, and so forth. This method means that critical packets receive higher priority but, overall, all packets have a fair chance of being queued. This is the generally recommended method for queuing.

Strict-or-Starve queuing allows users to ensure that all critical packets are transmitted before any high priority packets, which are then transmitted before any medium priority packets, and so on. This method does give priority to critical traffic, however, a situation can arise where the switch is receiving critical packets as often as it transmits them. This can lead to all lower priority packets being delayed indefinitely. For this reason, the Strict or Starve method of queuing is not recommended. If WFQ queuing does not appear to be working sufficiently well, it is likely that another issue on the network needs to be resolved.

Redundancy

The next important factor to consider for a critical network is redundancy, which allows failure of links, or in some cases, hardware without completely crashing communications between different parts of a network. A question often asked is: How much redundancy can one afford not to have? On a non-critical, corporate network, people may become annoyed if they do not have access to emails for a period, but this is not overly critical. On a utility network, breaks in communication lasting a few seconds or minutes can lead to safety systems shutting down entire substations or network segments as control and automation data are interrupted. This is a much more serious scenario to protect against.

The most commonly implemented and cost effective redundancy is simple link redundancy, normally implemented using RSTP (Rapid Spanning Tree Protocol). This protocol allows users to create physical loops on the network and temporarily disable the redundant links. The reason for this is that a loop on a network can cause broadcast storms, as data broadcasts will circle a loop indefinitely. These broadcast storms can be so severe that they lead to complete network failure, in some cases even affecting the end devices as all their processing power becomes used up inspecting broadcast packets.

RSTP will hold a redundant link in a discarding mode, meaning all data (with the exception of RSTP 'heartbeat' packets) is discarded rather than sent over that link. In the event that an active link experiences a break, the redundant link will be brought into operation. Even RSTP can take up to 30 seconds to fully recover in a worst case scenario, which is far too long for critical networks. Often a device manufacturer will implement a proprietary redundancy protocol that achieves faster recovery times. However, users must be careful not to become vendor locked (ie enter a position where any upgrades/expansions to the network require hardware from a single vendor).

Two newer redundancy mechanisms have been introduced recently, namely PRP (Parallel Redundancy Protocol) and HSR (High-availability Seamless Redundancy), which are known as bumpless recovery protocols. Previous redundancy protocols, such as RSTP, are measured by how quickly the network will recover in the event of a link failure. Bumpless recovery means that in the event of a link failure, the network will recover without any downtime.

PRP works by effectively creating two completely separate physical networks. End devices then connect to both of these networks, either directly (if the end device supports PRP) or via a RedBox (redundancy box). Any data sent by the end device will be duplicated across both networks. The receiving device will receive both duplicate packets, and will discard the second one received. In this way, if a cable link breaks on one network, the second network will already be transmitting

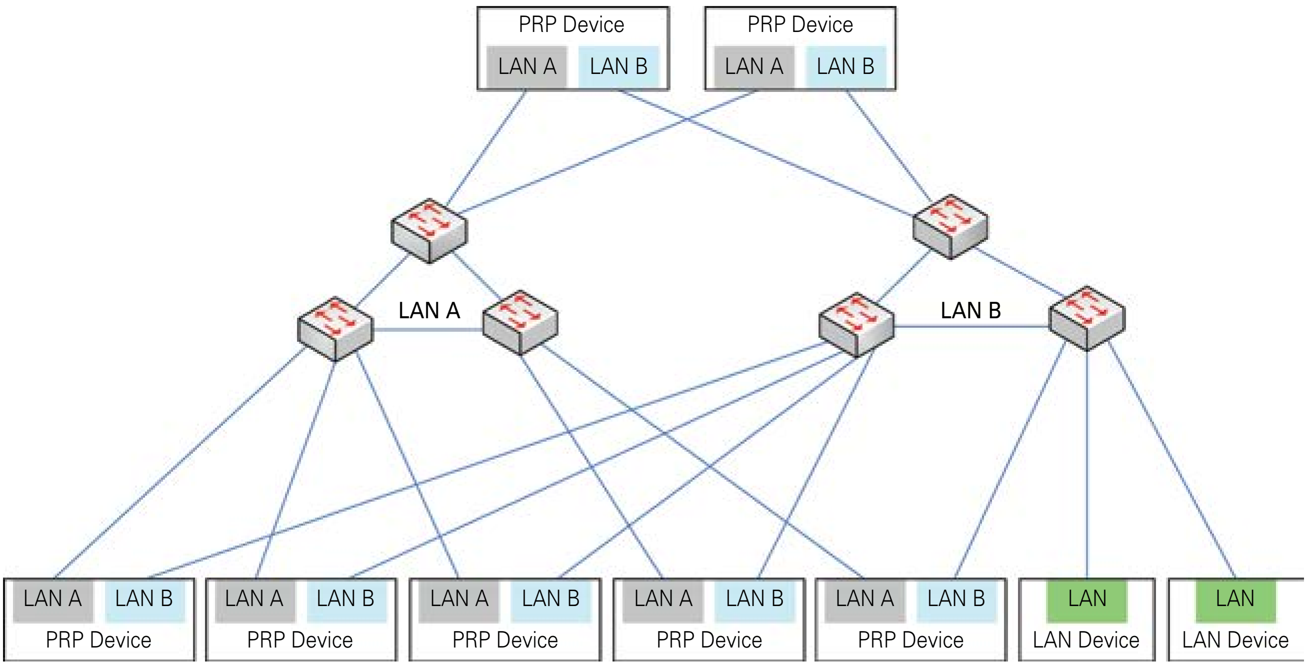


Figure 2: PRP Network [1].

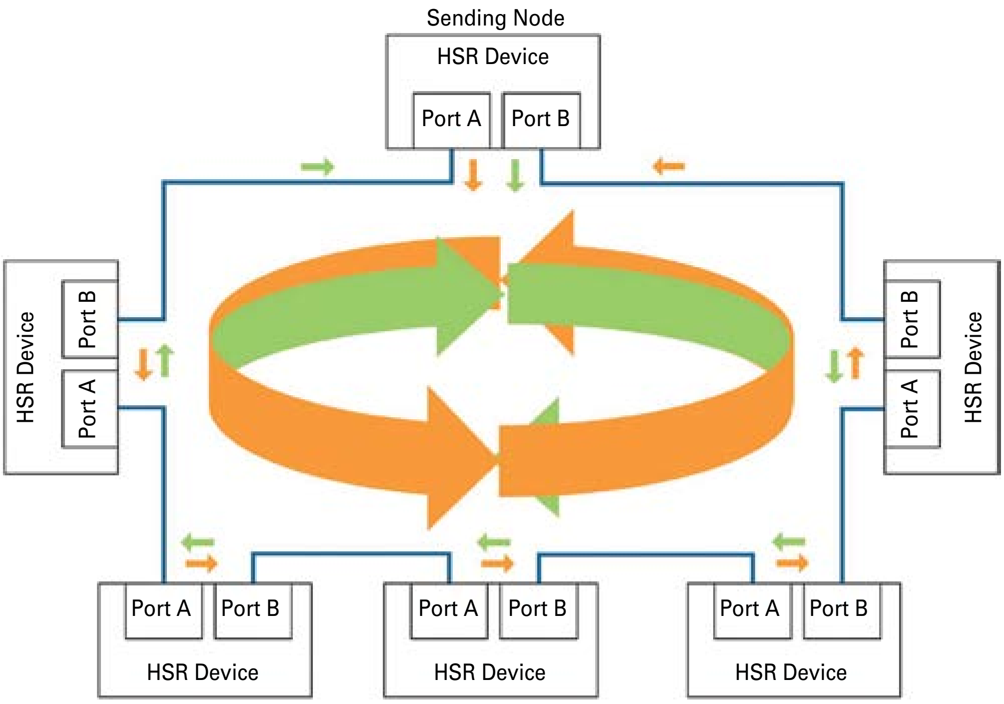


Figure 3: HSR Network [2].

the data, and thus no recovery time is needed. Edge devices that are not PRP compatible (or are not critical enough to require a RedBox) are able to be connected directly to either of the two redundant networks and can still communicate with devices within their network, or devices outside of the PRP network. The only limitation is that a device connected only to network A will not be able to communicate to a device connected to only network B (as there is no logical connection between the networks).

HSR works on a single physical network, and achieves bumpless redundancy by allowing the network to be built in a ring. Unlike most other ring redundancy protocols, HSR does not keep any of the links in a redundant mode. Rather, data is transmitted in both directions around the ring, with the HSR compliant devices able to discard the second received duplicate packet. Once again, this translates to a network that in the event of a cable break will already have the data travelling via a different path, and thus bumpless recovery is achieved. Similar to PRP, HSR will either require the end device to be HSR compliant, or will work through a RedBox.

Time synchronisation

Another important aspect of creating a network for critical, time sensitive data is correct time synchronisation. Often a simple time synchronisation protocol such as NTP (Network Time Protocol) is sufficient for most networks. The benefit of NTP is that 99% of networking hardware will cater for NTP, and this protocol does not require special hardware. NTP works either by end devices periodically (normally once an hour) requesting the current time from an NTP server on the network. If the device's local clock is far off the NTP server time, it will slowly be updated over multiple updates (known as slewing). A second option is that the NTP server will periodically send out an update broadcast to the entire network (this is know an unsolicited NTP synchronisation ie the end device does not solicit a time update, rather it waits for the broadcast to update). Devices will receive this update broadcast and again will either slew to the correct time over a period (if their local clock is far off the NTP server clock) or will update directly to the current NTP server time (if there is not much of a difference between the end device and NTP server times). The NTP standard does not specify a minimum accuracy, however it is generally accepted that NTP can achieve accuracy within tens of milliseconds across the internet, and milliseconds within a LAN.

In a critical utility control network, this level of accuracy is often not sufficient, especially when using the network for applications like synchrophasor measurements. In these cases a higher level of synchronisation is required, and for this PTP (Precision Time Protocol) is used. Although the concept of PTP is similar to NTP (in that devices request a time synchronisation from a PTP 'server'), the level of accuracy provided by PTP is much higher (the standard calls for different accuracy classes, although the commonly accepted standard is AC23 (Accuracy Class 23) which requires a synchronisation of no less than 1 µs). This is achieved by using special PTP compatible hardware that is able to more closely analyse various delays on the network (time spent on cable, time within each switch, etc.) and thus provide much higher levels of accuracy. On smaller networks it is common to find PTP achieving accuracies of up to nanoseconds.

Conclusion

In conclusion, it can be seen that while Ethernet is definitely able to cater for critical and highly time and latency sensitive data transfers, proper planning and commissioning of the network is required. Spending the extra time initially to cater for critical transmissions can lead to a highly stable and reliable network that can be trusted for mission critical control and automation systems.

References

[1] PRP Network Image: http://www.electronicproducts.com/Digital_ICs/Standard_and_Programmable_Logic/FPGAs_enhance_smart_grid_equipment_design.aspx

[2] HSR Network Image: http://www.electronicproducts.com/Digital_ICs/Standard_and_Programmable_Logic/FPGAs_enhance_smart_grid_equipment_design.aspx

Automation and control come to power systems. Smart grid technologies are permeating our distribution and transmission systems, including industrial sites. Smart grids ensure better quality and reliability of the supply by dynamically matching supply to load.

3

Higher utilisation of power systems

By M Sanne, Siemens South Africa

This article introduces the reader to the realm of Smart Grid technology which ranges from Smart Generation, Smart Distribution and Smart Transmission to Smart Consumption.

Higher utilisation of power systems is imperative for assisting major cities in Africa prepare for the millions of people that are expected to seek residence in urban areas. It is projected that by 2050 there will be more than 1,2 billion African city dwellers. The majority of Africa's urban residents, it is predicted, will live in slums and informal settlements unless radical corrective measures are taken.

We need to focus on integrating technologies and providing tailored energy efficiency solutions for private and public infrastructure. These will include intelligent power distribution systems, building technologies and integrated mobility solutions. Cities already consume 75% of the world's energy and account for 80% of the greenhouse gases. Cities and metropolitan regions are, of course, key drivers for global economic growth. They are increasingly challenged by modern megatrends such as urbanisation, globalisation, demographic and climate change. Today, 51% of worldwide GDP is generated in 600 cities. Until 2025 40% of worldwide GDP will be produced in middleweight cities in emerging markets according to a study released by McKinsey.

Smart Grid solutions are transforming the entire energy conversion chain into a living infrastructure that possesses the intelligence and automation to respond quickly, flexibly and comprehensively to the diversity of providers' and customers' needs. The Smart Grid represents a more efficient use of resources to achieve business and policy objectives. Integrating automation, wired and wireless networking and high-powered computing enable previously unimagined capabilities.

Solutions for today's challenges across the energy value chain need to be driven by answering the question: *where to invest in the Smart Grid for real and best returns?*

Smart Generation taps the potential of wind and solar power, geothermal energy and clean coal technologies. Smart Grid solutions strive to integrate renewable energy sources and cleaner fossil fuels into the grid, making access to energy more dependable, consistent and sustainable. Solutions cover the full range from utility-scale to micro-renewable generation. Smart Grid technologies thus provide solutions to help power producers, grid operators, industries, multi-utilities, cities and rail operators to expand intelligence in energy transmission and distribution grids as well as in efficiently and effectively integrating centralised and decentralised power generation. This is resulting in a growing market for products, solutions and services for protection, automation, planning, control, monitoring and diagnostics of grid infrastructure as well as products, complete turnkey solutions and services for railway electrification. With this, software and end-to-end solutions from Enterprise IT solutions through to Smart Metering solutions are becoming more and more important.

On the user side, Smart Consumption is when end users change their normal usage patterns to take advantage of dynamic pricing or incentive payments intended to reduce peak power demand in times when it is economically beneficial or when the power grid is in jeopardy. This has fuelled the development of turnkey demand response marketing and operations solutions to industrial and residential customers. Residential direct load control solutions have been developed for utilities seeking to manage consumption at the residential level (e.g. switching off geysers at peak consumption times). Similarly, loads in factories and large buildings can be controlled.

Smart Consumption is achieved via control strategies to dynamically change consumption patterns based upon incentive-driven demand response program signals, price- or time-based demand response program signals, or any 'micro-grid' solution for a campus or building complex that balances and optimises all on-site generation, energy storage and consumption loads. Consumers are becoming active participants in the energy network as so-called prosumers. They consume and generate power which has triggered the need for Smart Generation solutions. This has been made possible by using modern communications and management technology. Power monitoring is enabling intelligent demand and energy management solutions for utilities. Distribution networks are becoming more efficient, reliable and self-healing. Synchrophasors will help keep the grid in balance, avoid large outages and allow safe transfer of energy between systems. New solutions are improving safety and reliability through real time energy management systems, distribution automation, demand response, substation automation, protection, control and SCADA solutions.

Distributed energy resources can be used in a number of different roles on the utility and customer side of the electricity metering point. Deploying distributed generation can provide ancillary services on specific circuits, relieve transmission congestion, and simply improve situation specific power provisioning.

In the sense of: *What you don't measure you don't control*, Smart Metering solutions now allow the collection of metering data in centralised data management solutions with specialised back-office utility software. This can be combined or expanded with sub-metering network infrastructure for institutional, industrial and commercial applications. Web portals now allow home or business energy monitoring and allow control and automation to optimise electrical loads. This is being extended to Electric Vehicle (EV) infrastructure, which will introduce complex challenges and exciting possibilities with the increased use of electric vehicles. Charging solutions are being created for residential, fleet and commercial use with applications that integrate a user-friendly interface into a feature rich design that provides optimal charging scenarios for both charging station host and electric vehicle driver.

Improvements are achieved by the integration of sensor and controls technology, communications and information technology (IT) into the distribution grid. Grid optimisation permits awareness, control and automation of the electricity distribution network.

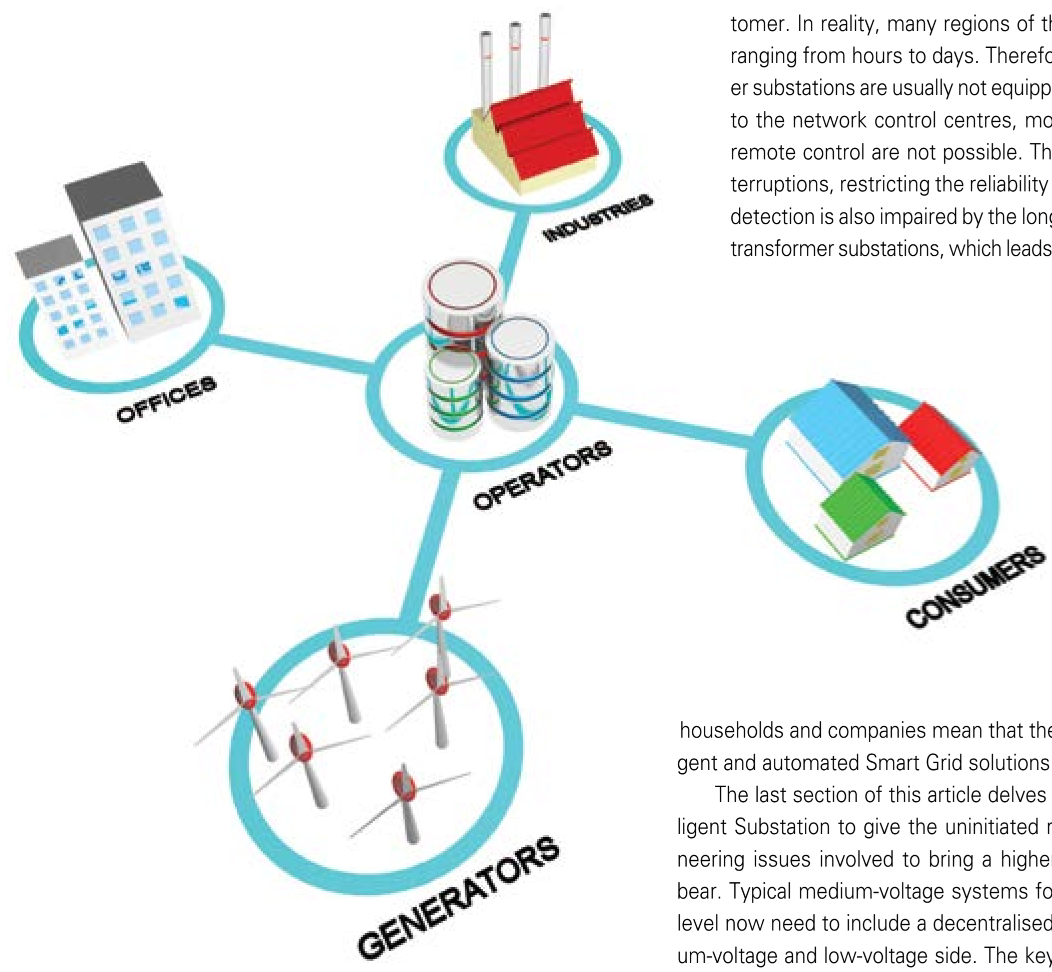
Communications technology is viewed as the underlying glue of the Smart Grid. This facilitates integration across the entire energy conversion chain to provide a 'grid-up' approach for performance, asset and configuration management. With the integration of numerous applications into the grid, the utility's control systems need to make a continuously increasing number of optimisation decisions, from generation to consumption, every day. An increase in computer control on the electrical grid also creates an increase in susceptibility to cyber attack and is driving the need for smart security solutions.

Integrating automation, wired and wireless networking and high-powered computing enable previously unimagined capabilities.

Innovative Energy Automation technology across the entire energy conversion chain – from power transmission right to the customer – makes it possible to adapt power grids to future demands, to modernise and further develop them, or to construct new power grids. This includes products, systems, standard solutions, and services – from individual components to turnkey solutions. Technology simplifies the control of power grids and ensures their stability and availability. Highly profitable grid operation is made possible through systems for substation automation. Instruments and applications deliver data for precise analyses. Proven protection technology ensures availability and security on all voltage levels.

Higher use of the power systems, variable load flows due to decentralised power generation from renewable energy sources and a growing need for information of the regulating authorities, place higher demands on fault detection and acquisition of system operating data. This translates into higher intelligence in transformer substations moving from a merely passive substation to the future of complete automation. For example, with a gas insulated medium-voltage switchgear, electrical engineering companies like Siemens offer the basis for intelligent transformer substations. These are optionally equipped with motorised operating mechanisms, short-circuit indicators and voltage detecting systems, as well as a variety of other sensors. They are plug connected to a Remote Terminal Unit (RTU) in a separated wall mounting cabinet, the switchgear fulfilling all preconditions for integration in an intelligent network infrastructure.

So, Smart Grid technology allows further differentiation in intelligence levels and communication to the telecontrol system to meet the requirements of future intelligent transformer substations. In the past there was only one principle: "power generation follows load" resulting in the paradigm of one direction of energy flow: from the power plant to the consumer. As mentioned previously, much has changed, renewable energies are generated in a decentralised way according to suitable locations. Energy is usually fed into the network at the medium-voltage or low-voltage level; in some cases even directly into the high voltage network.



Another essential feature of renewables like wind power and photovoltaics is the stochastic availability. This has a great influence on the requirement for the network to manage the overall power, especially in terms of an existing distribution system.

- Changed direction of energy flow
- Changed cable load
- Higher short-circuit currents
- More difficulties with power quality
- Additional demand for balancing energy
- Changed requirements on the protection concept

As electricity grids evolve, power consumption will tend to follow power generation rather than vice versa. Take the simple future example of electric cars that could be charged or operated at night drawing on inexpensive wind power. This means a 'grid' paradigm shift: from unidirectional energy flows to bidirectional power flows. This will not be possible without the key module of the future Smart Grid, namely the intelligent transformer substation that takes into account this new trend and still enables automatic and fast fault clearance whilst allowing active load management in secondary distribution systems.

Statistics from power supply companies referring to supply interruptions at the end customer show that most supply interruptions are caused by failures in the medium-voltage system. The grids are far from the ideal of 10 minutes of annual outage per customer. In reality, many regions of the world have outage times ranging from hours to days. Therefore, as secondary transformer substations are usually not equipped with communication links to the network control centres, monitoring of faults as well as remote control are not possible. This can cause long supply interruptions, restricting the reliability and security of supply. Fault detection is also impaired by the long distances to the secondary transformer substations, which leads to even longer outage times. Generally, the procedure for fault clearance requires a lot of time and a large number of personnel. A highly qualified service expert has to drive to many substations to identify the fault prior to supplying all customers with power again. The resulting financial inefficiencies for utilities by not supplying energy to households and companies mean that there is a great need for intelligent and automated Smart Grid solutions.

The last section of this article delves a little deeper into the Intelligent Substation to give the uninitiated reader a flavour of the engineering issues involved to bring a higher degree of 'intelligence' to bear. Typical medium-voltage systems for the secondary distribution level now need to include a decentralised power supply on the medium-voltage and low-voltage side. The key data for the circuit breaker switchgear of the primary distribution level and for the distribution system basically result from the data of the power transformer. Circuit breaker switchgear of the primary distribution level is fully automated and integrated in the 'substation automation system'. At the secondary medium-voltage level, cable systems with compact HV/LV-transformer substations are mostly used. Presently, secondary transformer substations are often not included in the 'substation automation system', and can therefore not be monitored or tele-controlled. The secondary distribution system is operated mostly as an open ring, ie with an open sectionaliser in one transformer substation.

The topic 'Intelligent Transformer Substations' is intensively discussed at many technical conferences and expert circles at the moment. There are three different levels of an intelligent transformer substation:

- Level 1: Monitoring -> higher availability by faster fault localisation
- Level 2: Monitoring+ remote control -> minimises breakdown times by fast fault clearance
- Level 3: Monitoring + remote control + load flow control = load flow control -> minimises losses -> manages decentralised power supplies

Depending on the objective, in an Intelligent Transformer Substation different components are used for monitoring and control:

- The voltage detecting system shows whether the outgoing feeders are live or not;
- Short-circuit/earth-fault indicators signal a distribution short-circuit or earth-fault in accordance with the transformer adjusted operating threshold
- Depending on the network structure and the direction of the energy flow, it may be necessary to use devices with detection of direction which require adequate voltage information
- Overcurrent-time protection systems with auxiliary contacts are used for transformer protection

Of course there are auxiliary switches, eg for position indications, interlocks, releases, gas pressure. Stored energy operating mechanisms with solenoids and motor operating mechanisms are available for remote closing and opening; voltage and current sensors transmit the voltage and current signal for the purpose of load flow control. The signals are derived from conventional voltage or current transformers or from modern sensors.

Modern gas-insulated medium-voltage switchgear provides all functions for applications in intelligent substations and fulfils all preconditions for integration in an intelligent network infrastructure. Later retrofitting of components for remote control can be performed easily and quickly.

The components of an intelligent transformer substation require a reliable auxiliary voltage supply. If the auxiliary voltage fails, an energy store supplies the components for time periods reaching from a few minutes to two hours. The size of the energy store results from the power demand to maintain the remote functions and the communication modules. In contrast to this, the energy consumption for motor operated CLOSING and OPENING of such 'disconnector' operating mechanisms is very low.

Conventional batteries and capacitor stores with double layer capacitors (ultracaps) or a combination thereof are used as energy stores. Special batteries are also available for extreme environmental conditions.

Communication from the RTU in the transformer substation can take place in different ways, via wire (eg Ethernet TCP/IP), optical fibre,or wireless (eg GSM/GPRS) to the network control centre. There the information is processed, and control commands are communicated back to the RTUs, if required. In the future, communication via WiMAX or BBPL (Broad Band Power Line) will become more important.

Communication protocols follow the standards of IEC 60870- 5 – 101 [1] and – 104 [2]. With a WiMAX or BBPL communication infrastructure, communication standards as per IEC 61850 [3] could be used in the future. The use of these protocols ensures interoperability between devices from different manufacturers. The following points are also important for selecting the communication medium:

- Availability and reliability of the communication channels; type of redundancy required; management of the data flood; data security/encryption protection against hacker attacks; costs for investment and running operating costs; risk of 'ageing of technology' that is used due to fast IT evolution.

Conclusion

In conclusion, increased demand for reliable electricity and achieving climate protection targets are leading to increased use of renewable energies with points of in feed in the medium-voltage and low-voltage systems. Maintaining the necessary power quality and network stability requires an active distribution system with intelligent transformer substations. Possible measures range from pure monitoring via remote control to targeted distribution network management, which means complete remote control of the transformer substations.

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No real network is as simple as a single source and a single load. Generation is embedded within the network, implying the need to be able to regulate the supply voltage throughout the network, easily and reliably. As network complexity increases, so does the automatic voltage control system.

Automatic voltage control of networks with embedded generation

By V Thornley, Siemens and N Hiscock, Fundamentals Limited

This article discusses the application of transformer Automatic Voltage Control (AVC) to networks in which generation is embedded, with reference to the application of MicroTAPP voltage control to these systems.

The issues addressed are the particular problems that can occur if the application of voltage control does not take into account the presence of generation. It addresses any requirements on a local (ie distributed) level. An overall network solution may make use of a network automation system to set up the Voltage Control Relay (VCR) for the system conditions. This, however, is a network management issue and is not relevant to the voltage control application.

Voltage control basics

The simplest form of AVC can be used where a single transformer supplies a single load (see *Figure 1*). If the load is some distance from the transformer, there may be a voltage drop in the line. The AVC relay measures the voltage and the current (V_{VT} and I_{CT}) and makes an estimate of the voltage at the load (V_{eff}) using a model of the line (R_{line} + j.X_{line}). This represents the ideal situation: in reality, there are usually a number of loads on a transformer distributed at different distances (electrically) from the transformer, so the model of the line will always be a compromise. The model is normally set up to establish a constant voltage point at the mid-point of the network, thus achieving a minimum overall variation between no-load and full-load conditions.

It is common practice to parallel transformers in order to give a higher security of supply (see *Figure 2*). For a site with two transformers in parallel, the load on each transformer is half of the total load. In order to obtain the correct voltage boost it is necessary to summate the loads of all paralleled transformers ($I_{load} = I_{CT,1} + I_{CT,2}$). If the open circuit terminal voltages of the paralleled transformers are not identical, a circulating current will flow around them. This will be reactive since the transformers are highly inductive. If two paralleled transformers operate the simple AVC scheme described above, eventually one transformer will be on the highest tap and the other on the lowest tap. The busbar voltage will be an average of their terminal voltages and a high amount of circulating current will flow between them. This will cause an unnecessary power loss within the transformers and the network, reducing their useful capacity and efficiency. Therefore, the main aims of any voltage control scheme must be to:

- Maintain the correct voltage at the customer, taking into account line voltage drops
- Minimise reactive circulating current around paralleled transformers, and across networks

Application of MicroTAPP

The MicroTAPP scheme, based on the negative-reactance AVC scheme, resolves the measured current of each transformer into load and circulating elements. *Figure 3* shows the current seen by an AVC relay ($I_{CT,1}$) with respect to its phase voltage (V_{VT}). The circulating current (I_{circ}) is resolved from $I_{CT,1}$, being the deviation from a set-point of system power factor (pf_{sys}). This element of current is then used to bias the voltage control in order to minimise the circulating current.

Line Drop Compensation (LDC) corrects for system voltage drops

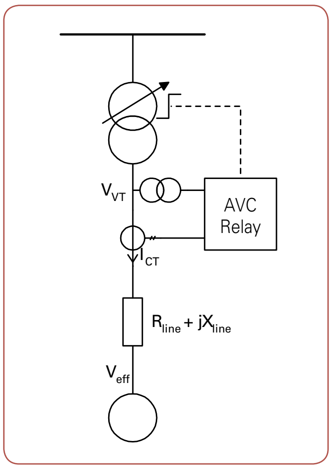


Figure 1: Transformer connected to single load.

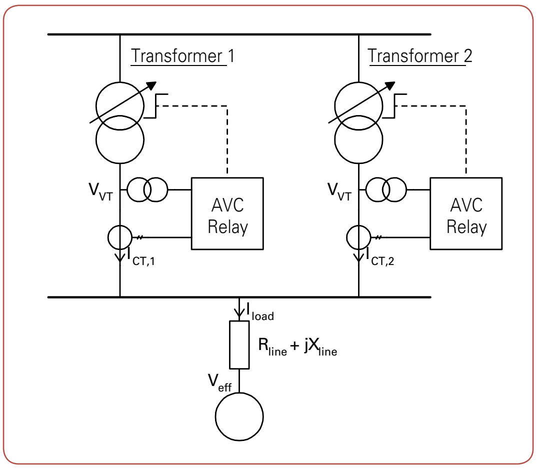


Figure 2: Parallel transformers connected to single load.

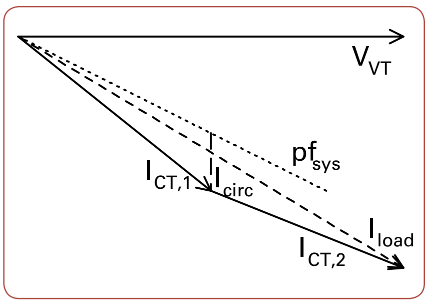


Figure 3: TAPP scheme.

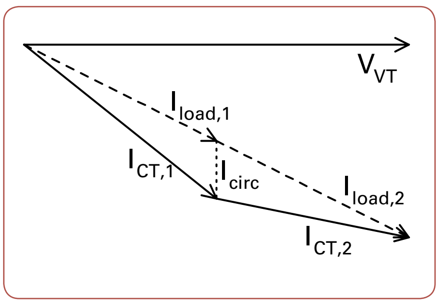
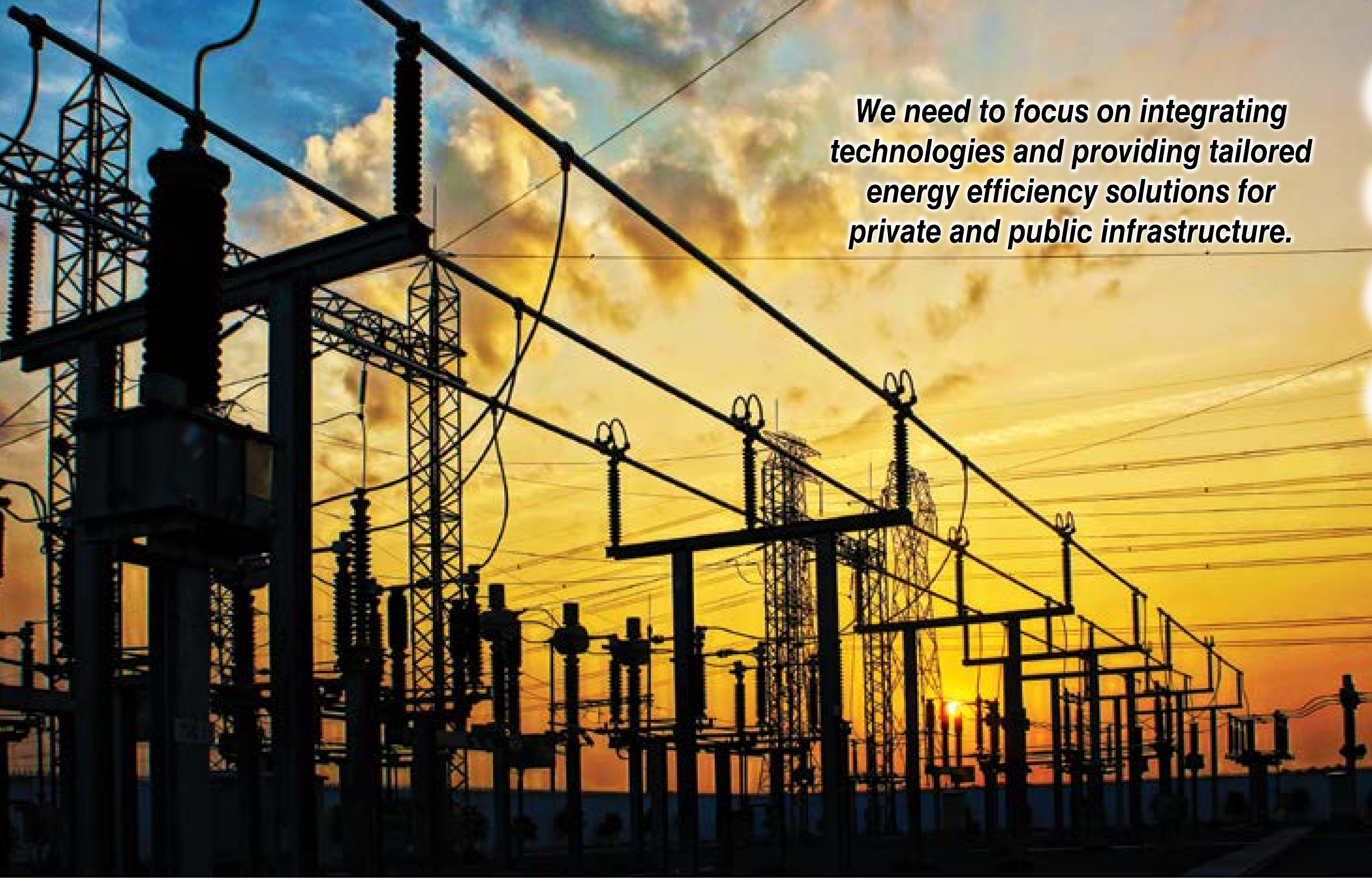


Figure 4: True circulating current scheme.



so that customers receive as close to ideal voltage as is possible. The total load on the busbar is calculated by summating transformer currents $I_{CT,1}$ and $I_{CT,2}$ (see *Figure 3*) and this is used to calculate a bias to apply to the voltage control. These two simple elements together achieve the main aims of voltage control. Other benefits of this system are that:

- The system is extremely simple
- Transformers and tap-changers on a site do not have to be identical
- Incoming voltages can be different
- Transformers can be paralleled across networks.

Although the actual power factor at a particular time may not be the specified power factor pf_{sys}, as long as the deviation is not large the voltage control will be satisfactory. If the actual power factor varies greatly from the set-point, the effect will be an error in the controlled voltage, as the load current will be considered as circulating current by the TAPP scheme.

Varying power factors

In circumstances where the load power factor can vary substantially, the TAPP scheme with its power factor set-point may not be a viable option. An alternative scheme, known as the true circulating current scheme, is described below and can be used in these circumstances. *Figure 4* shows the current seen by two AVC relays $I_{CT,1}$ and $I_{CT,2}$, with respect to their phase voltages V_{VT} (when the transformer LV circuit breakers are closed the measured voltages will be identical). The load currents, $I_{load,1}$ and $I_{load,2}$, have the same power factor. Transformer 1 is on a higher tap position than Transformer 2, hence a circulating current, represented by I_{circ} in the diagram, will flow. If the measured currents, $I_{CT,1}$ and $I_{CT,2}$, are summated, the network power factor can be found. The true load on each transformer and its contribution to circulating current can be established. Therefore LDC error is eliminated.

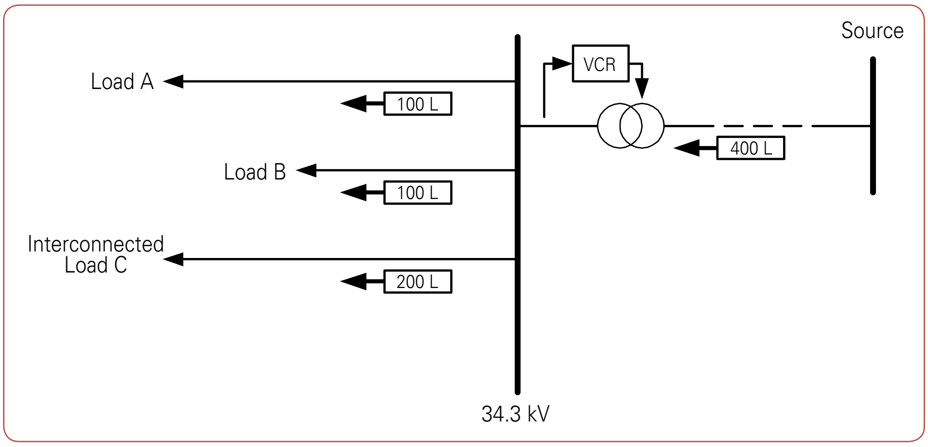


Figure 5: Example network for embedded generation scenarios.

Embedded generation

For this discussion, an example network is used and is shown in *Figure 5*. For the purpose of explanation a single transformer is shown supplying load to a nominal 33 kV busbar and the load is assumed to be unity power factor. Three circuits are supplied from the busbar. Load C is interconnected to a remote substation, and, for operational flexibility, the voltage control to the transformer tap changer is configured for reactive control (TAPP). If Load C is not interconnected to another site, true circulating current control can be implemented.

The basic voltage level is set to 33 kV and, at the transformer load shown (400 L), the load drop compensation (LDC) applied at 4% increases the busbar voltage to about 34,3 kV. These figures are used for the purpose of explanation only. A number of scenarios involving generation embedded in this network are discussed.

Small asynchronous generator

Small generators can be embedded remote from the busbar and supply part of or the entire feeder load. It is unlikely that a generator in this location would be capable of supplying the total substation load. *Figure 6* shows a generator connected to supply the feeder load. The generator reactive load is supplied from the source through the transformer (50R), with the result that the transformer contributes a smaller load to the busbar, at a lower power factor owing to the increase in reactive current.

As the real load is reduced, the LDC effect is reduced causing the LDC boost voltage effect to be reduced to 3%. Since voltage control is in TAPP mode, the decrease of power factor causes an error in the VCR target voltage that results in a further 1% reduction in voltage. When the generator is running, the busbar voltage is reduced to 33,7 kV from the desired 34,3 kV.

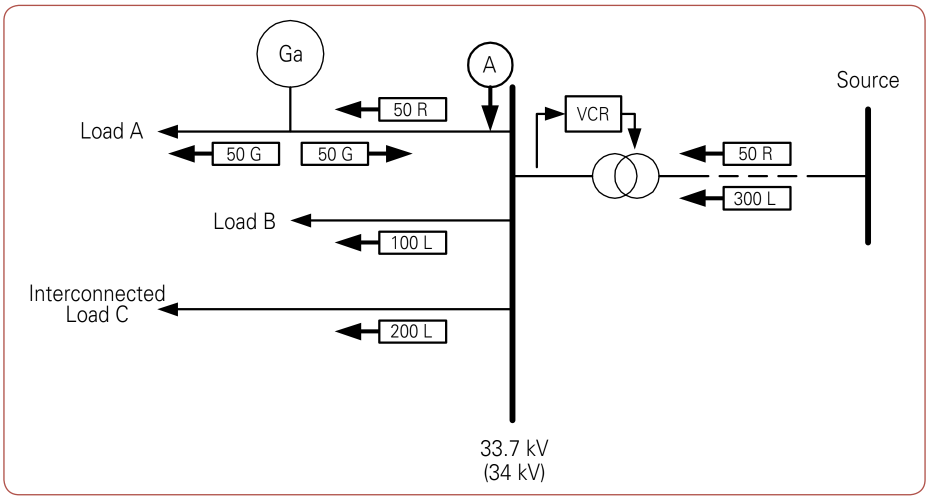


Figure 6: Remote embedded asynchronous generation.

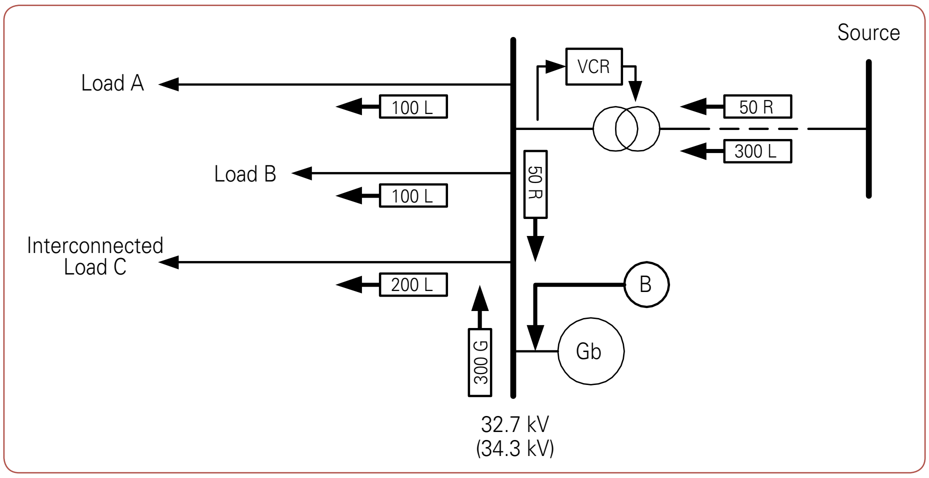


Figure 7: Large embedded asynchronous generation solution.

Solution

If the generator contributes an insignificant load relative to the transformer, the effect on the VCR will be insignificant. If the generator causes a significant change to both the transformer load and power factor, steps can be taken to exclude feeder load A from the transformer current applied to the VCR CT input. The transformer load will ignore the effect of all generation connected along feeder A. This can be achieved by use of a 'Load Exclusion Module' (LEM) applied at Point A. The module subtracts Load A from the current measured by the VCR CT. The current seen by the VCR will now be of the correct power factor and the LDC effect will be slightly reduced to 34 kV (since it does not include Load A). This can be corrected by a small increase to the LDC setting.

Large asynchronous generator

Large generating capacity would most likely be connected at the busbar and be able to supply a high proportion of the site load. *Figure 7* shows a generator connected at the busbar. The generator reactive load will be supplied from the transformer, the result being that the transformer contributes only reactive current to the busbar. In this case, the power factor of the transformer load will swing towards 0_{pf} lagging and, depending on the magnitude of the reactive current, have a significant effect on the VCR target voltage. The real load is reduced further, the LDC effect being 1% instead of 4%.

The large reduction in the apparent power factor also results in a target voltage error, say a further 2%. The sum of these effects is that, when the generator is running, the busbar voltage is reduced to 32,7 kV from the desired 34,3 kV. The generator will cause a significant change to the transformer load and the power factor. If the generator current is excluded from the VCR CT input, the transformer VCR will ignore the effect of the generation and assume the load connected only to the outgoing feeders. The VCR will, therefore, remain accurate at all times (34,3 kV). Again, this can be achieved by use of the load exclusion module, applied at Point B.

Synchronous generator

Figure 8 shows a generator connected to the busbar. The generator is set to produce power at the system power factor and the transformer VCR will control the busbar voltage level. The generator in this case is supplying virtually the complete busbar load, leaving the transformer at no-load. As the transformer is at no-load, the LDC effect is zero and the voltage reduces to the basic set-point level of 33 kV.

Solution

The generator will cause a significant change to the transformer load. If the generator current is excluded from the VCR CT input, the transformer VCR will ignore the effect of the generation and assume the load is connected only to the outgoing feeders. The VCR will, therefore, remain accurate at all times (34.3 kV). If the overall supply source is strong (high fault level) in relation to the local busbar, the solution will allow energy to be supplied into the higher voltage network. This can be achieved by use of the load exclusion module, applied at Point B.

Large synchronous generator

Figure 9 shows a generator connected at the busbar and power being exported into the higher voltage network. If the generator is set to produce power at the system power factor and the transformer VCR set to control the busbar voltage level, the system voltage may be in serious error. The sense of LDC will be in reverse and a corrective action by the VCR will increase the primary/secondary winding ratio, thus making the secondary voltage reduce to a point where the voltage is below the basic voltage level by an amount equivalent to the LDC setting value, in this case to 32,3 kV. In this situation, LDC cannot be used, which is operationally restrictive. If the primary system has a relatively low fault level the transformer voltage control may have to be disabled completely.

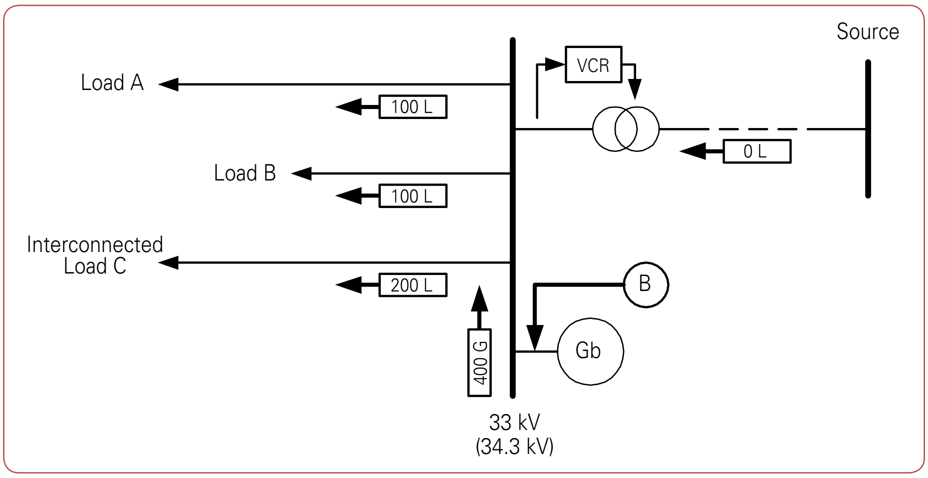


Figure 8: Synchronous generation.

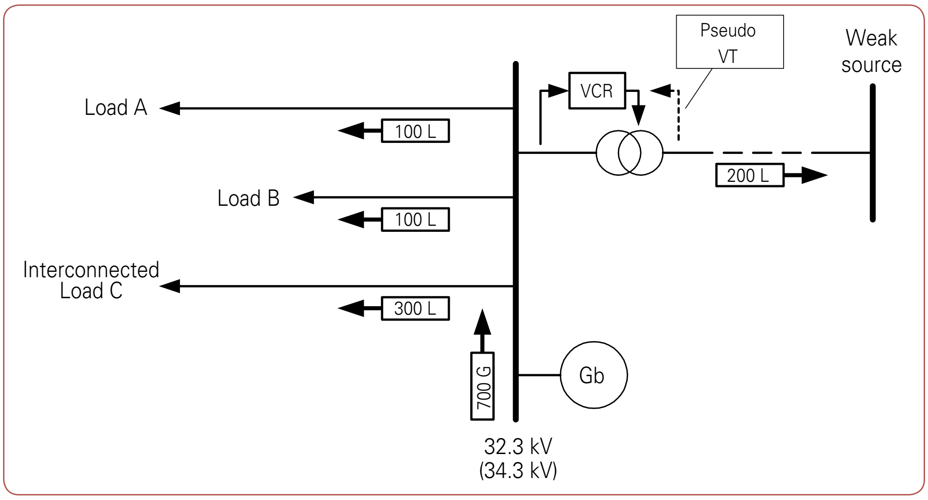


Figure 9: Large synchronous generation.

Solution

The generator will cause a significant change to the transformer load. If the generator current is excluded from the VCR CT input, the transformer VCR will ignore the effect of the generator and assume the load to be connected only to the outgoing feeders. If the overall supply source is weak (low fault level) in relation to the local busbar it may be required to transfer voltage control to the higher voltage network when the generator is running and allow the voltage of the local busbar to be controlled by the generator. The MicroTAPP voltage control system can be configured in this situation to operate in pseudo VT mode. Under this operating condition, the existing LV, VT and CT are used, and the voltage at the transformer HV terminals is calculated. The MicroTAPP then operates the tap changer to maintain the incoming voltage at the correct level.

Conclusion – see table below

Generation type		Asynchronous generation		Synchronous generation		
Size (relative to network strength)		Small	Large	Small	Large	
					Pf control	Voltage control
Expected location		Embedded remote from busbar	Busbar	Busbar	Busbar	Busbar
Voltage control	At point of generation	Generator	Transformer AVC	Transformer AVC	Transformer AVC	Generator
	Of busbar	Transformer AVC				
	Of HV network	by System	by System	by System	by System	Transformer AVC
Special requirements		None	Use LEM	Use LEM	Use LEM	Pseudo-VT mode

To measure is to know. We know that transformer failure is inconvenient and costly. Therefore, holistic strategies of condition monitoring are an important component of any transformer and substation system.

4

Transformer condition monitoring: making the electrical connection

By S Kuwar-Kanaye, Impact Energy

There is increasing pressure on large power users to engineer value back into the bottom line, particularly in areas of equipment and asset management, capital cost optimisation and life expectancy management. The fault-free operation of power transformers is of major economic and safety importance to power utilities and industrial consumers of electricity. Gas formation in transformers is attributed to two principal causes, ie electrical disturbances and thermal decomposition.

Detecting early signs of deterioration

Modern networks, with their varying complexities of load types, line interconnection requirements and harsh operating environments, place a greater need for key transformers on their systems. The cost of a power transformer is high, but monitoring its performance and its immediate environment is inexpensive compared to the costs of a failure and an interruption in power supply. An holistic approach to condition monitoring is essential for the transformers and the networks in which they operate.

Transformer failure – costly clean-ups and recovery.

There has been extensive progress in the field of Dissolved Gas Analysis (DGA) of the insulation oil for evaluating transformer health. The breakdown of electrical insulating materials and related components inside a transformer generates gases within the transformer. The identity of the gases being generated can be useful in a preventive maintenance programme. By reviewing the trends in the information provided, maintenance teams and reliability engineers can make a better judgement as to frequency of maintenance and detect early signs of deterioration that, if ignored, would lead to an internal fault.

There are fairly accurate guidelines, tolerances and limits for analysing the data of the chromatogram of oil-dissolved gases to determine the condition of the power transformers and consequently identify faults or problems while still in the incipient phases of development. However, finding linkages, trend analyses and patterns between DGA and the electrical network condition or Power Quality (PQ) monitoring may be useful in establishing the pre-cursors to incipient faults and consequential failure modes. Therefore, building databases of PQ data as well as data of chromatogram of oil-dissolved gases, is a developmental science that allows further advancements in asset life expectancy management.

Where advancements in DGA have been made over several years, now with the increasing accuracy of early fault detection in transformers, the same demands are placed on the reliability and availability of electrical PQ data that are aggravators and contributors to transformer failure.

Failure modes

Transformers age naturally and can deteriorate faster than normal under the influence of agents of deterioration (eg failure occurs when the withstand strength of the transformer with respect to one of its key properties is exceeded by operational stresses).

Operational stresses are usually dominated by events and conditions such as lightning strikes, switching transients, system voltage and frequency, load removals, short-circuits, overloading, harmonics, poor Power Factor (PF), increased losses resonance, inrushes due to large motor starts, and the like.

Catastrophic transformer failures are possible.

Harmonic currents increase the core losses, copper losses and stray-flux losses in a transformer. These losses are of no-load losses on load losses. No-load loss is affected by voltage harmonics, although the increase of this loss with harmonics is small, and has two components: hysteresis loss (due to non-linearity of the transformers) and eddy

Gas formation in transformers is attributed to two principal causes, ie electrical disturbances and thermal decomposition.

4

current loss (which varies in proportion to the square of frequency). Excessive harmonic currents contribute to overloading and additional power losses in the transformer and, in extreme cases, can lead to high thermal stresses and early ageing. A transformer's theoretical life expectancy of 30 – 40 years can be reduced to as low as 15 – 20 years owing to early ageing caused by increased harmonics pollution in the network. Most of the time, the effects of harmonics are hidden and not immediately visible.

The combination of harmonic currents and high grid impedance aggravates voltage distortions in the network and, in extreme cases, can shift zero-crossing points of the supply voltage waveform. This increases noise and electromagnetic interference in the network transformers, cables and Power Factor Correction (PFC); capacitors are the network components most affected by PQ disturbances.

Another concern is the presence of 'triple-n' harmonics. In a network, it is mainly the LV non-linear loads that produce harmonics. With a Medium Voltage (MV)/Low Voltage (LV) transformer of Δ/Y configuration, 'triple-n' currents circulate in the closed delta winding. Only the 'non-triple-n' harmonics pass to the upstream network. When supplying non-linear loads, transformers are vulnerable to overheating. Increased loading can overstress the transformer and risk its premature failure.

It is common understanding that fast transient overvoltages do exist and can cause damage on transformer windings. There is an increasing trend of transformer dielectric failures in the system, some of them with no specific causes. However, a number of unknowns remain regarding this issue with reference to transformer design and testing (particularly its insulation), transformer protection and interactions between transformers and fast transient system 'sources' such as circuit breakers, capacitor banks, and power electronics.

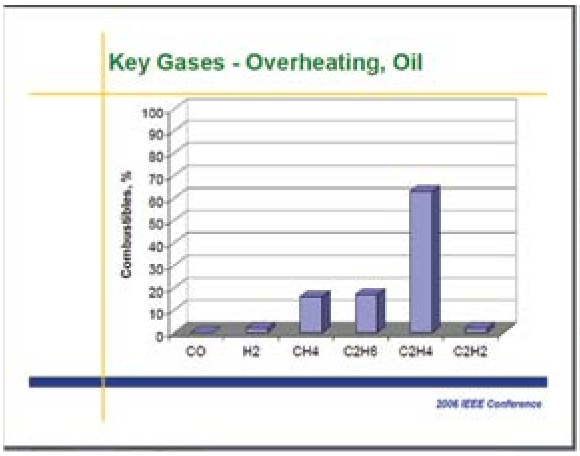
Digital simulations show that voltage stresses across transformer terminals are usually restricted to frequencies in the range 40 kHz-to 200 kHz. However, when these stresses are compared with the specified standardised waves, they may exceed the transformer withstand design.

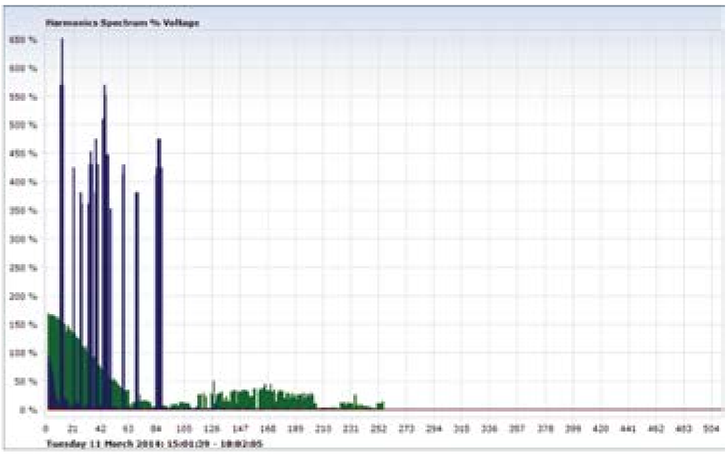
PQ conditioning or improvements and maintenance strategies, should be adopted to enhance the lifetime of network components and reduce failure rate. Power quality conditioning is fast becoming a 'must

have' as a means of increasing PQ performance levels in the network to the desired level. Investment in PQ conditioning has to be approached by carefully analysing PQ issues, establishing baselines and performance targets for engineering value and fulfilling the expectations of business financial investment models.

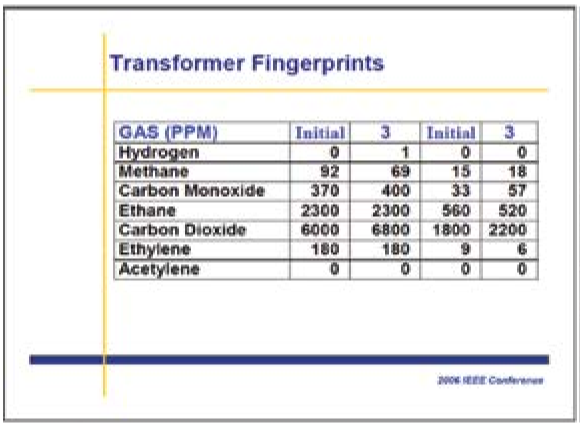
Common goals

The fundamental objective of life management can be defined simply as 'to get the most out of an asset' by ensuring that actions are carried out to promote the longest possible service life or minimise the lifetime operating cost, whichever is most appropriate. Key planned actions include the areas of: specification, procurement, design review and manufacture, maintenance, condition monitoring and diagnosis, reha-

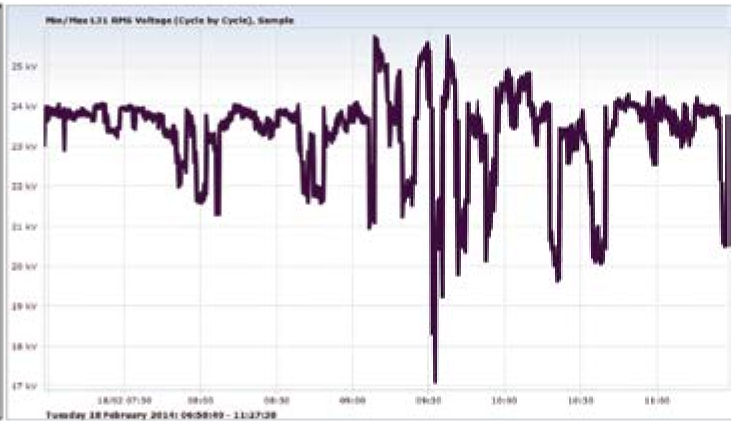




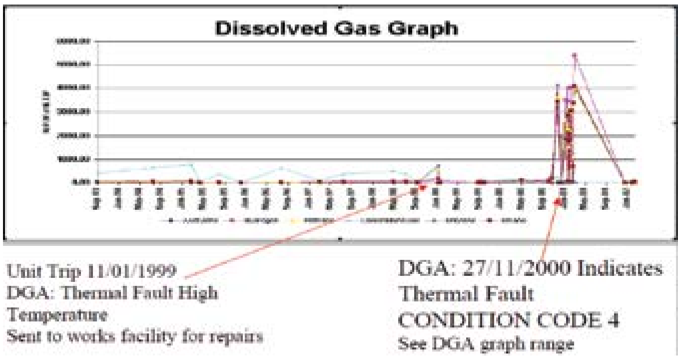
Figures 1 and 2: DGA and harmonics spectrum (sample data only. No correlation exists, used for illustrative purposes only).

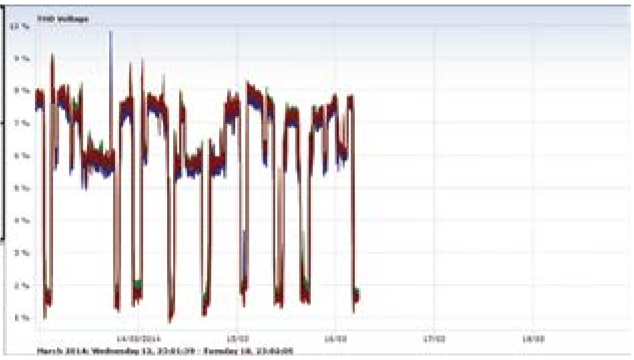


GAS (PPM)	Initial	3	Initial	3
Hydrogen	0	1	0	0
Methane	92	69	15	18
Carbon Monoxide	370	400	33	57
Ethane	2300	2300	560	520
Carbon Dioxide	6000	6800	1800	2200
Ethylene	180	180	9	6
Acetylene	0	0	0	0

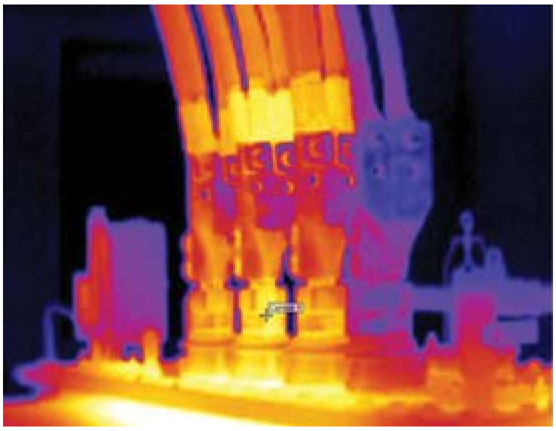


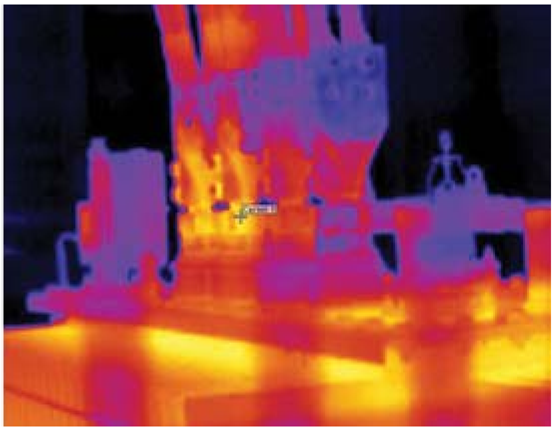
Figures 3 and 4: DGA fingerprints and RMS cycle by cycle voltage (sample data only. No correlation exists – used for illustrative purposes only).





Figures 5 and 6: Dissolved gas graph and THD voltage (sample data only. No correlation exists – used for illustrative purposes only).





Figures 7 and 8: Exit of cables from a transformer. Thermography and PQ statistics (with and without PFC).

bilitation, refurbishment and remedial work, life extension. To overcome the demands associated with continuous electrical condition monitoring of critical assets and networks, certain analysers empowered by patented PQ_{ZIP} compression technology, make it possible to store up to 1 000 times more than other typical file formats.

- Continuous waveform recordings: the device is able to record and store all electrical waveforms, all the time, for more than a year (voltage at 1 024 samples per cycle, and current at 256 samples per cycle) with no gaps in data. These innovations provide a clear and comprehensive picture of conditions leading up to, during and after an event
- Superior accuracy: the measurement uses the dual gain of 2 x 16 Bit to yield a superior accuracy, surpassing IEC 61000-4-30 [1] Class A requirements, thereby capturing the finest details and deviations in PQ and network condition parameters
- Threshold-free set-up: the set-up is free from any thresholds, triggers and events. If required, during set-up the device may be programmed with individual parameters for event flagging

PQ_{ZIP} takes the guesswork out of PQ and condition monitoring. It allows the analyser to continuously store the waveform of one or more power signals, regardless of whether or not an event of interest has been identified. Applied at different points and locations, the time synchronisation algorithm enables two or more devices to be synchronised with one another and provides a complete and comprehensive picture of the entire grid.

Under the guidance and development of experienced work groups, PQ data conditioning, including acoustic sensors and piezoelectric transducers, infra-red receivers, special sensitive microphones, radio wave receivers, hermography, etc. It is difficult for individual engineers to build up sufficient first-hand experience of problems and how to deal with them. In addition, failure processes in transformers are often complex and agreement between manufacturers, utilities and academics to share knowledge is necessary if these processes are to be understood, and solved. By co-operating in this way, problems experienced by individuals, their causes and possible remedial actions, likely coloured by local practices, can be combined and converted to general knowledge and theory.

Factors to consider:

- Initiation of failure
  - What caused the failure to occur when it did?
- Ageing aspects
  - In what respects did ageing or wear-out contribute to the failure?
- Pre-existing fault
  - What indications were there of any pre-existing faults prior to the failure?
- Initiation of the pre-existing fault
  - What initiated the -pre-existing fault?
- Other relevant information
  - Provide other information considered to be relevant to the failure

Trend analysis

For many diagnostic tests, the way in which measured results change with time can provide valuable additional information. Some techniques rely heavily on trend analysis, whereas others can provide a diagnosis from the results of one measurement. A rising trend, particularly when the rate of change is increasing, is probably a definite indication of a serious problem or at least something to be investigated further.

Use the tools in the toolbox

Condition monitoring is important to guarantee the safe running of power transformers. With condition monitoring, unexpected failures can be avoided by quality information from various sources relating to real-time, continuous and on-line. Moreover, with condition monitoring, maintenance of power transformers can be condition-based rather than periodically-based. The physical processes of failure are not an exact science and the monitors usually set up mappings between the faults and their appearances and then diagnose the faults with pattern recognition techniques.

Conclusion

Indication of potential problems within transformers should not be limited to the concentration levels of the key dissolved gases. PQ monitoring opens a new approach to anomalies on a network for further understanding of contributors to asset degradation.

Depending on site-specific conditions, once the initial links are made between PQ data and typical condition monitoring such as DGA, it is important to benchmark alarm levels depending on the tolerance to risk of the maintenance personnel and on the maintenance budget available. This benchmarking could be key to making the electrical connection in condition-based monitoring of critical assets.

Reference

[1] IEC 61000-4-30: 2008. Electromagnetic compatibility (EMC) - Part 4-30: Testing and measurement techniques - Power quality measurement methods.

Electrifying performance from your transformer

The local and international transformer oil market is undergoing major changes, compounded by the requirements of many new building and other electrification projects underway on the African continent. Recent transformer oil supply shortages and corrosive sulphur issues have raised questions about product quality, resulting in the introduction of new specifications and test methods. Quality and specification levels are crucial factors, even superseding price.

Engen Lubricants has positioned itself to be a major supplier of a full range of high quality transformer oils through an exclusive supply agreement with APAR Industries Ltd of India. These oils meet all the latest international and Equipment Builders' specifications. Engen, a trusted supplier of transformer oils for many years, has full technical support from APAR whose expertise spans over four decades. With a production capacity of ± 200,000 MT p.a., APAR are pioneers and market leaders in India - their POWEROIL brand being world-renowned and accepted.

Situated in Durban, Engen's Lubricant Blend Plant covers bulk import, storage and blending of various grades of transformer oils. The South African location enables Engen to meet most market demands and specifications, while costs and inventory are kept in balance. Supplies of POWEROIL TO 1020 (60U) (uninhibited) and POWEROIL TO 1020 (60 UX) (inhibited) are available in bulk (30,000L road tankers within South Africa and neighbouring countries), 20L steel pails (60 U), 210L steel drums (both products) and in 900L plastic IPS bags (both products).

POWEROIL Transformer Oils are made from carefully selected naphthenic base oils produced from wax-free low sulphur naphthenic crude specially refined to meet today's stringent specifications. Activities within APAR's R&D laboratories form the nucleus of close cooperation with leading transformer manufacturers, OEM's and major utilities. POWEROIL meets standards such as IEC: 60296 - 2012 General Specification, ASTM D1275B (Doble's modified) Test requirement for corrosive sulphur, Eskom 32-406 specification, NRS 079-1:2004 and SANS 555:2007.

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Engen has a focused industrial lubricants team that covers the lubrication needs of the complex industry sector of South Africa. Various segments are serviced including paper and pulp, power generation, mining and construction, general industry and manufacturing, cement, rail, marine and aviation. Engen markets a broad range of industrial mineral and synthetic lubricants under the Engen and PETRONAS brands, which fulfils most of the local and African-based industry's needs

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THE Oil CENTRE

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As blood tests disclose one's state of health, so oil analyses disclose the condition of a transformer. If regularly conducted, oil analysis allows identification of specific fault conditions that may be developing. Adequate oil treatment and, if necessary, additional interventions, can be undertaken.

4

Transformer oil analysis – basic introduction

By N Robinson, WearCheck

Regular oil analysis is useful in monitoring the condition of engines, drivetrains, hydraulics, turbines and many other types of oil lubricated equipment. The same can be said for transformer oils, which are used to insulate transformers and other electrical distribution equipment.

The analysis of transformer oils provides information about the oil, and enables the detection of other potential problems, including contact arcing, ageing insulating paper and other latent faults, and is an indispensable part of a cost-efficient electrical maintenance programme.

Figure 1: WearCheck's Michelle Alexander sorts oil samples.

Ensuring transformer reliability

Transformer maintenance has evolved over the past 20 years from a necessary item of expenditure to a strategic tool in the management of electrical transmission and distribution networks. Extreme reliability is demanded of electric power distribution, and even though the failure risk of a transformer and other oil-filled electrical equipment is small, when failures do occur, they inevitably lead to high repair costs, long downtime and very real safety risks. Moreover, transformers are too expensive to replace regularly and must be properly maintained to maximise their life expectancy.

By accurately monitoring the condition of the oil, many types of faults can be discovered before they become serious failures and outages can potentially be avoided. Furthermore, an efficient approach to maintenance can be adopted and the optimum intervals determined for replacement. Some of the checks are relatively simple: the operation of the gas relays, the operation of the on-load tap-changer, checks on oil leaks, etc. However, breakdown of one of the most crucial elements, the oil/paper insulating system, can only reliably be detected by routine oil analysis. By measuring certain physical and chemical properties of oil, in addition to the concentrations of certain dissolved gases, a number of problem conditions associated with either the oil or the transformer can be determined.

The following are some common tests performed on electrical transformer oils:

Moisture content

One of the most important functions of transformer oil is to provide electrical insulation. Any increase in moisture content can reduce the insulating properties of the oil, which may result in dielectric breakdown. Water and oil, because of their differing chemical properties are not mutually soluble; however, up to a certain limit a small amount of water will dissolve in the oil. The limit is a function of the temperature of the system and the solubility increases exponentially with increasing temperature. This is of particular importance with fluctuating temperatures because as the transformer cools down any dissolved water will become free, resulting in poor insulating power and oil degradation. A point to note is that, as the oil ages in service, a certain amount of oxidation occurs, which changes the chemical make-up of the oil, which in turn allows more water to dissolve. In addition, many transformers contain cellulose-based paper used as insulation in the windings. Again, excessive moisture content can result in the breakdown of this paper insulation with a resultant loss in performance. The moisture content of the oil is determined using coulometric Karl Fischer. This is an extremely sensitive test and can detect water at levels down to a few parts per million.

Acid number

Like lubricating oils, transformer oils are oxidised under the influence of excessive temperature and oxygen, particularly in the presence of small metal particles that can act as catalysts. Oxidation products are usually acidic in nature and result in an increase in acid number. Further reaction of these acids with the bulk oil can result in sludge and varnish deposits. In the worst-case scenario, the oil canals become blocked and the transformer is not cooled adequately, which exacerbates oil breakdown. Furthermore, an increase in the acidity has a damaging effect on the cellulose paper. Oil degradation by-products, such as acids and hydroperoxides, generally have the ability to conduct an electrical charge, which in turn reduces the insulating properties of the oil. An increase in Acid Number often goes hand-in-hand with a decrease in dielectric strength and increased moisture content shown in *Figure 2*. Again, like their industrial cousins, the acid content of transformer oils is determined by Potentiometric titration with potassium hydroxide.

Dielectric strength

The dielectric strength of a transformer oil is a measure of the oil's ability to withstand electrical stress without failure. Because transformer oils are designed to provide electrical insulation under high electrical potentials, any significant reduction in the dielectric strength will indicate that the oil is no longer able to perform this vital function. Some of the things that can cause a reduction in dielectric strength include contaminants such as water, sediment, conducting particles, oil degradation by-products and cellulose paper breakdown. The test method for determining dielectric strength is relatively simple and involves applying an ac voltage at a controlled increasing rate to two electrodes immersed in the transformer oil. The gap is a specified distance and when the current arcs across this gap the voltage recorded is used to determine the dielectric strength.

Just like machinery oil analysis, the ability of transformer oil analysis to provide an early warning sign of a problem condition depends on the quality of the oil sample that is sent to the lab.

Power Factor (PF) or dissipation factor

The Power Factor (PF) of a transformer oil is the ratio of true power to apparent power and is a measure of the current leakage through the oil, which in turn is a measure of the contamination or deterioration of the oil. In a transformer, a high PF is an indication of significant power loss in the transformer oil, usually as a result of contaminants such as water, oxidised oil and cellulose paper degradation. It may also be any substance in the oil that either resists or conducts electricity differently to that of the oil itself and may include diesel fuel, lubricating oil and kerosene. The test is not specific in what it detects and is usually carried out at elevated temperatures as contaminants that affect the test may remain undetected at 90°C and only reveal themselves at >90°C.

InterFacial Tension (IFT)

The interfacial tension of transformer oil is related to its deterioration. Transformer oil is generally a hydrocarbon and thus hydrophobic; however, when the sample undergoes oxidative degradation, oxygenated species such as carboxylic acids are formed, which are hydrophilic in nature. IFT is the surface tension of a sample of the oil carefully floated on top of a layer of water. The more hydrophilic the oil becomes, the lower the value of the surface tension between the two liquids. Studies have shown that there is a definite relationship between acid number and IFT. An increase in acid number generally shows a decrease in IFT; however, when there is a loss in IFT without the corresponding increase in acid number, it is generally because of contamination with another hydrophilic substance not derived from oxidation of the oil.

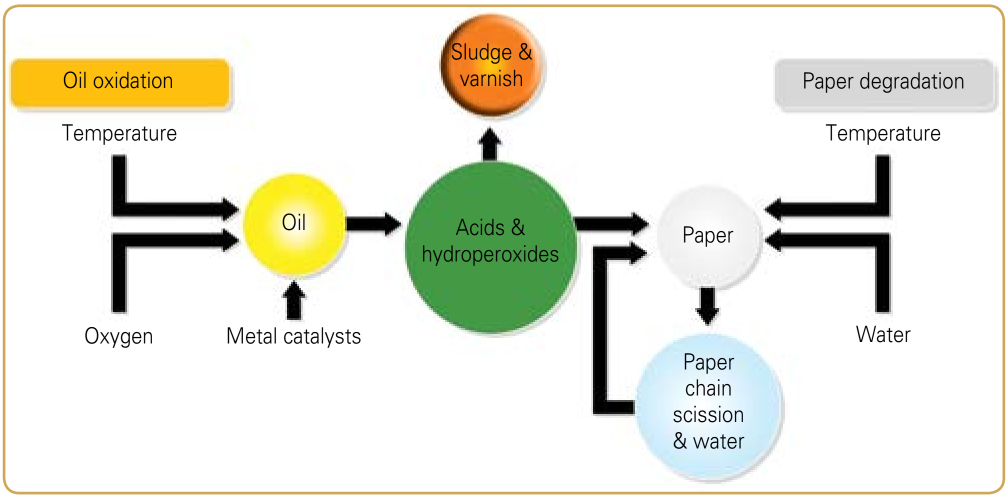

Figure 2: An increase in the acid number often goes hand-in-hand with a decrease in dielectric strength and increased moisture content.

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Furanics or (degree of polymerisation)

The solid insulation (cellulose-based products) in transformers degrades with time at rates that depend on the temperature, moisture content, oxygen and acids in the insulation system. Heat and moisture are the main enemies of the solid paper insulation with oxidation as the primary culprit. When degradation occurs, the cellulose molecular chains (polymers) get shorter and chemical products such as furanic derivatives are produced and dissolve in the transformer oil. Of the furanic compounds, the 2-furaldehyde is the most abundant. Its concentration in oil has been related to the Degree of Polymerisation (DP) and consequently to the physical strength of the solid insulation (see *Figure 3*).

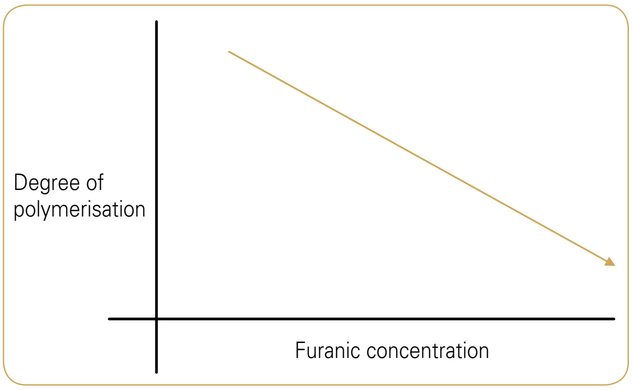

Figure 3: The concentration of 2-furaldehyde in oil is related to the DP.

The cellulose materials are the weakest link in the insulation system. Since the life of the transformer is actually the life of the cellulose insulation and degradation of the cellulose is irreversible, the decay products should be removed before they can do any further damage to the cellulose. With proper maintenance, the cellulose can have an indefinite life. To test for furanics, a sample of the oil is obtained and certain chemical techniques are used to extract the furans from the oil. The extract is analysed using a process called High Performance Liquid Chromatography (HPLC). The results are usually reported in terms of parts per billion (ppb).

Dissolved Gas Analysis

The analysis of gases from petroleum products has been performed for decades using gas chromatography. However, this technique was not applied specifically to transformer mineral oils until the late 1960s/early 1970s and is commonly called Dissolved Gas-in-oil Analysis (DGA). DGA has become a standard in the electrical maintenance industry throughout the world and is considered to be the most important oil test for transformer oils in electrical apparatus. More importantly, an oil sample can be taken at any time from most equipment without having to take it out of service, allowing a 'window' inside the electrical apparatus that helps with diagnosing and trouble-shooting potential problems.

As the insulating materials of a transformer break down from excessive thermal or electrical stress, gaseous by-products form. The by-products are characteristic of the type of incipient-fault condition, the materials involved and the severity of the condition. Indeed, it is the ability to detect such a variety of problems that makes this test a powerful tool for detecting incipient-fault conditions and for root-cause investigations after failures have occurred. Dissolved gases are detectable in low concentrations (ppm level), which usually permit early intervention before failure of the electrical apparatus occurs, and allow for planned maintenance. The DGA technique involves extracting or stripping the gases from the oil and injecting them into a Gas Chromatograph (GC).

Typical gases generated from mineral oil/cellulose- or paper and pressboard-insulated transformers include:

- Hydrogen, H_2
- Methane, CH_4
- Ethane, C_2H_6
- Ethylene, C_2H_4
- Acetylene, C_2H_2
- Carbon Monoxide, CO
- Carbon Dioxide, CO_2

Additionally, oxygen and nitrogen are always present - their concentrations vary with the type of preservation system used on the transformer. Gases such as propane, butane, butene and others can be formed, but their use for diagnostic purposes is not widespread. The concentration of the different gases provides information about the type of incipient-fault condition present as well as the severity. Four broad categories of fault conditions are described and characterised in *Table 1*.

Key gases	General fault condition
Methane, Ethane, Ethylene and small amounts of Acetylene	Thermal condition involving the oil
Hydrogen, Methane and small amounts of Acetylene and Ethane	Partial discharge
Hydrogen, Acetylene and Ethylene	Sustained arcing
Carbon Monoxide and Carbon Dioxide	Thermal condition involving the paper

Table 1: Categories of key gases and general fault conditions.

The severity of an incipient-fault condition is ascertained by the total amount of combustible gases present (CO, H_2, C_2H_2, C_2H_4, C_2H_6, CH_4) and their rate of generation. Transformers generally retain a large portion of the gases generated and therefore produce a cumulative history of the insulating materials' degradation. This is an important tool for detecting and trending incipient problems. However, it also means that care is needed in interpreting values for a first-time analysis on service-aged transformers (more than several years old), which could contain residual gases from previous events.

Some gas generation is expected from normal ageing of the transformer insulation and it is important to differentiate between normal and excessive gasing rates. Normal ageing or gas generation varies with transformer design, loading and type of insulating materials. Routinely, general gasing rates for all transformers are used to define abnormal behaviour. Specific information for a family of transformers can be used when sufficient dissolved gas-in-oil data are available.

Acetylene is considered to be the most significant gas generated. An enormous amount of energy is required to produce acetylene, which is formed from the breakdown of oil at temperatures in excess of 700°C. Excessively high overheating of the oil will produce the gas in low concentrations; however, higher concentrations are typically symptomatic of sustained arcing, a more serious operational issue that can cause transformer failure if left unchecked.

DGA is used not only as a diagnostic tool but also to stem apparatus failure. Failure of a large power transformer not only results in the loss of expensive equipment but it can cause significant collateral damage as well. Revenue losses due to operational outages may be the least worrisome consequence of a failure. Replacement of that transformer can take up to a year if the failure is not catastrophic and can result in tremendous revenue losses. If the failure is catastrophic, then additional losses could be realised, such as adjacent transformers, environmental problems from the release of oil, (which could be as much as 20 000 litres), and the resulting fire that must be contained and smothered. In order to avoid such a failure, the sample frequency of most large power transformers is between one and three years. However, sampling frequencies will increase as an incipient fault is detected and monitored. Often sampling frequencies are dictated by insurance requirements, which can stipulate that annual transformer oil analysis be conducted to ensure continued coverage.

PCB analysis

PCBs (PolyChlorinated Biphenyls) are a group of synthetic oil-like chemicals of the organo-chlorine family. Until their toxic nature was recognised and their use banned in the early 1980s, they were widely used as insulation in electrical equipment, particularly transformers. Three types of PCB are normally used in electrical transformers: Aroclor 1242, 1254 and 1260, commonly known by various brand names, including Askarel, Chlorectol, Elemex, Inerteen, and Pyranol.

One of the most important problems with PCBs is that they concentrate in the fatty parts of micro-organisms. This concentration factor between the organism and the water can be as much as a million times. Concentrations are further amplified as the micro-organisms become food for animals further up the food chain. PCBs are stable and their degradation process is slow, making for greater amplification in organisms. Although not overly toxic in themselves, PCBs are poisons that have been shown to cause damage to the reproductive, neurological and immune systems of wildlife and humans.

Far more serious are the risks of a fire or an explosion. At temperatures around 500°C, extremely toxic compounds – PolyChlorinated Dibenzo-Furanes (PCDF) and PolyChlorinated Dibenzo-Dioxins (PCDD) – are formed. Small amounts of these compounds have been found at accidents where transformers and capacitors have been exposed to fire or have exploded. Even if the amounts have been extremely small and have caused no personal injuries, it has been necessary to perform extensive and costly decontamination work.

PCDDs and PCDFs cause damage and death in doses ranging from 1 ppb to 5 000 ppb. Damage to the liver, kidneys and digestive tract, miscarriages and sterility can occur. They are among the most potent cancer promoters known.

Methods of PCB analysis

Current methods of analysis are divided into two major groups: PCB Specific and PCB Non-specific. Non-specific methods test for PCBs indirectly by detecting one of the components of the PCB compound, usually chlorine. In general, non-specific methods are quicker and less expensive than the specific methods; however, these tests are susceptible to false positive results, since the test does not detect PCB itself. Specific methods use some type of chromatography to separate PCB molecules from each other and interfering compounds. It is not a case of simply finding an easily quantifiable compound, but of quantifying a complex mixture of compounds. Of the three major chromatography types, gas chromatography (GC), thin layer chromatography (TLC) and liquid chromatography, GC is the preferred and most extensively-used method.

PCB associated terminology defined:

Non-PCB: Any fluid, including that in electrical equipment and any item that has a measurable PCB concentration of less than 50 ppm of PCB, is considered a non-PCB item.

PCB contaminated: any fluid, including that in electrical equipment, and any item that has a measurable PCB concentration of 50 ppm or greater but less than 500 ppm is regarded as being PCB contaminated.

PCB item: any fluid, including that in electrical equipment and in any item that has a measurable PCB concentration equal to or greater than 500 ppm, is regarded as a PCB item.

Note: transformer oil that has not been tested must be classified as PCB contaminated until shown to be otherwise.

Once the PCB status is determined, a sticker is issued and fixed to the item in question. This allows for quick reference and ensures that potential cross-contamination is avoided during future sampling, maintenance and decommissioning if necessary.

Blending PCB-contaminated oil with virgin or other oil to meet the legal requirements is an illegal practice that has happened from time to time. This practice simply has the effect of contaminating virgin oil supplies. It ensures that the PCBs persist in the environment, leading to further contamination.

Proper transformer sampling

Just like machinery oil analysis, the ability of transformer oil analysis to provide an early warning sign of a problem condition depends on the quality of the oil sample that is sent to the lab. A sampling point on any equipment should be identified and clearly labelled for the technician. As with sampling locations in other types of equipment, the same location should be used each time a sample is collected to ensure representative conditions are tested. This point should be located in a place where a live oil sample can be collected rather than in an area where the oil is static.

Like machinery oil analysis, electrical transformer oil analysis can play a vital role in preventing unscheduled outages in electrical transmission and distribution equipment by determining the condition of the equipment itself, and other vital components, including the condition of the oil and the cellulose paper insulation. For all critical oil-filled electrical equipment, including transformers, circuit breakers and voltage regulators, regular, routine oil analysis should be the cornerstone of any PM programme.

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Gray IAR, Guide for PCB management of insulating oils in South Africa.

GIS is commonly used in modern power networks. But, in many cases, there are multi-media interfaces between the gas and air in its oil systems. In addition, GIS is subjected to heating and cooling cycles owing to environmental conditions. As such, any leak must be reliably detected and the condition of the gas reliably known.

Continuous humidity measurement in gas-insulated switchgear

By T Jung, WIKA

Switchgear within power transmission systems has a service life of over 30 years – and to guarantee lasting operational safety over such a time span is a major challenge.

For network operators and equipment manufacturers, therefore, the topics of smart grid and online monitoring are gaining in importance. The interest in continuous and digital monitoring has risen strongly, particularly in the area of gas-insulated switchgear. Here, attention is turning to the loss rate and the humidity content of the Sulphur hexaFluoride (SF_6) used. If the critical phases of both parameters are not identified in good time, operational safety can be compromised.

So that SF_6-filled equipment is always optimally insulated, its gas content must be monitored permanently. For this, in most cases, operators use mechanical gas density monitors with switching functions. When the SF_6 volume has dropped to a particular level, the measuring instrument sends an alarm signal and automatically shuts down the equipment using a second contact.

The round-the-clock monitoring also has an ecological basis: the specific global warming potential of SF_6 is 22 000 to 24 000 times greater than that of CO_2. The F-gas regulation limits, or even prohibits, the use of the gas in most applications. However, the power industry cannot operate without SF_6's insulation properties. European switchgear manufacturers have therefore signed a voluntary commitment. Within it are defined limit values for leak rates for the systems, which are binding and must be documented. According to this, medium-voltage equipment should not lose more than 0,1% of the gas per year and high-voltage equipment not more than 0,5% of the gas per year. With previous mechanical trade article and electronic solutions, however, detection of such values has only been possible to a limited degree, because of insufficient accuracy.

A further factor that strongly influences equipment safety is the humidity content of the gas. Each switching operation releases enormous amounts of energy, which breaks the SF_6 molecules into their atomic constituents. The decomposition products of sulphur and fluoride recombine into their original condition after a short period – so long as the gas is dry. However, with the increasing time-in-service of the equipment, the penetration capability, and with it the humidity level, increases. Humidity and oxygen, as unavoidable reactants, in turn, prevent the recombination of sulphur and fluoride. This leads to highly toxic and corrosive compounds such as HF and SO_2 in the insulating gas, which can significantly affect the equipment safety and attack the internal surfaces of the gas tanks.

Such decomposition products are generally measured and investigated by maintenance staff using portable analysis instruments. Depending on the results, the reusability of the gas will be decided and a recycling process initiated if necessary.

The limit value for the humidity content specified in IEC 60376 [1] is -36°C Td. Its checking demands a relatively tightly-scheduled maintenance cycle with corresponding costs - as a result of personnel, equipment, travel and, not least, switching the equipment off. This significant expense can be reduced through continuous monitoring of the condition. For these reasons, the demand for control systems with online dew-point measurement has risen sharply in recent years. The instrument described in this article is capable of measuring the relative humidity, pressure and temperature precisely over a wide measuring range. The high-accuracy transmitter enables continuous and digital monitoring of gas-insulated switchgear to be set up. Even the best monitoring system only provides the operator with something if the hardware works accurately. The innovative sensor is set apart from previous products, not only through the high-accuracy pressure and trade article temperature measurement and the density evaluation, but also through a new calculation model for humidity content.

During the transmitter project, the manufacturer and the sensor

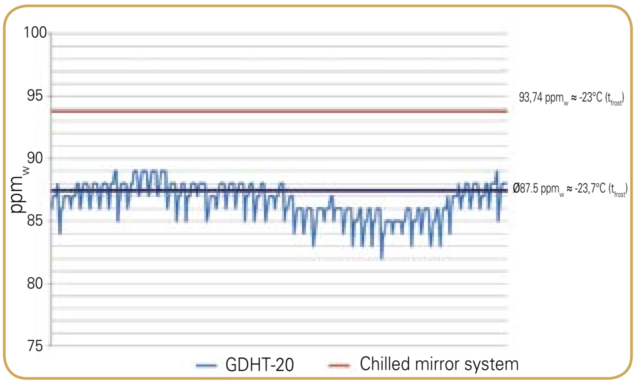

Figure 1: Comparative measurement between a chilled-mirror dew point meter and a GDHT over 24 hours on a switchgear system.

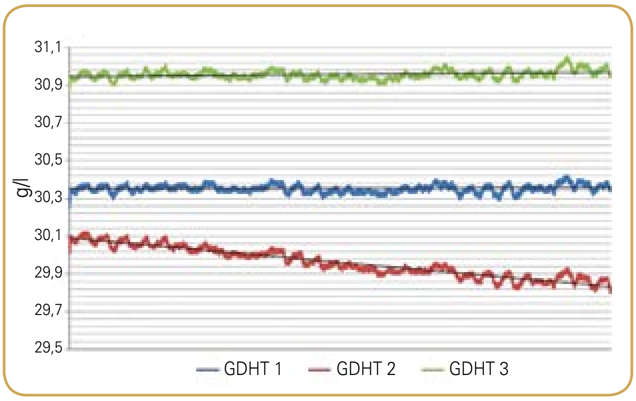

Figure 2: Trend analysis with the GDHT-20 on a switchgear system.

manufacturer investigated the accepted calculation models scientifically and subsequently optimised them. The results, which were published in the 'International Journal of Thermophysics' [2], were incorporated into the development of the unit. The sensor can determine the dew point within ±3 K. The accuracy of the pressure signal in the positive temperature range is ±0,06% of the measuring range and in the negative temperature range is ±0,2%. The density calculated from the pressure and temperature is indicated by the instrument with an accuracy of 0,75% and typically better than 0,6%.

The high accuracy of the new instrument and the possibility of trend analysis using the measured data delivered were among those substantiated through a field test on the world's largest gas-insulated switchgear system in the Itaipu hydro-electric power station in Brazil. A chilled-mirror dew point meter served as a reference for the humidity measurement and deviation from the chilled-mirror dew point meter averaged under 0,7 K. With the density measurement, using trend analysis, a leak on one of the gas chambers was identified that had not been detected by conventional mechanical instruments. This illustrated and confirmed the formidable performance of the transmitter.

Further internal tests have shown that the sensor is virtually unaffected by its positioning on the gas chamber, as a result of its sophisticated measurement technology. Even the sometimes extreme temperature differences during the tests had only a small effect on the measurement. The fluctuations in the density signal were less than 1 g/l.

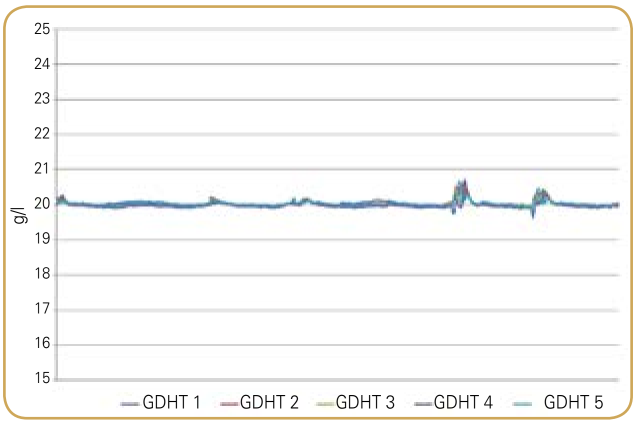

Figure 3: Influence of temperature fluctuations on the density measurement <1 g/l during the outdoor test.

A new transmitter on the market presents a combined solution for the monitoring of the most important parameters in condition monitoring, such as density, humidity, pressure and temperature.

The multi-functionality of the sensor ensures continuous and proactive monitoring. With this, trends can be identified and maintenance planned in a targeted manner. This leads to a move from a time-based maintenance strategy to a condition-based one. Digital technology offers a lower installation cost than its analogue equivalent. The unit features a standardised RS485 interface and an established MODBUS protocol. With analogue measurement technology, all signals must be routed through an evaluation unit, while thanks to the BUS system, up to 247 sensors can be coupled together. This saves on installation and cabling costs.

Conclusion

Against the call for digital solutions for optimised SF_6 monitoring, and in the face of rising cost pressures, the instrument presents a combined solution for monitoring the most important parameters in condition monitoring, such as density, humidity, pressure and temperature. Operators save themselves several measuring points or complicated and un-coordinated assemblies from different individual sensors. Measuring error sources and potential leaks that can come from a combination of the individual components are kept to a minimum. The high-accuracy transmitter provides the basis for cost-efficient online condition monitoring with maintenance on demand – a milestone in the monitoring of gas-insulated switchgear.

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[2] International Journal of Thermophysics. Published by Springer US.

We often speak of safety, and we recognise its importance. But accidents happen. The best strategy is to be prepared for the unexpected and to reduce the risk of injury. This means using the right protective kit.

Arc-rated gloves and the new ASTM test method

By H Hoagland and Z Jooma, e-Hazard

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This article discusses the glove protection standard and concludes with advances by other international standard committees.

If one subscribes to the Hominid theory, then the importance of standing on two limbs summarises the importance of using the other two limbs for advancing mankind. Hands are critical to performing tasks. In an electrical context, tasks ranging from fault finding to switching are performed by hand. The irony is that prior to 2013, no standard had covered the arc rating of hand protection. A new standard published in 2013 has addressed this gap.

Hands and hazards

Electrical workers' hands are exposed to many workplace hazards such as electrical shock, electrical arc flash burns, flash fires, cuts, splinters, oil, electrical solvents, pinching and crushing. The NFPA 70E - 2012 [1] requires the use of rubber insulating gloves with leather over-protectors when shock protection is required. The rubber insulating gloves provide the actual shock protection whilst the leather over-protectors serve to reduce damage to the rubber gloves. When it comes to arc flash protection, the standard requires that hand protection consisting of either leather or arc rated gloves be worn. At the time of publication of the NFPA 70E – 2012 [1], however, no standard addressing the arc rating of a glove existed. It was merely implied that arc rated fabric could be used to produce a glove. The arc rating of the leather glove is also not stipulated, but a minimum thickness of 0,7 mm is required.

The rubber insulating glove and leather over-protector of a specified minimum thickness, may have offered a definitive level of shock protection whilst addressing other hazards but no published standard existed which allowed for the arc rating of the rubber and leather combination.

The standard for insulating gloves, the ASTM D120 [2], requires a Class 00 glove for work on systems rated 500 V and below. This could be 0,5 mm with a leather over-protector of perhaps 0,7 mm and, the gloves generally become thicker with increasing voltage (increasing dielectric material to offer higher voltage withstand). However, the IEEE 1584a [3] guideline used to determine incident arc flash energies dictates that fault current and not system voltage is the dominant contributor to energy. This would imply that it is theoretically possible to receive greater arc flash energy from a 480 V system than a 4,8 kV system. From a shock perspective, however, the 480 V system glove is noticeably thinner than the 4,8 kV system glove. In other words, as the system voltage decreases, the thickness of the rubber and leather glove combination decreases, which may imply a decreased arc rating; however, a decreasing system voltage may theoretically result in higher arc flash energies.

Historically, the incident arc flash energy could be calculated but the arc rating of the glove was not stipulated on a rubber and leather combination. In certain cases, gloves were manufactured by arc rated fabric and thus assigned arc rating value. Such gloves offered arc protection but may have failed to offer shock protection or cut resistance.

Another case in point would be cut-resistant gloves. Such gloves offer good finger dexterity and oil withstand, but may contain melting substrates. Some gloves may appear to be arc resistant, until exposed to an arc [4], in which case they could melt onto the user's hands.

Legislation and the arc rating glove standard

The South African Occupational Health and Safety Act (OHSA) No 85 of 1993 as amended by the Occupational Health and Safety Amendment Act No. 181 of 1993 requires, in Section 8 (1) (b), that employers' duties include in particular: 'taking such steps as may be reasonably practicable to eliminate or mitigate any hazard or potential hazard to the safety or health of employees, before resorting to personal protective equipment'.

As required by NFPA 70E – 2012 [1] Section 130.2, live work is generally prohibited. This section aligns with the requirements of the OHSA in terms of eliminating the risk which in this case is shock or electrical arc flash or a combination of the two. However, Section 130.2 (A) (2) states that; 'energised work shall be permitted where the employer can demonstrate that the task to be performed is infeasible in a de-energise. Fault finding and live, dead, live testing are some tasks where de-energising is not feasible'.

The General Safety Regulations of 1986, a sub regulation of the OHSA, requires in Clause 3(a) that the employer, taking into account the nature of the hazard, in this case, electric shock and arc flash, provide the worker with gloves. Clause 5 states that: 'an employer shall instruct his employees in the proper use, maintenance and limitations of the safety equipment' and Clause 6 requires that: 'an employer shall not require or permit any employee to work unless such an employee uses the required safety equipment'.

The US Occupational Safety and Health Standards (OSHA), 1910.138 (a) Subpart 1: addressing hand protection states; general requirements: 'employers shall select and require employees to use appropriate hand protection when employees' hands are exposed to hazards…severe cuts or lacerations; severe abrasions; punctures… thermal burns; and harmful temperature extremes' and 1910.138(b) states; selection: 'employers shall base the selection of the appropriate hand protection on an evaluation of the performance characteristics of the hand protection relative to the task(s) to be performed, conditions present, duration of use, and the hazards and potential hazards identified'.

Traditionally, legislation and standards stipulated the use of leather gloves with a minimum thickness or gloves manufactured from arc rated fabric. Arc rated fabrics are generally designed for minimal shrinkage, colour retention and comfort on skin; although these characteris-

Prior to 2013, no standard had covered the arc rating of hand protection. A new standard, published in 2013, has addressed this gap.

tics may not necessarily achieve the aims for cut resistance and grip, for example. Research and development in providing arc rated gloves which address arc flash in addition to other hazards did not progress to its potential owing to the absence of an arc rating standard for gloves. That changed in 2013 following the approval of an ASTM International standard ASTM F2675-13 (determining arc ratings of hand protective products developed and used for electrical arc flash protection [5]).

The standard has many benefits, with the most obvious being that the glove is tested as it would be used in the field. As discussed previously, gloves constructed from fabric tested on panels (using ASTM F1959 [6] or IEC 61482-1-1 [7]) are not the most comfortable and useable. The new standard allows for knit, leather and other gloves to be tested for arc flash protection. Rubber gloves are not required to be arc rated, but most manufacturers are opting to provide test data that can be critical owing to the ignition values of low voltage gloves in some colours. Specifying arc rated gloves will ensure that the desired protection is achieved by a single glove or a layered arrangement.

Requirements and limitations

ASTM F2675 [5] does not provide any validation or results for the shock protection performance of a glove. This does not prevent dielectric or insulating gloves from being tested and, in fact, a major benefit of the standard is the ability to arc test products historically designed for shock.

Gloves constructed from fabric which complies with ASTM F1506 [8] do not necessarily have to be retested, however, to determine the performance as 'used in the field' testing may be beneficial. The test is aimed more at gloves that are not manufactured from flat panels or fabric which cannot be tested on a flat panel due to shrinkage.

Prior to arc testing, however, performance testing is required to ensure that the material does not melt or drip; the after flame is less than two seconds and the char length is less than 150 mm.

Only new size 10 gloves qualify as test specimens. Subsequent usage in the field and exposure to contaminants may reduce the arc rating of the glove. Used gloves may be tested for the purposes of field performance testing, research and development but not with the intention to offer an arc rating as the standard.

The arc generating rig setup is similar to that specified in ASTM F1959 [6] and IEC 61482-1-1 [7], however, the glove product holders and sensor arrangement (i.e. the arc measuring) setup is different.

The glove testing rig consists of a glove holder and two monitor sensors on either side of the glove holder. The incident energy is the average of the two monitor sensors. A single sensor located on the glove holder provides the measured energy through the glove. It is important that the glove rests snugly on the sensors and the test lab may use further means to ensure that satisfactory contact is made before testing.

Each glove holder and sensor is spaced 30° apart. Theoretically, this implies that six glove holders and six monitor sensors may be present, however, four test stands are recommended by the standard. A minimum of 20 data points is required by the standard. Analysis depends on the Stoll1 (refer to definition 3.1.15 of [5]) curve performance to determine a burn or no burn. A minimum of 15% of the valid data points should result in a burn while a minimum 15% of the valid data points should not result in a burn. A valid mix zone consisting of at least 50% of the data points should be within 20% of the final arc rating.

General

The biggest challenge facing industry in terms of hand protection is a glove which offers arc flash protection and shock protection. The standard has opened the way for advance in this area. Standards require that rubber gloves used for shock protection be worn with leather over-protectors. Leather, however, has some weaknesses such as it is not nearly as good at cut resistance as many other glove materials. Also, it has poor chemical resistance. Light chain hydrocarbons, such as hydraulic fluid and transformer oil or diesel fuel, pass through leather almost instantaneously and are easily held in leather allowing leather gloves to ignite and burn quite readily. This standard has opened the way to using insulating gloves according to ASTM D120 [2], however, composite over-protectors that may offer arc flash protection, cut and chemical resistance, grip and finger dexterity are on the cards.

Conclusion

ASTM F2675-13, Test Method for Determining Arc Ratings of Hand Protective Products Developed and Used for Electrical Arc Flash Protection, is a new ASTM International standard published in 2013.

NFPA 70E-2012 [1] Standard for Electrical Safety in the Workplace required arc flash leather gloves to be made of a certain thickness. Now, the gloves could be made thinner and still meet minimum protection for the hazard. Some leather gloves and gloves manufactured from fabric tested on flat panels were inadequate for multi-threat hazards. Now, non-leather speciality gloves that grip when wet or oily can be engineered to make the gloves more task-specific and ergonomical. These gloves can now be arc rated, cut and chemical resistant and offer shock protection. Ergonomically designed gloves can be tested for operations where no hazard exists.

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[1] NFPA 70E. 2012. Standard for electrical safety in the workplace.
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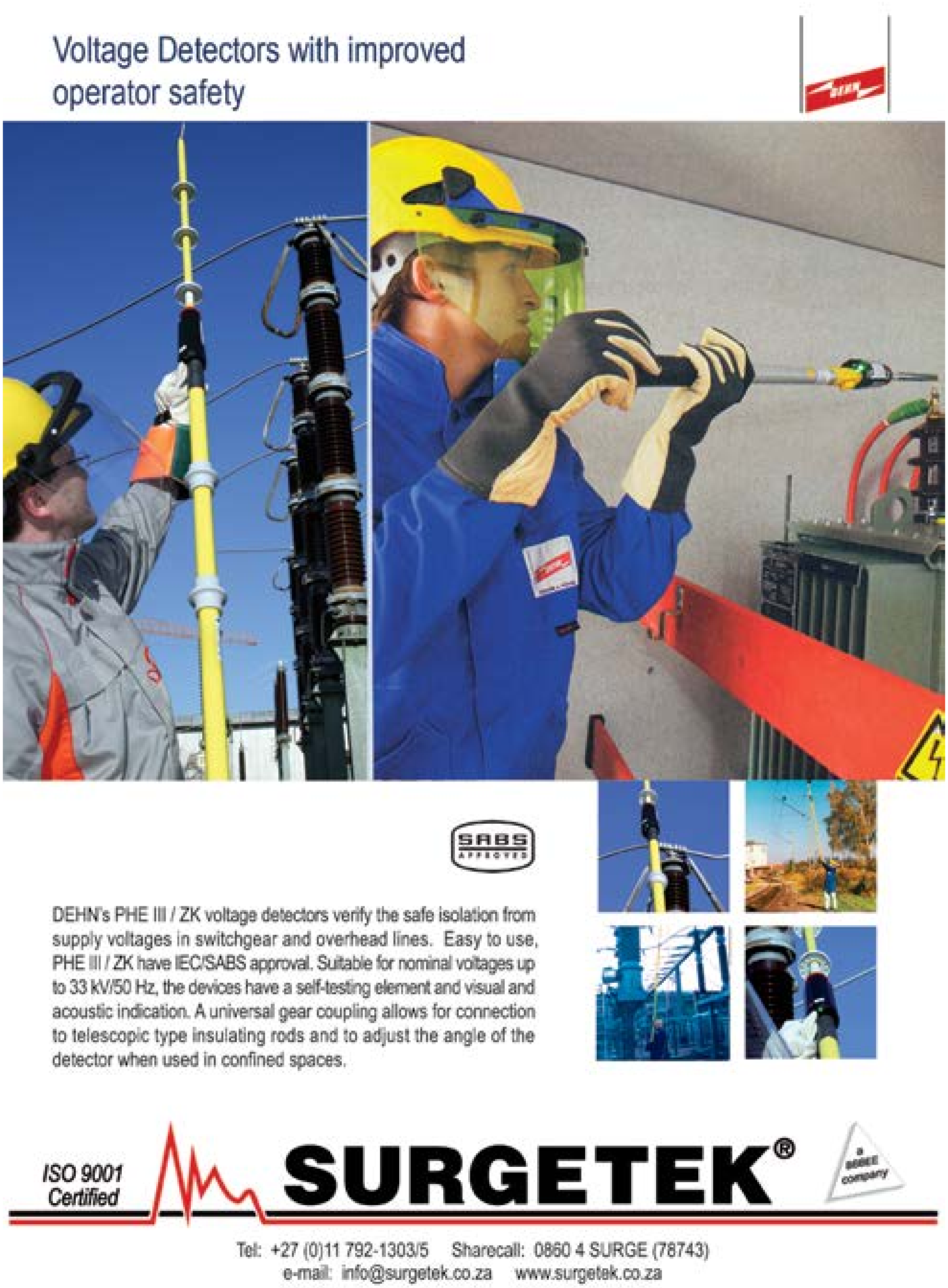


Looking ahead

An additional option that the ASTM F18 committee is currently working on is to allow OSHA-required (1910.137) protector gloves to be something other than leather. The 90-year-old technology of using rubber insulating gloves for shock and leather gloves for protection of the rubber could be a thing of the past through innovation spurred on by the cut standards, puncture standards and now the arc flash standards for gloves. Protecting workers from shock and arc flash hazards while using lighter and thinner gloves that offer better grip, may not be as far off as once believed. Numerous countries subscribe to the International Electrotechnical Commission (IEC) standards. The chairman of the ASTM F18 sub-committee responsible for ASTM F2675 [5] is also part of the IE CTC 78 Live Working sub-committee; this is the IEC committee that is working on the arc rating standard for hand protection. The latest feedback is that the last meeting held in Sao Paulo, Brazil, towards the end of January 2014, resulted in a draft scope, which will be forwarded to the committee members who will start formalising a standard.

Each gas in transformer oil tells a story. Part of that story is knowing what it means; the rest is taking the appropriate action.

Transformer oil management overview

By J De Bruto, Saftronics

This article outlines the importance of oil management and will give readers an overview of dissolved gases and their role in the transformer insulation system.

Transformer oil maintenance and management are important factors in the performance of oil-filled transformers. Many transformer owners periodically make use of companies that service their transformers and submit oil test certificates prior to and after oil purification.

Oil in transformers

Oil in transformers plays an important role in transformer reliability and life expectancy. The main functions of transformer oil are to:

- Provide dielectric strength
- Provide heat transfer for cooling
- Protect the transformer paper insulation
- Test as a diagnostic tool for condition of equipment

Oxidation is damaging to oil and is increased by the following factors:

- Heat owing to load conditions
- Oxygen content
- Presence of metal catalysts (iron, copper and aluminium)
- Electrical stress cellulose
- Oxidation products

By-products of oxidation include alcohols, acids, ketones, peroxides, etc. They act on each other and the oil to form sludge, within the cellulose and this is aggressive towards the insulation paper.

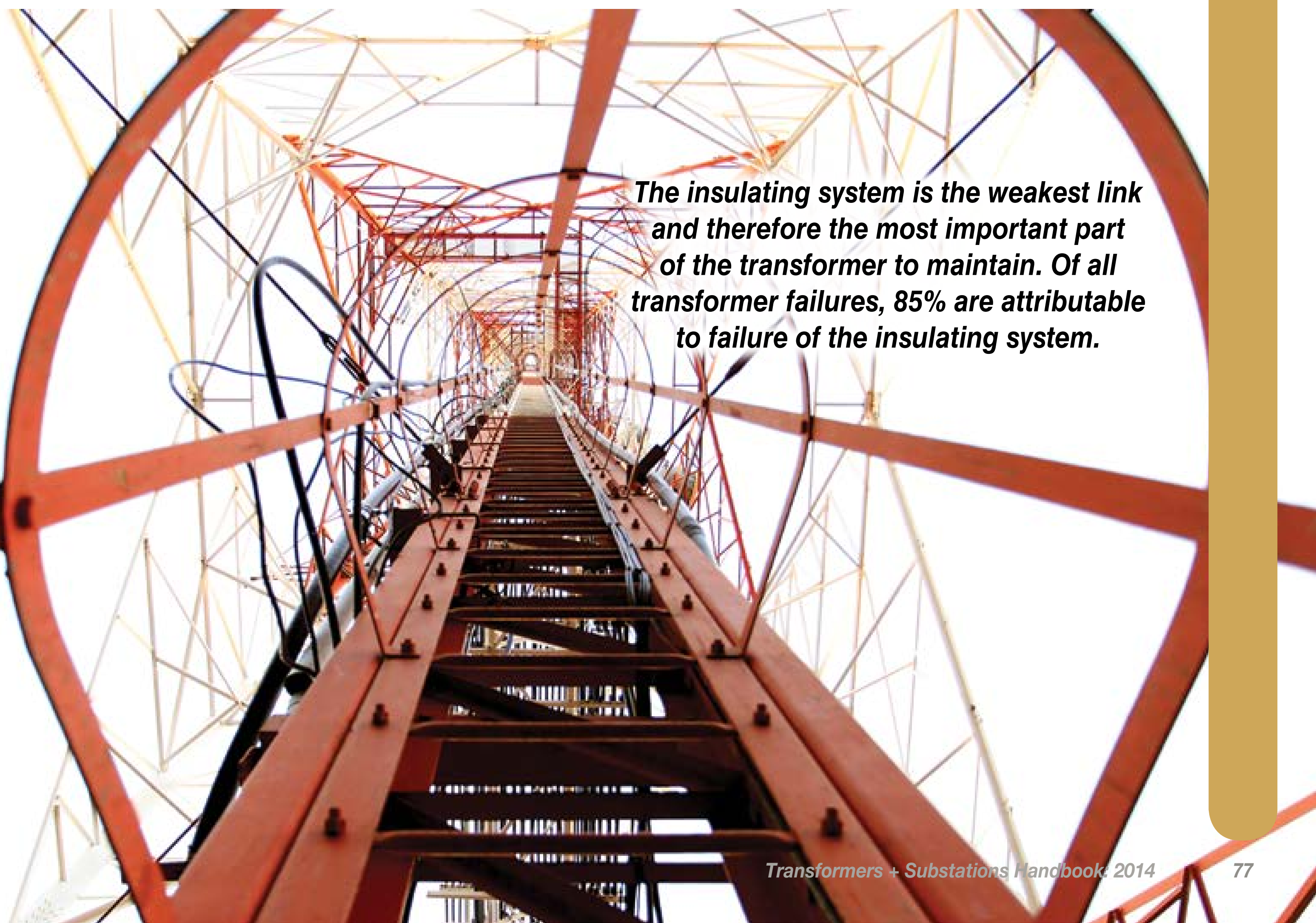
Oxidation not only shortens the life of the insulation paper, but it also restricts heat transfer and this can lead to overheating.

To control oxidation it is necessary to control four of the factors just mentioned. They are:

- Oxygen content
- Moisture content
- Heat
- Oxidation products

Routine oil monitoring and diagnostic tests

Before the oil can be treated it is important to monitor and understand the dissolved gas analysis trends, oxidation and decay products,



The insulating system is the weakest link and therefore the most important part of the transformer to maintain. Of all transformer failures, 85% are attributable to failure of the insulating system.

contamination and operational problems and faults. No single test is consistently adequate for pinpointing a transformer problem, and various monitoring and diagnostic tests can be done for in-service oils, namely:

- Dissolved Gas Analysis (DGA)
- Moisture content
- Liquid power factor/ dissipation factor
- Furans
- Dissolved metals
- Oxidation inhibitor
- Corrosive sulphur

Results analysis and fault diagnosis

IEEE Guide for the interpretation of gases (Institute of Electrical Electronics Engineers Incorporated)			
Gas	**Normal**	**Elevated**	**Abnormal**
Hydrogen (H_2)	< 100	100 - 700	< 700
Oxygen (O_2)	As tested	As tested	As tested
Nitrogen (N_2)	As tested	As tested	As tested
Methane (Ch_2)	< 12	120 - 400	< 400
Carbon Monoxide (CO)	< 350	350 - 500	< 570
Carbon Dioxide (CO_2)	< 2 500	2 500 – 4 000	< 4 000
Ethylene (C_2H_2)	< 15	15 - 100	< 100
Ethane (C_2H_2)	< 35	35 - 100	< 100
Acethylene (C_2H_2)	< 0	0 - 50	< 50

Table 1: IEEE guide for the interpretation of gases.
(The listing in Table 1 determines the solubility of gases within oil).

Ageing gases	**Hydrocarbon gases**
Oxygen	Hydrogen
Nitrogen	Methane
Carbon Monoxide	Ethylene
Carbon Dioxide	Ethane
	Acetylene

Table 2: Dissolved gas classification.

Impurities in transformer oil

The following tests can be used to detect impurities in transformer oil:

- Dielectric strength test – kV
- Moisture content test – ppm
- Acid content test – mg KOH/g
- Visual inspection – identification of visual impurities

Ageing gases

Ageing gases can be described as:

- Gases that are naturally generated by the ageing process of the active part of the transformer as a result of the transformer being constantly surrounded by various strengths of electric fields
- The constant supply of voltage stresses and current being drawn result in heat being induced into the entire transformer, which in turn results in ageing of the transformer
- More heat equals faster ageing and rapid hydro-carbon chain transformation
- The hydro-carbon gases, defined as hydro-carbon chains, generate from a thermal reaction within the oil molecules and surrounding insulating oil, with heat being the primary catalyst which, simultaneously, ages the paper resulting in thermal degradation
- Under fault conditions, the ageing gases are influenced proportionally depending on the type and severity of the fault, but only in a reactive condition
- Carbon monoxide and carbon dioxide play a critical role in determining the presence of internal winding irregularities

Hydro-carbon gases

- Under the normal ageing conditions of a transformer, the ppm levels of hydro-carbon gases previously mentioned are generally low and fluctuate between 0 - ± 15 – 20 ppm with special reference to Acetylene being 0 ppm = acceptable and 1 ppm = attention and manage
- If faults occur in the transformer, the type and severity of the fault can be accurately identified and addressed when hydro-carbon gases grow and interact with each other
- The rate of growth of dissolved gases is directly proportional to the rate of growth of the fault
- The type of fault can be reasonably accurately predicted with the availability of correctly tested and regularly monitored oil samples from the transformer in question

Hydro-carbon gas interaction and fault identification

It is important to note that insulating oil is produced to contain a primary cooling characteristic with strong insulative and high flash point properties to assist the internal transformer solid insulation, being primarily of cellulose and fibre origin.

The insulation oil contains long hydro-carbon chains, which represent different hydro-carbon gases at various temperatures when internal fault conditions exist. The fault conditions generate various temperatures, which in turn heat the immediate oil surrounding the fault, resulting in varied chemical and molecular reactions within the oil. This produces various lengths of hydro-carbon chains that are identified by means of chemical gas chromatography in order to quantify type and quantity of the various nine gases.

Defined fault - partial discharge - takes place at the existing operating temperature. The predominant gas is the hydrogen chain, H_2, which generates a volatile hydrogen gas chain - H_2 – and increases the oxygen level, which becomes electrically ionised and readily discharges. This leads to excessive corona owing to sharp edges on the designed active part, and high moisture and acid content within the oil. The higher the voltage, the higher the risk.

Defined fault – thermal degradation at low temperature – takes place at temperatures of between 150 and 300°C, with the predominant gas being the ethane chain, C_2H_6. The fault is indicated by a hot-spot, anywhere on the active part, with no specific reference to the location. A sharp rise in temperature heats the oil surrounding the fault, generating the ethane gas chain, C_2H_6.

A loose or faulty connection or conductor joint within the transformer circuit, can cause plant vibration and loading, and can aggravate the fault.

Defined fault – thermal degradation at high temperature – takes place at temperatures of between 300 and 700°C.

The identification gas is the ethylene chain C_2H_4 supported by an already elevated methane gas chain, C_2H_6 and the introduction of the methane gas chain CH_4, which grows quickly.

This indicates that the hot-spot is severely aggravated. If the fault is located near or under paper insulation, an inflated carbon monoxide content chain, CO, will be present in excess of 500 to 700 ppm, and if the carbon monoxide is greater than the carbon dioxide chain, CO_2, the fault location is likely to be in a winding and will result in an inter-turn fault. This is difficult to locate or repair and is a dangerous state of fault condition.

Defined fault – discharge of high energy – takes place at temperatures of between 800 and 1 200°C. The introduction of the acetylene chain, C_2H_2, is associated with the already elevated gases, and indicates that arcing is taking place somewhere on the active part, with no specific reference to its location. The high temperatures generated by the fault again induce high concentrated heat into the oil which, in turn, chemically reacts with the hydro-carbon chains within the oil, resulting in the generation of the acetylene gas chain C_2H_2, indicating an arcing condition. This type of fault is dangerous and results in a rapid, to instant, failure of the transformer.

High temperatures within the transformer represent a condition that directly influences its life expectancy. High temperature results in:

- Rapid paper ageing, resulting in insulation failure
- Moisture emission from the transformer solid insulation, resulting in increased oil discharge
- Growth of acid, resulting in insulation failure and overheating – sludge stops cooling
- Rapid thermosyphoning, resulting in a reduction of insulation flash point levels

The limits and guidelines given should clarify the justification to sustain insulating oil analysis when monitoring the trend analysis of power transformers. The type of oil treatment will also be determined by the types of influencing factors, ie:

- Poor dielectric strength – filtration
- Moisture content – dehydration
- Acid growth – regeneration/oil change
- Historic dissolved gases – degassing
- High gas concentration – degassing

Oil samples and laboratory instruments

Oil samples should be taken by trained samplers to ensure correct sampling procedures. The sample container and the nitrile seal inside the sample tin cap play a vital role in ensuring that the sample reaches the laboratory intact for correct analyses.

The laboratory instruments required for analyses are specialised and samples are analysed by laboratory oil specialists. Regularly updated computer programs are used to do analyses according to the Rodgers Ratio and Duval Triangle methods.

The tests and analyses are also performed to applicable specifications, such as ASTM D1533, D877, D1816 and IEC 60814 ... etc.

Conclusion

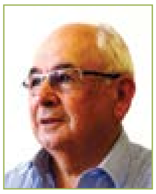
The ability to interpret through analysis methodology, the oil sample and the oil sample results, and then to generate the relevant recommendations and specific scopes of work to address the diagnosis, is founded primarily on the management and formulation of the individual trend analysis of the transformer, which is based on the sample history of that specific unit.

All sample results, methods of analysis and oil sampling procedures, have to be constantly audited in order to ensure the conformity and confidence required to establish a sound foundation upon which correct and qualified oil results can be obtained. It is of paramount importance to relate a specific sample result to the transformer from which the sample was drawn and not to transformers of a similar make, design or nature of application. A sample result relates only to the sample submitted and cannot be compared to any other sample submitted or results obtained therefrom. Properly maintained and serviced oil can give practically unlimited extension of life, free from formation of sludge or excessive acidity due to oxidation.

The insulating system is the weakest link and therefore the most important part of the transformer to maintain. Of all transformer failures, 85% are attributable to failure of the insulating system. Before the oil can be treated it is necessary to monitor and understand the dissolved gas analyses trends, oxidation and decay products, contamination and operational problems and faults. No single test is consistently adequate for pinpointing a transformer problem.

Authors

Chapter 1: Design and manufacture of transformers



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Evert Swanepoel is Centre Director for the Copper Development Association Africa (CDAA) - responsible for promoting and expanding the use of copper in Africa. His vast experience in managing large businesses has provided him with the skill and knowledge to promote copper projects that are positioned to increase the demand and utilisation of this ductile metal throughout Africa. He aims to expand CDAA membership throughout the continent to include the complete spectrum of the copper industry, from primary through to downstream companies and service organisations.

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Carel Carelsen

Carel Carelsen joined Asea Electric (now Powertech) in April 1982. The first position he held was Non Destructive Testing Technician, which involved X-rays, ultrasonic testing, etc. His experience includes winding assembly and winding manufacture. His current position is Development and Support Manager (Mechanical).

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Mluleki Hlatshwayo

Mluleki Hlatshwayo has completed a BSc degree in Electrical Engineering from the University of KwaZulu-Natal and an MSc degree in Electrical Engineering from the University of the Witwatersrand. He is registered as a professional engineer with ECSA. He is currently the Development and Support Manager in the Electrical section of the Group Technology Department at Powertech Transformers. Mluleki worked as an electrical engineer and researcher responsible for development work of leakage flux problems, load losses and hot-spots evaluation in structural parts of power transformers. He joined the company in 2009 as an engineer-in-training. He also chairs the Electrical Equipment Testing and Research subcommittee of the SAIEE's Power and Energy Section.

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Gareth Stanford

Gareth Stanford holds a BSc in Electrical Engineering, a Graduate Diploma in Electrical Engineering and a Masters of Science in Engineering – all from the University of the Witwatersrand. He joined Eskom in 1997 as an Electrical Engineer-in-Training. Rising up the ranks, in 2007 he became Chief Electrical Engineer in Eskom's Industry Association Resource Centre (overhead lines and distribution auxiliary equipment). In 2008, he joined Desta Power Matla as Technology Manager. In 2010, he moved to Powertech Transformers Technology Development and Support as Small and Medium Distribution Transformers manager.

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Johan Haarhoff

Johan Haarhoff joined IST (now Powertech SI) in March 2006 as a CFD specialist, after part time lecturing and CFD consulting on gas cleaning systems at the University of Pretoria. In 2009, Johan joined Powertech Transformers as Senior Engineer, working on simulations and optimisation, and is currently running the Mechanical Research and Design Optimisation group, focusing on FEM and CFD simulations, as well as optimisation.

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Chapter 2: Design and installation of a substation

Paulo De Matos

Paulo De Matos has an NHD in Electrical Engineering. He held the position of Senior Technician (flameproof switchgear) at Fermlec for eight years; he was Project Manager (signal systems) at ETM for four years; and he worked as a Technical Manager (Transformer Equipment) at Galbro. He is currently Technical Sales Manager (Transformer Equipment) at Allbro.
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Warwick Jackson

Warwick Jackson BSc (Hon) Electrical Engineering, returned to South Africa at the end of 2006 after working for GHD Ltd Brisbane, Australia, where he held the position of Senior Electrical Engineer for power delivery. His career began with Eskom (South Africa) in 1997 where he worked in the protection and setting section of the Pretoria Power Distributor. In 2001, he joined Thales Communication in the UK before going to Brisbane in 2005. He worked for Anglo - Kumba for just over seven years, having worked as Engineering Manager for the Anglo American Kumba Iron Ore Sishen Ramp Up Project, the Sishen Expansion Project as well as having held the position of Lead Electrical Engineer for the Kolomela mine project. He is currently the Managing Director of Efficient Power.
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Gilson Semiano

Gilson Semiano was born in Taió, Brazil, in 1980. He received a BSc in Electrical Engineering from the University of Blumenau, Brazil. He is a Design Engineer of WEG Electric Corporation. His research interests include power electronics, modelling and simulation of power systems and power transformers.
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Roger Billiet

Roger Billiet obtained a degree in Electrical Engineering in his home country, Belgium – and worked for the Belgian Electricity Board for six years. He immigrated to South Africa in 1982, studied through UNISA and worked in various organisations. He is currently employed by NTSA as General Manager.
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Alexis Barwise

Alexis Barwise holds a BEng (Electrical and Electronic) from North-West University in South Africa. He is the Managing Director of DEHN Protection SA. Prior to joining the company, he was the Key Vertical Accounts Manager for IT Business in southern Africa at Schneider Electric South Africa. His experience in electrical design engineering, systems engineering, and management has provided him with the skill and knowledge to promote the use of DEHN's products throughout the continent.
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Jean-Noël Bérubé

Jean-Noël Bérubé is a Global Fibre Optic Product Specialist at Neoptix, a division of Qualitrol Company LLC. A founding member of Neoptix, he is heavily involved in the design and application of fibre optic temperature probes used for hot-spot temperature monitoring in power transformers. Bérubé travels worldwide to train transformer manufacturers on how best to install and use fibre optic probes. An electrical engineer and IEEE member with more than 40 years' experience, his field of expertise is in instrument design and application where optic, electronics and software are applied together.
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Jacques Aubin

Jacques Aubin is a transformer consultant especially active in the field of thermal behaviour and insulation ageing. He was, until recently, with GE Energy in Montreal where he was mainly involved in development and testing of advance-monitoring systems for power transformers. Until1998, Jacques was with Hydro-Quebec in Canada where he directed research activities related to overloading, short-circuit strength and acceptance tests on power transformers. Jacques graduated in 1962 from École Polytechnique de Montréal.
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Bill McDermid

Bill McDermid graduated from the University of Manitoba with a BSc in Electrical Engineering. Since 1962, he has been working with Manitoba Hydro where he is involved in the diagnostic testing of electrical insulation applied to all types of apparatus. He has, for many years, been a technical advisor on a number of CEA research projects related to on-line partial discharge measurements. Bill was honoured with the 2009 IEEE Canada Power Engineering Award for his contributions to the development of diagnostic test methods for the insulation systems of rotating machines. Bill's innovations in the field have been adopted as industry standards and have contributed to the enhanced reliability of electric power generation.
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Chapter 3: Substation automation

Tim Craven

Tim Craven joined H3iSquared in 2008 in a technical support role and has been with the company since then, providing technical support, network auditing and training to leaders in the industrial, utility and ITS industries.
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Martin Sanne

Martin Christian Sanne completed a BSc in Electrical Engineering at the University of the Witwatersrand and an MSc in Digital Systems at Cranfield, England. Martin is a registered Professional Engineer in South Africa and started his career in various roles in R&D in Germany, including heading up the Engineering Division at Siemens Telecommunications in South Africa in the 1990s. As General Manager of SEACOM SA and Global Head of Sales of SEACOM, Mauritius, Martin helped SEACOM to build its operational and sales business across Africa and internationally. Prior to joining SEACOM, Martin headed up Mobile Network sales of Nokia Siemens Networks as Sales Director and Divisional Managing Director in Southern Africa.
A significant part of Martin's career was with Siemens AG in Germany where he headed up the line of business for 3G and helped place Siemens on the map amongst the top three 3G equipment vendors of the world. Since October 2012, Martin's role has been that of Divisional Cluster Lead for Smart Grid in Africa.
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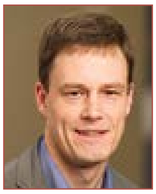

Vincent Thornley

Vincent Thornley has more than 20 years' experience in the power industry across a variety of roles, including manufacturing, academia, consultancy, technology development and project delivery. This experience covers many technological fields, including nuclear generation, power system protection and control, integration of renewable energy (PV, wind, hydro, landfill gas) and smart grid technologies. Vincent is Portfolio and Technology Manager in the Siemens Smart Grid division, where he is responsible for the energy automation product and solution portfolio. A key aspect of his work is guiding Siemens technology development to meet the business change needs for low carbon energy systems and flexible networks. He is a chartered engineer (CEng) and a Member of the Institution of Engineering and Technology (MIET).
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Chapter 4: Maintenance

Sishal Kuwar-Kanaye

Sishal Kuwar-Kanaye, currently Group Project Engineer at Impact Energy, has spent more than 17 years in HV project, commissioning and maintenance environments. His early years at Eskom's Majuba Power Station involved commissioning and maintenance of protection and measurement systems. Twelve years at Richards Bay Minerals enabled a deeper understanding of protection systems, metering and billing, power quality, energy and project management. Sishal holds a BTech Elec degree, a Masters Certificate in Project Management (GWCPM), Certified Energy Manager (CEM), Certified Measurements and Verification Professional (CMVP) and he is registered with ECSA. He has set his current and future career aspirations as a catalyst and an enabler for a new era in PQ with the support of Elspec technology and product range.
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Neil Robinson

Neil Robinson is Managing Director of the WearCheck division of the Set Point group. He holds a BSc (Applied Chemistry) from De Montfort University, in the UK. After joining WearCheck in 1997 as laboratory chemist at the Durban laboratory, Neil was appointed Managing Director in 2005. With more than 17 years' experience in the oil analysis and condition monitoring industry, he has focused on expanding the network of the WearCheck laboratories and condition monitoring services on the African continent and beyond, with an active involvement in introducing the latest reliability solutions and laboratory technology to address the ever-evolving maintenance needs of heavy industry.
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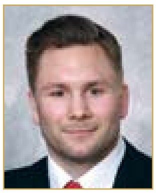

Jung Tobias

Tobias Jung joined WIKA's 'SF6 Centre of Excellence' in 2012 and works as a Product Manager.
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Hugh Hoagland

Hugh Hoagland is among the foremost experts on electrical arc testing and safety. His career began with safety testing at LG&E Energy. Later, he worked as R&D Director for NASCO, manufacturer of protective outerwear solutions. He has been involved in the development of most of the arc-resistant rainwear used today and for the first face shield to protect against electric arcs. He assisted Cintas to develop a strategy for meeting the needs of OSHA 1910.269 and NFPA70E standards, before moving to full-time training and consulting.
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Zarheer Jooma

Zarheer Jooma is a professionally registered electrical engineer with ECSA and a senior member of the South African Institute of Electrical Engineers. Zarheer is the Director of the South African branch of the US-based company, e-Hazard. The company consults to garment manufacturers, performs arc flash calculations and electrical safety consulting work. e-Hazard offers NFPA-accredited electrical arc flash training, and garment testing/ SANS compliance.

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Johann De Bruto

Johann De Bruto was employed as Electrical Design Engineer by ABB Powertech from 1984 to 1995. He joined Hawker Siddeley Tranformers as Engineering Manager until 1999 and then held the same position at NEI Transformers until he became Group Technology Manager at Desta Power Matla in 2004. He was Director at Free State Transformers from 2007. He is currently works for Saftronics.

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Abbreviations

A

AC – Accuracy Class
APD – Asset Protection Devices
ASTM – American Society for Testing and Materials

B

BBPL – Broad Band Power Line

C

C&I – Control and Instrumentation
CB – Circuit Breaker
CoS – Class of Service
CTC – Continuously Transposed Conductor

D

DGA – Dissolved Gas Analysis
DIL – Design Insulation Level
DP – Degree of Polymerisation
DSCP – Differentiated Services Code Point

E

EEG – Erneuerbare Energien Gesetz (Law on)

F

FWLI – Full Wave Lightning Impulse

G

GaAs – Gallium Arsenide
GC – Gas Chromatograph
GIC – Geo-magnetic Induced Currents
GIS – Gas-insulated Switchgear

H

HPLC – High Performance Liquid Chromatography
HSR – High-availability Seamless Redundancy
HV – High Voltage
HVAC – Heat, Ventilation, Air Conditioning

I

IEC – International Electrotechnical Commission
IEEE – Institute of Electrical and Electronics Engineers
IFT – Inter Facial Tension
IP – Internet Protocol
ISO – International Standards Organisation

L

LV – Low Voltage

M

MAC – Media Access Control
Mcb – Mini circuit breaker
MCC – Motor Control Centre
MEBB – Main Equipotential Bonding Bar
MV – Medium Voltage
MVA – MegaVolt Amperes

N

NEMA – National Electrical Manufacturers Association
NFPA – National Fire Protection Association
NOAA – National Oceanic and Atmospheric Administration
NTP – Network Time Protocol

O

ODAF – Oil, Directed Air, Forced
OEM – Original Equipment Manufacturer
OFAF – Oil Forced Air Forced
OHSA – Occupational Health and Safety Act
OIP – Oil Impregnated Paper
ONAF – Oil Natural Air Forced
ONAN – Oil Natural Air Natural
OSHA – Occupational Safety and Health Standards

P

P&G – Provisional and General
PCB – PolyChlorinated Biphenyl
PCDD – PolyChlorinated Dibenzo Dioxins
PCDF – PolyChlorinated Dibenzo Furanes
PF – Power Factor
PFC – Power Factor Correction
PM – Preventative Maintenance
Ppb – Parts per billion
PPE – Personal Protection Equipment
Ppm – Parts per minute
PQ – Power Quality
PRP – Parallel Redundancy Protocol
PTP – Precision Time Protocol
PTT – Press-to-Test

R

RE – Renewable Energy
RIP – Resin Impregnated Paper
RMS – Root Mean Square
RMU – Ring-Main Unit
RSTP – Rapid Spanning Tree Protocol
RTU – Remote Terminal Unit

S

SAIDI – Systems Average Interruption Duration Index
SCADA – Supervisory Control and Data Acquisition
SMT – Surface Mount Technology
SPD – Surge Protection Device

T

TCP – Transmission Control Protocol
TLC – Thin Layer Chromatology
TOC – Total Owning Cost
TVSS – Transient Voltage Surge Suppressor

U

UPS – Uninterruptible Power Supply

V

VFD – Variable Frequency Drive
VFT – Very Fast Transient
VFTO – Very Fast Transient Overvoltage
VLAN – Virtual Local Area Network
VSD – Variable Speed Drive

W

WFQ – Weighted Fair Queuing
WiMAX – Worldwide Inter-operability Microwave Access

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