May 2006
Volume 18, No. 4

North American Policies and Technologies

ELECTRICITY Transmission & Distribution TODAY

THE ELECTRICITY FORUM

GOING ON LINE WITH TRANSFORMERS

On-line fault gas analysis stresses safety

3D simulation of solutions to field problems

PUBLICATION MAIL AGREEMENT # 40051146

ELECTRICITY TODAY
THE ELECTRICITY FORUM

Volume 18, No. 4 May 2006

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Electricity Today Magazine is published 9 times per year by The Electricity Forum [a division of The Hurst Communications Group Inc.], the conference management and publishing company for North America's electric power and engineering industry.
Distribution: free of charge to North American electrical industry personnel who fall within our BPA request circulation parameters. Paid subscriptions are available to all others.
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215-1885 Clements Road,
Pickering, Ontario, L1W 3V4
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Canada Post - Canadian Publications Mail Product Sales Agreement 40051146
ISSN 0843-7343
Printed in Canada.

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CHINESE METERING MANUFACTURERS EYE NORTH AMERICAN MARKET

By Don Horne

It isn't the redcoats this time around, but the Chinese who are coming; and they are seriously looking at the advanced metering market in North America.

The group made stops in Raleigh, North Carolina, Atlanta, Georgia and Toronto, Ontario, listening to speakers from such companies as Itron, Elster Electricity, Georgia Power, Alabama Power, Toronto Hydro and yours truly from Electricity Today magazine.

The Chinese Meter Components & Manufacturers Technical Study Tour – North America were taking a week-long look at the shape of advanced metering in Canada and the United States. In the case of their stopover in Toronto, it was Ontario's Smart Metering initiative that they were interested in and, specifically, the opportunities available to provide smart metering to meet the government's 2010 target of making the entire province smart meter compliant.

The President of Shanghai Wanjia Precision Components and Wenzhou Wanjia Electric Equipment companies, Pan You Jin, is extremely interested in what Ontario needs in the form of smart metering – as Pan You Jin is hoping to capitalize on his new Canadian citizenship by opening a metering factory in that province.

Wanjia Electric currently has 50 per cent of the electrical relay market in China, a country of more than 1.3 billion people.

Accompanying Pan You Jin on the tour was James Lau, the Managing Director of GSL Consulting Ltd. in China, a company that specializes in the research, marketing and advising of companies working in the metering field. GSL has provided data, advice and opinions to more than 30,000 individual clients over the past 30 years.

Wanjia Electric currently has 50 per cent of the electrical relay market in China, a country of more than 1.3 billion people.

Representatives from a Hong Kong-financed company, Changsha Weisheng Electronics Company (founded in April of 2000), were also very interested in the North American metering market. Their company specializes in electronic multifunctional three-phase electric energy meters, electronic multifunctional single-phase electric energy meters, remote meter reading systems, and large-scale application and system software.

Advanced metering is progressing by leaps and bounds across North America, and it would be foolish to think that this multi-billion dollar market isn't drawing attention from across the Pacific and Europe (it should be noted that a representative from the firm Zera in Germany also participated in the tour – and yes, they also make meters).

As utilities continue to expand and upgrade their metering network, through integrating wireless technologies, smart two-way meters and system-wide automation, the demand for such products will grow exponentially in the coming years. Judging by the level of curiosity shown by this touring group and their interest in how Ontario is moving forward with smart metering, the North American marketplace should be prepared to welcome the new kid on the block – and this kid is experienced and ready for what the future holds.


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3D SIMULATION TO SOLUTIONS OF FIELD PROBLEMS AND PERFORMANCE UPGRADES OF LARGE POWER TRANSFORMERS

By Zoran Andjelic, Member, IEEE, Asim Fazlagic, Member, IEEE, Ramsis S. Girgis, Fellow, IEEE

Over the transformer life in operation, the dielectric strength withstand of the transformer insulation typically decreases as a result of normal aging, accelerated aging caused by moisture, oxygen and high operating winding temperatures, insulation wear, mechanical damage of windings due to system shortcircuit incidents, emergency overloading, etc. Concurrently, the stress applied on the transformer often increases with time due to load growth and increased generation on the power system.

On the other hand, the needs of the generating companies have also changed as the new generation of energy companies has developed. Instead of the traditional power companies with a mix of generation, transmission, and distribution assets, we now see large energy companies that have a mix of generating plants in different parts of the country . No longer are the generation plants linked to the traditional utility or to the service organizations of the original owners. As a result, the new energy companies end up with a mixture of assorted transformers spread out across the country. More often than not, the personnel with asset management responsibilities do not have the historical knowledge of the transformers or their condition. Faced with an aging population of transformers (~38 years average age in USA) with unknown life expectancy, the companies have looked for a solid technical basis to make asset-planning decisions, especially field modifications, to address operational problems and also upgrades deemed necessary because of new system requirements.

Since it is impractical to do much experimenting with power transformers in the field, there is a need for simulation-based, accurate, reliable, and efficient analysis of the performance and proposed modifications/upgrades of power transformers in service. One of the attributes for such a need is to use the emerging 3D simulation technologies in both design and service activities for large power transformers.

Fig. 1 - Bus-duct configuration of an 850 MVA, 3-phase GSU

In this article, we shall demonstrate how 3D analytical tools can be used for Simulation-Based Transformer Services (SBTS) of large power transformers when field modifications and upgrades are necessary . The following applications of the 3D simulation analysis is presented:

- GSU Bus-Duct overheating
- Temperature distribution in Core-Clamping Structure
- Analysis of Core Hot-Spot in core-form transformers
- Overload capability of shell form transformers
- Electric-field stresses in a modified LTC lead structure
- Dielectric verification of the support structure of EHV bushings

ANALYSIS OF OVERHEATED BUS DUCT OF A LARGE GSU

In this application, the 3D simulation was applied to analyze the thermal performance of the bus-duct structure of an 850 MVA, three-phase GSU transformer. The configuration of this bus-duct is shown in Figure 1, where two bushings in each phase carry the full LV winding current from two different phases and the delta is externally closed at the top of the bushings. Analytical details and the simulation techniques used for this application will be the subject of a future IEEE Power Delivery Transactions paper.

In this 3D simulation application, it was necessary to:

1. Properly model the transformer/bus-duct geometry to

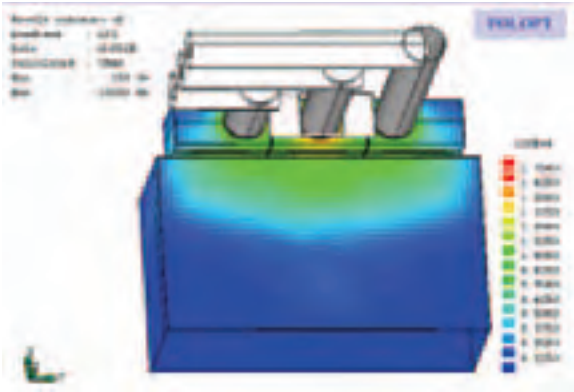

Fig. 2 - Magnetic field distribution in tank-wall/tank cover/bus-duct structure

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3D simulation

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limit the size of the model but, at the same time, obtain accurate values of the desired temperatures.

2. Determine the most efficient/appropriate numerical approach for the analytical solution.
3. Select the appropriate values for the thermal, electrical, and magnetic parameters of the materials involved, namely, tank wall, tank cover, magnetic and conducting shields, and bus-duct.

The first step, in the simulation workflow, is the calculation of the current distribution in the bus ducts and the magnetic field produced by those currents, shown in Figure 2.

The next step is the calculation of eddy-currents and eddy-losses in this structure. This part is performed using the Boundary Element Method (BEM)-based numerical procedure. Figure 3 shows the distrib ution of eddy-losses over the tank wall and bus-duct structure of this transformer. The temperature calculation is obtained using the calculated eddy-loss densities as the e xternal load for the thermal run (Figure 4).

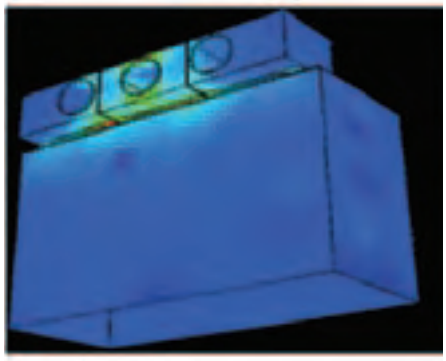

Fig. 3 - Calculated eddy-losses distribution in the tank-walls/tank cover/bus-duct structure

Fig. 4 - Calculated temperature distribution in the transformer's tanks wall/tank-cover/bus-duct structure

The simulation output has been validated by comparison with thermography measurements done during the transformer operation (Figure 5). It can be seen that the simulation results agree very well with the measured results. The deviations could be explained by the difficult task of estimating the true heat transfer coefficients used in the simulation for the dif ferent materials of the model. As demonstrated above, only 3D simulation would be capable of analyzing such a f ield problem and e valuating the proper solution/field modification.

VERIFICATION OF THERMAL PERFORMANCE OF CLAMPING STRUCTURE

Another example where 3D simulation is necessary is in calculating the temperature distrib ution in the clamps of core form transformers due to leakage flux from the windings.

Figure 6 shows one of these applications where 3D simulation was used for this purpose in a lar ge, single-phase, high-impedance power transformer.

The simulation provides critical information on areas of the clamping structure having the highest temperatures (Figure 7).

Fig. 7 - Temperature distribution in the clamping structure of a large high impedance core form transformer

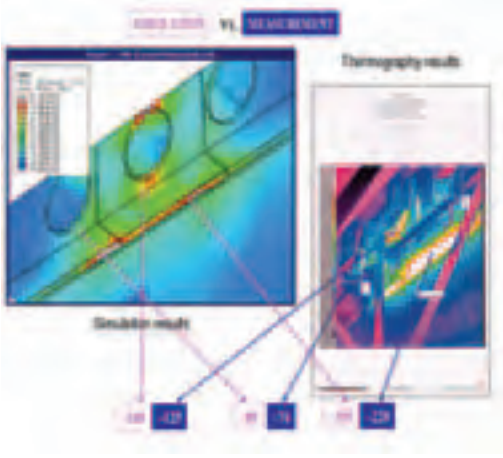

Fig. 5 – Comparison between the simulation results and the thermography measurements

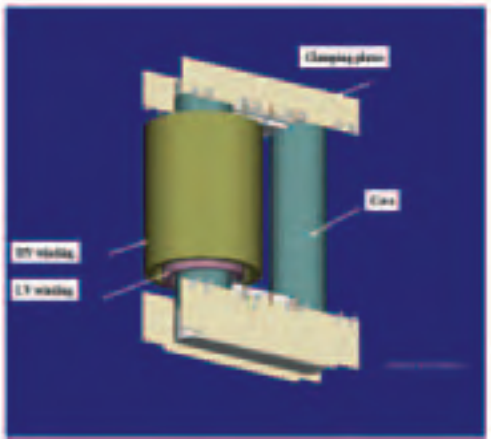

Fig. 6 - Model of the single-phase core form transformer

This allows providing the proper amount and type of shielding in the right locations to a void overheating and subsequent gassing. The 3D simulation has also been used to analyze problems of hot metal gassing in the f ield, determine corrective action(s), and verify effectiveness of the applied solution(s).

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3D simulation

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ANALYSIS OF CORE HOT-SPOT IN CORE FORM TRANSFORMERS

More often than not, the cores of GSUs and, to some extent, system transformers, are overexcited due to over-voltage resulting from higher load and reactive power demands. As a result, the core hot spot rises to levels that would cause the thin oil-film between the core laminations to disintegrate, resulting in the generation of Hydrogen and Methane in transformers in the field. In these cases, it is necessary to accurately calculate the value of the core hot-spot temperature in order to explain the problem and suggest an effective solution.

Also, such a calculation is becoming very critical to be performed at the design stage in order to ensure adherence to new lower values of allowed core hot-spot temperatures.

Appropriate simulation using 3D modeling was necessary to understand the thermal performance of the core and hence develop simpler equations for this calculation in the design process. As demonstrated in Figure 8, the 3D simulation method provides an excellent accuracy in the range of 2ºC from measured values.

This accurate method of core hot spot calculation has been used extensively to evaluate the thermal performance of older designs of power transformers, especially when more loading is envisioned for these transformers. It is often part of the life assessment process of these transformers. The method was also successfully used to diagnose and propose solutions in cases of higher rates of generation of Hydrogen and Methane in large power transformers in operation. Many of these transformers are GSUs that were overexcited under high load conditions and high ambient temperatures.

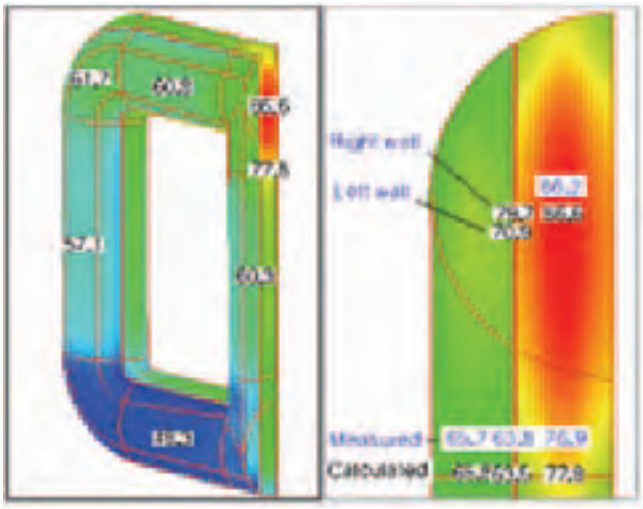

Fig. 8 - Temperature distribution in a core of a core form Transformer

Fig. 9 - Cross-section of a shell-form transformer

EVALUATION OF OVERLOAD CAPABILITY OF A SHELL-FORM TRANSFORMER

Higher power demands often require upgrades of large power transformers while in service, as transformers (after turbines and generators) are typically the bottleneck in these cases. In order to be able to accurately determine whether an upgrade is necessary or determine the amount of the upgrade needed, one needs to first accurately evaluate the true loadability of the transformer in its present condition using present day calculation methods. This requires accurate calculation of the following parameters under the originally claimed to be 100% power capacity (MVA) of the transformer:

1. Eddy and circulating current losses in each of the winding segments, down to the strands level.
2. Corresponding hot-spot temperatures under maximum ambient temperature conditions.
3. Magnetic/conducting shielding loading.
4. Core currents/losses and corresponding core hot spot.

Accurate calculation of the above parameters for shell-form transformers is only possible through the use of 3-D field calculations. This is due to the asymmetric nature of the shell

form winding geometry around the coil periphery . The coils have four different regions, namely, the core region, top & bottom of the core region, corner region, and top & bottom coil region (see Figure 9). The 3D magnetic flux calculation is also necessary for the appropriate design of the T-Beam and tank-wall magnetic shielding to prevent overheating in the core, tank, and other parts of the winding clamping structure. Finally, the 3D calculations are the only calculations that can provide information on the third component of leakage flux which can, if not properly designed for, cause excessive core currents and overheating, especially in old designs of 3-phase shell form transformers. The same is true for properly designing the sidewall magnetic shielding, which is only possible using 3D magnetic field calculations

In order to demonstrate the effectiveness of these 3D field calculations, Table 1 presents one of the many applications where these calculations were used successfully in evaluating the true load-ability of an old large shell form transformer in its present condition as well as the prospects of increasing the load ability of this transformer with cooling system enhancements in the field. Given in Table 1 are four loading cases and

Cases	1	2	3	4
MVA	406	406	425	440
Average Oil	36.5	31.0	32.8	29.8
HV Braze	82.2	75.3	79.9	79.7
LV Winding H.S.	87.6	76.9	81.6	77.5

Table 1 – Temperature rises in a 406 MVA shell form transformer calculated using 3D simulation

corresponding calculated temperatures for a 406 MVA, 3-phase transformer. Case #1 represents the full loading of the transformer in its present condition.

Although the transformer was originally designed many years ago to satisfy the 80°C hot-spot temperature rise according to the original design calculations, the 3D calculated values given in the table exceed the 80°C limit for both the HV Braze and the LV windings. The 3D calculations show that, with enhanced cooling (Case #2), to be provided in the field, these temperatures can be brought down to a normal level that will stop the insulation life degradation when the transformer is fully loaded. Case #3 corresponds to case #2 but when the transformer is operating at 425 MVA. Case #4 demonstrates that, with the 3D calculations of the winding hot spot, one can determine what additional custom made cooling system will be necessary to operate this transformer up to 440 MVA and at the same time maintaing a loss of insulation life equivalent to a new properly designed transformer.

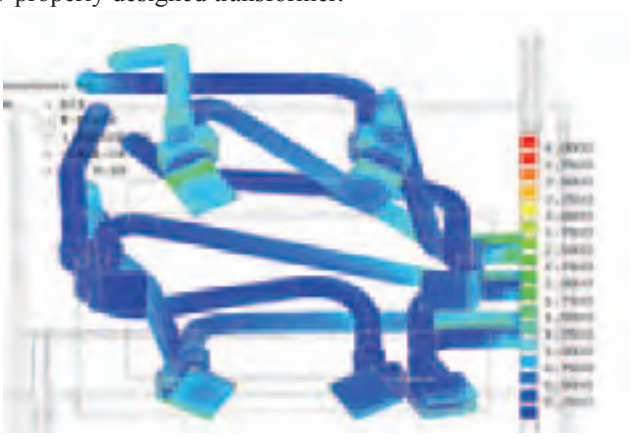

Fig. 10 - Electric field strength distribution of the TC leads

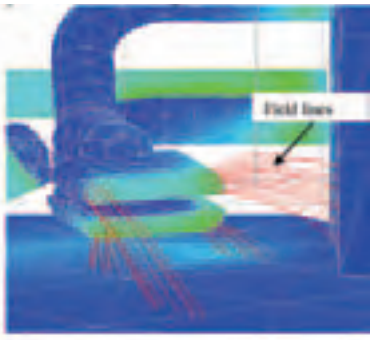

Fig. 11
Electric field lines tracing from the positions with the critical electric field density values

DIELECTRIC VERIFICATION OF RE-CONNECTION OF TAP CHANGER'S LEADS FOR A HIGHER OPERATING VOLTAGE

In this application, the task was to use the 3D-based simulation to confirm the feasibility from dielectrics considerations of the new configuration of the tap changer's leads. The 3D modeling of such geometry is very challenging due to the large disproportion in the model dimensions. For example, typical transformer winding's radii are in the 100s – 1000s of mm's, but the curvature radius of the shielding ring on the same winding is in the region of a few mms. Also, neglecting or underestimating the proper modeling of small details like screws or bolts in the transformers can very often lead to the prediction of completely wrong values for the critical stresses within the transformer.

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3D simulation

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Figure 10 shows the detailed field distribution for the proposed new configuration of the tap changer's leads in a large power transformer. The main requirement was to ensure that admissible stress levels along the surfaces of the solid insulation and average and maximum admissible stresses between the leads are not exceeded.

After calculating the field distribution, positions with the highest field strength are located and then evaluated against the design criteria for allowable stress levels. The evaluation is based on tracing the field lines starting from the positions with the critical field values (Figure 11).

DIELECTRIC VERIFICATION OF SUPPORT STRUCTURE OF EHV BUSHING

This is another important application of the 3D-based simulation for transformers in the field and at the design stage.

Figure 12 shows the model of a 525 kV transformer, containing the HV/LV windings with the dielectric barriers, shielding electrodes, and HV bushing.

The calculated electrical field distribution is shown in Figure 13. Field lines, shown in the circle, are launched from the location having the maximum calculated electrical field strength. In this case, the highest field appears on the thin paper insulation around the shielding-ring of the LV winding.

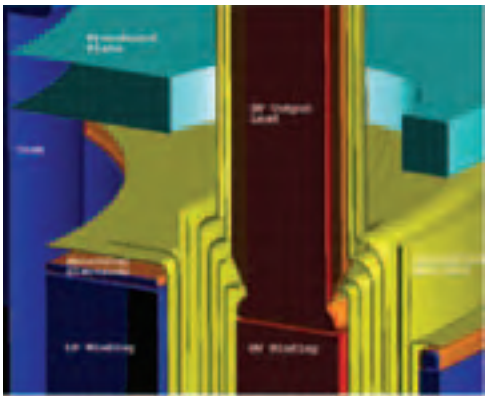

Fig. 12
Cross-section of the transformer insulation system model, including the HV & LV windings and HV bushing

CONCLUSIONS

This article has highlighted a number of applications where 3D-based simulation is, and has been, used extensively for field problem analysis, engineered solutions, and performance verification of proposed field modifications/upgrades of large power transformers in service, as well as in the design

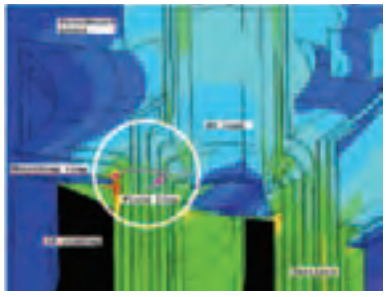

Fig.13
Electrical field distribution over the winding/HV bushing insulation structures

process of these transformers. The applications dealt with the dielectric, thermal, electromechanical and magnetic performance parameters of the transformers.

It is shown that, thanks to efficient numerical technology, it is possible, in a fast and efficient way, to obtain sufficiently accurate calculations based on 3D-simulation that could not be done to any reasonable degree of accuracy using 2D-based modeling. This is because of the 3D nature of these structures and also because some of the performance parameters are driven by the third component of the magnetic and electric fields found in the transformer during operation.

As it is generally not feasible to pre-validate the solution and resulting performance improvements of the field modifications of large power transformers, there is strong need for reliable analytical tools that will ensure the expected performance. The proven success and accuracy of the 3D simulation, as demonstrated in the above applications, make it the ultimate tool for Simulation-Based Transformer-Services (SBTS).

ACKNOWLEDGEMENT

Special acknowledgement is due to Messrs. Peter Balma & Don Fallon of PSE&G as well as Messrs. John Hugo and Ray Cameron of Exelon/COMED for their technical support during the execution of the studies involved on some of the applications presented in this article.

The authors would also like to acknowledge technical support from Dr. Hasse Nordman of ABB Finland, and Messrs. Eric Pisila and Gary Burden of ABB St. Louis, and Mr. Ed teNyenhuis of ABB Guelph, Canada.

TRANSFORMERS SAFELY MANAGED THROUGH ON-LINE FAULT GAS ANALYSIS

By PJ de Klerk, HP Nieuwenhuis, A de Beer Eskom, South Africa; S Lindgren, Serveron Corporation

Dissolved Gas Analysis (DGA) is a fundamental technique in establishing fault mechanisms in oil-filled power transformers. Manual sampling and testing of insulating oil has con ventionally been utilized to monitor for developing faults. Although this technique has provided valuable information in determining transformer condition, a more ef fective means of re vealing incipient faults and preventing serious f ailures is through the continuous e valuation of the f ault gases in po wer transformer oil. This is achieved through the use of on-line monitoring systems such as the True Gas Analyzer.

By monitoring the dissolv ed gases on the po wer utilities generator step-up transformers, three instances of progressing faults and possible transformer f ailure were successfully tracked. The DGA data w as applied to establish the seriousness of each situation and allow the controlled operation of the three transformers to a safe repair interv ention. Visual inspections on the 700MVA transformers re vealed the fault mechanisms, which related agreeably to the gases observ ed by the on-line monitoring. The on-line data is presented together with detailed descriptions of the f ault mechanisms on each of the transformers.

1. INTRODUCTION

Power transformers, being key components in any electrical network, require vigilant operation and maintenance in order to obtain a safe and optimum w orking life. As transformers age, monitoring of their condition becomes more vital, with surveillance and diagnostic techniques needed to pre vent the possibility of surprise f ailures. Dissolved Gas Analysis (DGA) is a fundamental technique in establishing f ault mechanisms in oil-filled power transformers. Although well-established, periodic manual sampling and testing of insulating oil is being used, a need e xists for the continuous assessment on key, oil-filled electrical plant.

Several years ago Esk om embarked on a program of installing on-line fault gas analyzers on its generator step-up transformers, considering the continuous monitoring equipment as an essential tool in the management of these costly and vital links in the power generation and transmission chain.

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Figure 1: Serveron True Gas Analyzer Installation

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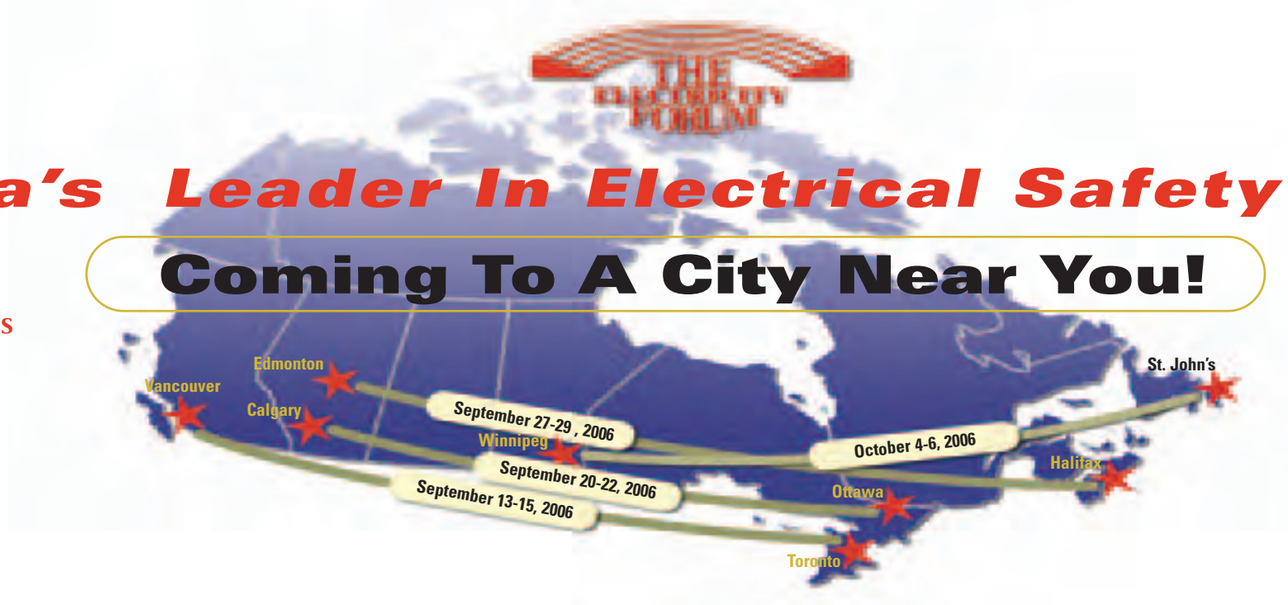

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gases, in parts per million (ppm) range:

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- Methane (CH4)
- Carbon Monoxide (CO)
- Carbon Dioxide (CO2)
- Oxygen (O2)

The data is trended to reveal an on-screen plot of the dissolved gases, ongoing with time, on a host computer remotely connected to the Analyzer. Alarm thresholds are user settable for each gas level. Analyzer status and gas alarm conditions are provided locally and remotely.

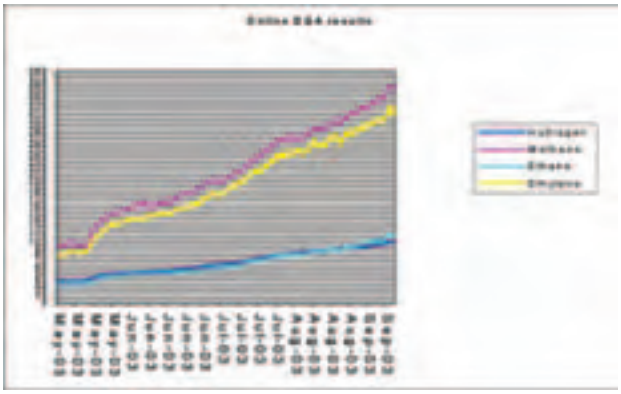

Figure 2: Transformer A – Dissolved Gas Profile

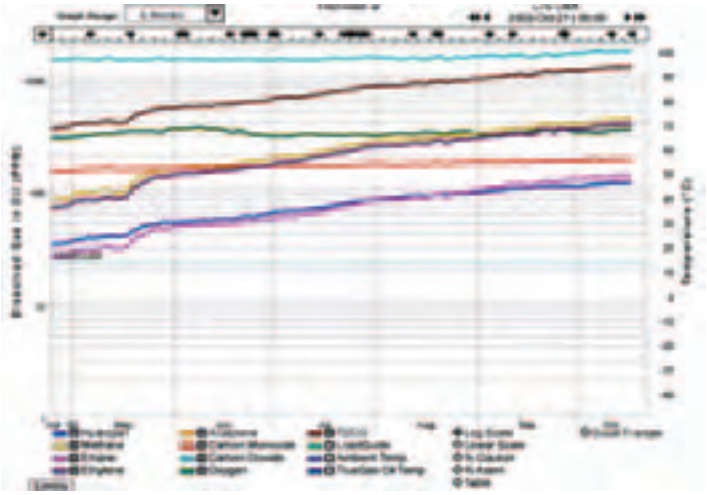

Fig 2A: Transformer A – Dissolved Gas Profile (all gases for 6-months)

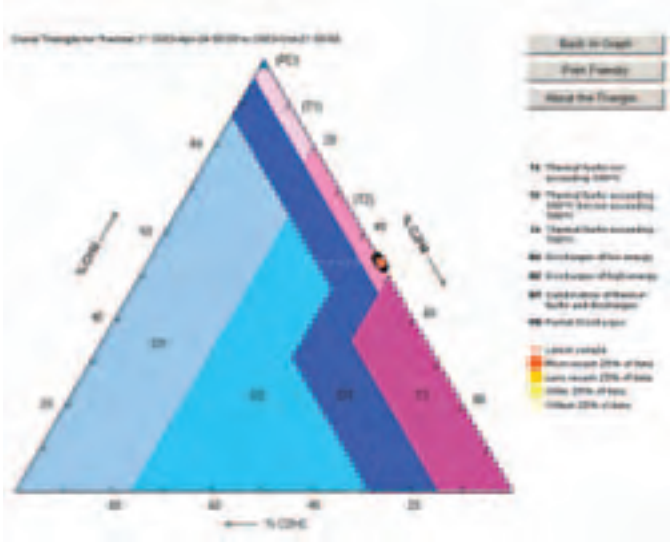

Fig 2B: Duval Triangle Indicating Thermal Fault – 300 to 700 C

3. ON-LINE DGA DATA AND INTERPRETATION

The Transformer System Engineers are able to remotely download data from the on-line analyzers installed at their sites and view the trend. Generally, each engineer has established a 'base line' for the eight gases on each transformer and is subsequently able to set alarm threshold values. There are internationally recognized guidelines for the interpretation of dissolved gases in transformer insulating oil.

4. CASE STUDIES

Shortly after implementing the True Gas Analyzer program, three 700MVA, 22/400kV generator step-up transformers with developing problems were identified:

TRANSFORMER A

After detecting rising Ethylene levels in routine oil sampling and laboratory analysis on this transformer, a True Gas Analyzer was employed to closely observe and trend the dissolved gases on a four-hourly basis. From the gas content and trend, it was apparent that a high temperature fault existed.

In order to establish where the overheating was taking place, separate oil sampling and laboratory analyses on the transformer main tank and the tap selector tank were undertaken – which confirmed that the problem lay in the bulk oil of the main tank.

During scheduled, short-term maintenance, various electrical tests were performed on the transformer. These consisted of a suite of (Doble M4000) tests, core earthing circuit tests, partial internal inspection and, finally, a vacuum treatment filtering of the insulating oil to remove all the residual dissolved gases. No obvious abnormalities could satisfactorily explain the production of the high temperature gases. As there was no spare transformer available, the transformer was returned to service, albeit under strict observation.

Before being loaded, the transformer was 'soaked' at full voltage for a lengthy period, while the dissolved gases were closely observed. An initial increase in gas, which subsequently stabilized, was attributed to 'leaching' from the active components of the transformer.

After the transformer was returned

Figure 3: Transformer A – Overheated LV Connection

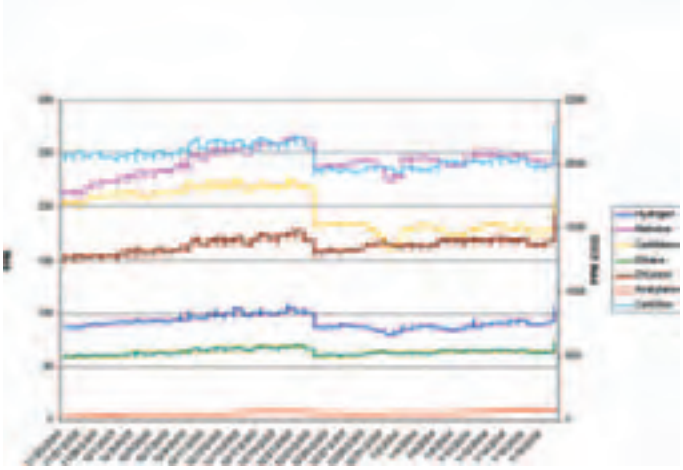

Fig 3A: Transformer B - Dissolved Gas Profile

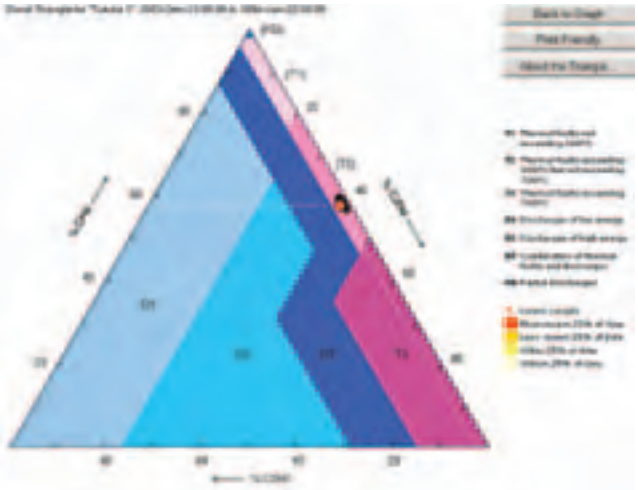

Fig 3B: Duval Triangle Indicating Thermal Fault – 300-700 C

to service, the gases immediately started to rise once again, with Ethylene and Methane being dominant (Figure 2).

The transformer load was reduced, but it was kept in service. A gas production rate limit of ± 2 ppm per day was used as the guide for loading.

Finally, once a spare transformer became available four months later, the faulty one was taken out of service and fully inspected in a workshop.

Visual inspection revealed severely overheated brazed connections at the bottom end of a low-voltage winding lead (Figure 3).

TRANSFORMER B

An alarm condition from the True Gas Analyzer was received by the Transformer System Engineer, indicating there was a positive trend of Hydrogen, Methane, Ethylene and Ethane on this transformer. These results were immediately confirmed by laboratory DGA of an oil sample, indicating a high temperature fault. The loading of the transformer was reduced and, although seemingly controllable, the gassing trend continued to be positive. It was established that load was a contributing factor in this fault condition.

Finally, after operating the transformer for a further month and a half, it was deemed necessary to shut it down and make detailed investigations.

Electrical tests, including impedance test results, revealed no abnormalities. Some discolouration of the insulation around the A-phase high-voltage turrets was observed and overheated insulation around the corresponding HV exit lead seen. Severe burning of insulating material was found on the brazed connections at the bottom of the low-voltage windings of the A-phase (Figure 4). The bolted connection was in good order.

The conclusion of the investigation highlighted a possible design flaw and it

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Figure 4: Transformer B – Severely Overheated LV Connections

STATIONARY FUEL CELLS FOR POWER GENERATION - PART 2

This is the second part of a two-part series on stationary fuel cells for power generation in Texas

II. OBSTACLES

Cost

The numerous items on the benef it side of the fuel cell ledger are, at least for now, overwhelmingly outweighed by cost. Commercial fuel cell units available today cost around $4,000 per kW of capacity, excluding site costs. Although unit costs are coming do wn, it will be some time before FCDG is economically competitive.

Many of the fuel cell research and development projects no w being funded by DOEs involve finding ways to reduce the cost of k ey components. The budget proposed for DOE includes a 32% increase in funding for fuel cell research and development.

DOE's future cost-reduction tar gets follow the normal pattern of a commercially maturing technology. As costs fall, unit sales increase. Eventually, the industry achieves critical mass: demand is large enough to make economies of scale possible, and costs fall even more.

While this pattern of critical mass has been e vident in personal computers and many other high-technology industries, wind po wer provides an e xample more apropos of fuel cells. Lik e fuel cells, wind turbines have been around for a long time. P artly as a result of the OPEC oil embargoes, the federal government accelerated R&D funding for wind turbines in the 1970s. As Figure 2 shows, costs began to f all dramatically in the 1980s, and by the end of the 1990s wind turbines had achie ved a magnitude of cost reduction similar to what now is targeted by DOE for fuel cells.

Interconnection

Distributed generation (DG) resources must meet interconnection standards so that they do not pose a reliability risk to the rest of the electric power system. A DG site can include primary energy generation equipment such as fuel cells; po wer converters such as induction generators; or po wer control center and v oltage level equipment such as protective devices, metering, and step-up transformers. Connecting these facilities to the electric power system must satisfy the following objectives:

- **Safety.** A DG unit should not create any undue safety hazard for utility personnel, customers or the public.
- **Voltage quality.** The unit must not cause objectionable po wer quality, voltage regulation or v oltage flicker on the utility system and for any customers.
- **Reliability.** The unit should not degrade the reliability of the po wer system.
- **Utility system over current devices.** The unit must not interfere with the operation of the utility system o ver current protection equipment.
- **Safety to utility and customer equipment.** The unit should not cause damage to utility and customer equipment during steady state and f aulted system-operating conditions.
- **Restoration.** The unit must not interfere with restoration of power on the utility system.
- **Utility system operating efficiency.** The unit must operate at po wer factors and at generation density levels that maintain utility system efficiency.

In areas where electric utilities are still vertically integrated, it is sometimes difficult for DG customers to obtain an interconnection to the grid. All else being the same, an integrated utility has a fundamental disincentive for DG because it means the customer is buying less of the utility' s

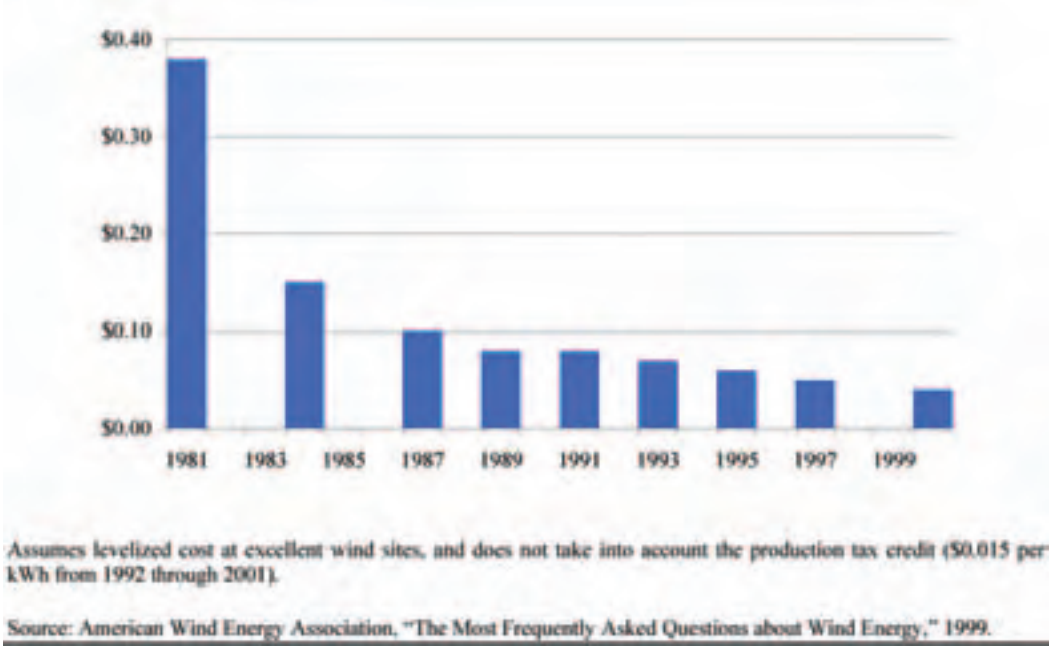

Figure 2: Historical cost of producing wind power (per kWh equivalent)

power. In a restructured market, however, the utility providing the grid connection is not the entity that sells the power.

While concerns have arisen elsewhere in the country, the commission has received very few complaints about transmission and distribution service providers in Texas making interconnection difficult. The commission has attempted to facilitate DG generally by promulgating a set of uniform interconnection standards for all utilities under its jurisdiction. (Municipally owned utilities and electric cooperatives are not subject to these rules, however, and may have different standards.) In short, while interconnection may be a problem elsewhere, it is not a problem in Texas.

III. ROADMAP TO COMMERCIALIZATION

The Lessons of Renewable Energy Development

If one looks at how Texas has performed in the area of renewable energy development, two facts are readily apparent. First, a tremendous amount of renewable energy generation – mostly wind power – is being installed in Texas. In its report on wind power development in 2001, the American Wind Energy Association noted that Texas installed more new wind capacity in 2001 (915 MW) than had been installed in the entire country during any previous year. The group observed that "The state more than tripled its wind capacity, and would rank sixth among the nations of the world in wind capacity if it were a country, based on one year's development alone."

Second, unlike most other states, Texas does not directly subsidize the purchase of wind turbines, photovoltaic panels or any other renewable-powered generating equipment. Instead, the Texas approach has been to assure renewable energy developers that they will have a market once they get their hardware up and running. But the developers have to find their own road to that market. And while the market as a whole is guaranteed, no individual's piece is. Developers have to compete among themselves for a share of that market.

The success of wind power in Texas is attributable to three specific factors: a firm and specific legislative goal for renewable energy, a federal renewable energy production tax credit, and – most important of all – aggressive efforts by the wind power industry to reduce its costs of production, as shown previously in Figure 2. These three factors have converged to put wind power developers within profitable striking range of a large market, a significant piece of which is guaranteed until 2019. (Authorized under PURA §35.904, P.U.C. SUBST. R. 25.173 requires retail electric providers to maintain a renewable portfolio standard until 2019.)

State policy should encourage the fuel cell industry to follow the example of the wind power industry: a model that relies on entrepreneurial effort and competition.

However, the state should not simply clone the SB 7 goal for renewable energy and apply it to fuel cells. This would be a recipe for failure. It would also be a misunderstanding of the most important lesson of wind power's success: the greatest results tend to occur when entrepreneurial effort and public policy meet each other halfway. The wind power industry reduced its costs, and public policy helped span the rest of the economic gap. This expectation must be built into the state's fuel cell policy.

One should be mindful of two facts. First, the success of public policy toward renewable energy in Texas has been limited to wind power; technologies that remain costly have not shared in that success. Second, nowhere did wind power enjoy more success in 2001 than it did in the policy environment found in Texas. In other words, the particulars of the state's policy prescription were well-suited to the circumstances of one renewable technology, but not all of them.

The success of wind power provides insight into fundamental policy principles that are applicable to fuel cells, but by no means do these lessons validate using the same program design. The details of what has worked for wind power are not suited to fuel cells, just as a medical treatment that cures one illness may not work against another disease that has similar symptoms but different causes. A fitting policy prescription for fuel cells needs to take into account where the industry is today on its own cost reduction curve. It took the wind power industry many years to turn government-funded research and development into reduced production costs. The current level of federal funding for fuel cell R&D will also require time to

continued on page 22

fuel cells

continued from page 21

mature economically. The best way for Texas to help hasten the industry's progress down the cost curve is to offer incentives that reflect the expectation that costs will fall over time and that offer the greatest rewards to entrepreneurs who do the best job of reducing their costs.

Market Principles

In order to be consistent with the new world, state fuel cell policy should recognize the following principles.

• There can be no sustainable commercialization without entrepreneurial effort.

Good technology and good business strategies are two different things and both are necessary for the widespread economic deployment of fuel cells. Without entrepreneurial innovation, good technology will remain a high-priced novelty.

• Entrepreneurs respond to market-pull incentives. If there is a profit potential, entrepreneurs will find ways to permanently reduce costs and improve services so that they can reach their target market and expand it over time. "Market-pull" incentives are those that improve an investment's anticipated profit stream.

• Incentives should reward entrepreneurs who do the best job of bringing products to market. Competition among entrepreneurs accelerates innovation. If the greatest rewards go to those who get to the market first, then each entrepreneur will put forth a greater effort to be first.

• Incentives should not subsidize unused equipment. Capital equipment does not produce benefits either for the purchaser or for the economy at large if it is not put to use. Equipment subsidized at the time of purchase allows developers to go home before the job is done; they're no longer "on the hook" to make sure their products replace conventional generation.

• Incentives should not subsidize overpriced equipment. If a good idea is executed inefficiently, the inefficiency should not be rewarded. A program that merely offsets economic dead weight will not stimulate long-term commercialization.

• Commercialization must be consistent with electric restructuring in all respects.

In the new world, regulated electric utilities do not own or dispatch generation. A fuel cell commercialization program that contemplates "electric utilities" in the traditional sense would therefore be inapplicable and irrelevant in Houston, Dallas and Fort Worth – the state's biggest potential markets for fuel cells.

Year	FCDG Goal (MW)	Small-Scale Goal (MW)	Total
January 1, 2004	37.5	12.5	50
January 1, 2005	150	50	200
January 1, 2006	300	100	400
January 1, 2007	450	150	600
January 1, 2008	600	200	800
January 1, 2009	750	250	1,000

Policy Outline

The commission recommends that state fuel cell policy include the following elements:

a) Goals for Stationary Fuel Cells

1) 750 MW of FCDG capacity and 250 MW of small-scale capacity by January 1, 2009 with annual intermediate goals10:

2) If any intermediate goal is exceeded, the incentive level for that category that year would be reduced. For example, if by the beginning of 2005 the state had anywhere between 100 and 150 MW of small-scale capacity successfully installed, the buy-down for additional fuel cells installed in 2005 would be set at the 2006 level, which would be less. (Section (c) describes the proposed buy down.)

b) Fuel Cell Distributed Generation Production Incentive

1) The incentive would be paid to FCDG owners based on the gross kWh of metered output. The incentive would be paid for a period of ten consecutive years at the rate in effect for the first year of the payment period.

2) The incentive rate for 2004 was

determined by the commission on the basis of three inputs: cost of a typical fuel cell, 2003 price to beat for general service customers (weighted average of all affiliated REPs), and available federal production incentives, all expressed in cents per kWh. initial incentive rate = average market cost – price to beat – federal incentives.

3) The incentive rate for new installations would decline in equal increments each year after 2004, reaching zero in 2010.

4) Fuel cells earning the production incentive described in this section would not be eligible for buy-down incentive described in section (c).

c) Fuel Cell Buy-Down Incentive for Small-Scale Applications

1) The buy-down incentive would be paid to fuel cell owners at the time the unit was activated, based on the rated capacity of the unit (in kW).

2) The buy-down incentive rate for 2004 was determined by the commission on the basis of three inputs: cost of a typical fuel cell, 2003 price to beat for residential customers (weighted average of all affiliated REPs), and available federal production incentives, all expressed in dollars per kW.

3) The incentive rate would decline in equal increments each year after 2004, reaching zero in 2010.

4) Fuel cells that earned the buy-down incentive described in this section would not be eligible for the production incentive described in section (b).

d) Funding options

Fuel cell commercialization involves changing the behavior of generators, retailers and customers in the electric sector. Therefore, it is appropriate that incentive programs intended to change behavior within the sector be funded from economic activity within that sector, and that the funding be structured in such a way that it augments the public policy goal. Aside from the agency resources needed to put them in place, the alternatives suggested here would not require any commitment of state general revenues.

1) Emission-based dispatch fee. Each generating plant in the state would be assessed for each MWh delivered to its transmission grid. The assessment rate would be graduated according to the plant's NOx emission rate (pounds per MWh) using the following formula plant assessment rate = plant NOx emission rate ? statewide annual coefficient

The statewide annual coefficient would be adjusted each year so that total projected revenues would equal actual expenses under the incentive programs during the previous year. Current-year expenses under the incentive programs would be paid under state general revenues, to be reimbursed the following year by revenues from the dispatch fee.

Advantages: Would leverage the policy objective of encouraging fuel cell development. A generator that replaced high-NOx capacity with low-NOx fuel cells would both earn the production incentive and reduce the cost of the fee.

Annual adjustment would eliminate waste, ensuring that funding was never in excess of what was required. Assessment at the generator level enables the behavior-changing effects to flow throughout the market: retailers would have a greater incentive to buy from low-NOx suppliers, and customers would have a greater incentive to sign up with retailers who bought from low-NOx suppliers.

Disadvantage: Would exclude nuclear plants and hydroelectric plants.

2) Flat-rate dispatch fee. Per-MWh assessment would be at the same rate for all generators, and would be set each year so that total projected revenues would equal actual expenses during the previous year. Generators who installed fuel cells would receive a credit on the fee based on the amount of fuel cell capacity installed and operated, partially offsetting the cost of the dispatch fee.

Advantages: Similar to emission-based assessment, but would include nuclear and hydroelectric plants in the assessment.

Disadvantage: Price signal would not be as broad as with emission-based assessment, but would be limited to installation of fuel cells.

3) System Benefit Fund. Customers would be assessed the cost of the program on a per-kWh basis through the non-bypassable SBF fee.

Advantages: Similar to how some other states fund fuel cell programs.

Mechanism already exists.

Disadvantages: Would remove all program burden from generators (they would not be paying any program costs) and would place it entirely on customers.

Generators would therefore have less direct financial incentive to adopt fuel cell technology. Would require an increase in the SBF fee.

4) Emission reduction credits (ERCs). Generators and customers who install fuel cells and can document the offset of conventional generation would earn ERCs that could then be sold.

Advantage: Would link incentives to the market value of emission reduction, which is the main public benefit of fuel cells.

Disadvantages: Would be limited to areas where emission credits are used. EPA and TCEQ have not yet worked out a method of awarding ERCs for indirect emission reductions. Would require a different incentive structure than what is proposed here. Incentives would have no fixed value because they would vary according to the value of ERCs, making it difficult for a prospective purchaser to accurately assess the costs and benefits of buying a fuel cell.

5) Redirect transmission congestion charges. Revenues collected by ERCOT for congestion management would be set aside for fuel cell incentives, rather than being redistributed on a load-share basis as is done now.

Advantages: Leverages the distributed generation benefits of fuel cells by sending location-appropriate price signals. Higher incentives would be paid to fuel cells installed at transmission-constrained locations.

Disadvantages: Computationally complex, and would be affected by how transmission congestion costs are assigned. Would require a different incentive structure than what is proposed here. Would not work in non-ERCOT portions of Texas where there is no direct assignment of local congestion costs.

These general elements form a cohesive policy strategy in which the fiscal mechanism leverages the policy objective. On all other details, the Commission makes no recommendation.

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was recommended that a redesign of this part be undertaken. The transformer was subsequently scheduled for winding replacement, as the present Degree of Polymerization (DP) of the paper insulation material indicated relatively poor insulation condition.

TRANSFORMER C

Following a factory refurbishment, this transformer was commissioned on site. After one week back in service, the True Gas Analyzer initiated an alarm, based on rising Acetylene gas in the oil in the transformer. See Table 1.

The transformer was removed from service within twelve hours of the fault detection, drained of oil and visually inspected.

The source of gas production was traced to a bad earth connection from a corona ring shielding the high-voltage turret main-tank flange. The earthing strap to the corona ring was not properly connected – some solid insulating material having being caught between the earth strap connector and the earth connection on the transformer tank (Figure 5).

Intermittent earthing was offered by the fastening bolt – which was severely spark eroded - causing a transient potential rise and subsequent discharges occurring between the corona ring and the main tank earth point, resulting in the production of Acetylene gas in the oil.

An on-site repair was effected and the transformer returned to healthy service.

Figure 5: Transformer C - HV Corona Ring Shield Earth Connection (note burn mark on corona ring material)

TimeStamp	Hydrogen	Methane	CarbMono	CarbDiox	Ethane	Ethylene	Acetylene
29/10/2003 12:00	<10	<50	61.50	245.00	<10	<7	<5
29/10/2003 16:00	<10	<50	63.20	253.50	<10	<7	<5
29/10/2003 20:00	<10	<50	63.90	261.10	<10	<7	<5
30/10/2003 00:00	<10	<50	65.30	275.90	<10	<7	<5
30/10/2003 04:00	<10	<50	67.70	280.60	<10	<7	<5
30/10/2003 08:00	<10	<50	68.80	282.70	<10	<7	<5
30/10/2003 12:00	<10	<50	70.50	285.20	<10	<7	<5
30/10/2003 16:00	<10	<50	72.30	289.10	<10	<7	<5
30/10/2003 20:00	<10	<50	73.20	304.10	<10	<7	<5
31/10/2003 00:00	<10	<50	74.50	315.20	<10	<7	<5
31/10/2003 04:00	<10	<50	74.90	323.50	<10	<7	<5
31/10/2003 08:00	<10	<50	77.50	325.40	<10	<7	<5
31/10/2003 12:00	10.90	<50	79.60	326.00	<10	<7	5.60
31/10/2003 16:00	16.60	<50	81.30	332.40	<10	<7	8.40
31/10/2003 20:00	22.70	<50	81.60	339.00	<10	<7	14.10
01/11/2003 00:00	35.10	<50	83.10	355.30	<10	<7	23.80
01/11/2003 04:00	56.10	<50	86.50	353.30	<10	<7	36.90
01/11/2003 08:00	76.70	<50	88.00	349.40	<10	7.20	50.50
01/11/2003 12:00	90.40	<50	88.20	345.80	<10	9.20	62.60

Table 1: True Gas Data for Transformer (all values are in ppm)

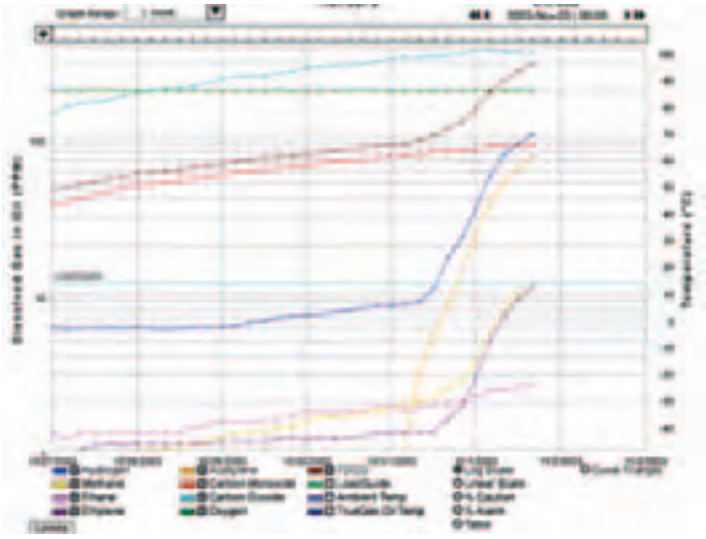

Fig 5A: One-Week Profile of Gases (note sudden acetylene increase)

5. CONCLUSIONS

Eskom has successfully identified these transformers as being faulty during service, using the True Gas on-line dissolved gas analyzer. These particular transformers were allowed to safely function under strictly controlled conditions, by being "nursed" to a planned intervention.

In two of the cases, overheating low-voltage winding leads and connections were responsible for the production of Hydrogen, Methane, Ethylene and Ethane, while Acetylene was the primary indicator of the sparking condition in the third example. In both these examples, the fault condition may have escalated to a catastrophic failure – with dire consequences.

Without the True Gas Analyzer on Transformer C, the situation may have gone unnoticed - until the next oil sample and laboratory analysis (ie. 6 months time). A stream of gas bubbles emerging from the discharge site could have caused the total breach of the insulating path between the HV exit lead and the tank wall, with catastrophic consequences. Fortunately, in this instance, a relatively quick on-site repair was possible – and the transformer returned to service with minimal production loss to Eskom.

The utilization of on-line dissolved gas analysis will allow Eskom to continuously monitor its fleet of Generator transformers, leading to early detection of developing problems and providing an opportunity for safe de-loading of the transformers until a repair outage can be scheduled.

MONTREAL READY FOR PES GENERAL MEETING

By Don Horne

The Power Engineering Society is holding its 2006 General Meeting June 18-22 at the Palais des congres in Montreal, Quebec. The conference, with its theme Inno vation and Rein vestment in Po wer Infrastructure, will address polic y, infrastructure and workforce issues.

Colleagues will have the opportunity to participate in man y high-quality technical sessions and tours, committee meetings, networking opportunities and more. There will also be special student events and activities planned throughout the week.

The General Membership Meeting will be June 19 at 8 a.m. in the Palais des congres. IEEE Power Engineering Society 2006-2007 President John McDonald will provide an o verview of PES challenges and accomplishments of 2005 and discuss the Society' s objectives and agenda for 2006 and beyond. Additionally, candidates for the newly-created position of IEEE Division VII-Elect will each have five minutes to present their platform.

An open Question & Answer session will allow members to ask President McDonald and other Go verning Board members to discuss specific issues.

That evening there will be an opportunity to speak with the Di vision VII-Elect candidates indi vidually during a reception that will be held in conjunction with the Poster Session. It is an excellent opportunity to discuss the future of PES and the IEEE.

The Plenary Session immediately follows the General Membership Meeting at 9 a.m. A group of notable, highly-respected speakers will address topics of major concern in the po wer engineering world from various perspectives.

Technical panel and paper sessions are scheduled each day of the conference, from June 19 through 22, with

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PES general meeting

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some committee meetings scheduled the week end before on June 17, 18.

There will be a variety of awards activities during the General Meeting. Here are two of the highlights:

- IEEE Fellows Reception

Please stop by to congratulate IEEE Fellows who were elected to the Class of 2006. A reception will be held in conjunction with the Poster Session the evening of June 19.

- Awards Luncheon

The Awards Luncheon will be held from noon until 2 p.m. on June 20 where IEEE and PES award winners are honored for their outstanding achievements.

This year will feature several special sessions including a Cyber Security Panel Session moderated by Richard T. Lord, Chief Executive Officer of The Steadfast Group. The interest in this session is well reflected by the numerous panelists that will be on hand to discuss and answer questions. Included in the session are:

- Jerrod Moll, Engineer II - Transmission Automation & Fault Analysis Transmission Interconnections & Operations, Alabama Power;
- Jamie Carmichael, IT Security Administrator, Subnet Solutions;
- Martin Ferland, IT Security Coordinator, Hydro-Québec TransÉnergie;
- Joe Weiss, Executive Consultant, KEMA, Inc. (KEMA's leading expert on control system cyber security);
- Ron Farquharson, Product Segment Manager, Network Reliability Product & Services, General Electric Canada Inc.;
- Alex Apostolov, Market Segment Leader and Principal Application Engineer, AREVA T&D;
- Jim Hammond, Consultant, Garrettcom, Inc.;
- Joe Gould, U.S. Director of Sales, RuggedCom, Inc.;
- Robert Kirkaldie, Director of Sales & Marketing, Southwest Microwave, Inc.;
- Mario Bisanti, President, Bisanti & Associates;
- Gary Sevounts, Director of Power and Energy Strategies and Solutions for Symantec Corporation.

The Palais des congres in Montreal, Quebec.

DALLAS CONFERENCE A SUCCESS

The 2005/2006 IEEE PES Transmission and Distribution Conference and Exposition in Dallas, Texas had something to offer the power-delivery professional from every aspect of the industry.

The conference was an excellent opportunity to speak with chief executives, engineering and operating vice presidents, distribution engineers, transmission engineers, maintenance engineers, relay engineers, control engineers, communi-

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PES general meeting

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