A Short, but Representative, ‘Perspective Piece’ on Industry Uptake of ‘Near 50 Hz’ PD Testing Internationally

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Preamble:
When assessing what might at first appear to be a “new technology” in the power industry, it is reasonable of any client to seek a degree of evidence of its established provenance offshore and in the application to which it is intended to be applied in the 'local' context.

When that ‘new technology’ is in fact well established offshore but new to the local market, one must consider the question as to what would constitute a suitable level of information to inform, address, and allay in reasonable fashion any uncertainties or questions as to the suitability of the technology for the intended application and also the quality of its said provenance. Clearly, no technology will ever hold 100% of the market or technical opinion but it would be a fair observation that evidence of widespread uptake over a longer term, coupled with a selection of technical papers that all concur on the technical quality and advantages of the technology over alternative or conventionally-deployed solutions, should be deemed to be a tipping point to allow that technology’s confident and optimistic deployment locally.

The purpose of this paper is to convey the background, deployment level, international uptake, and technical evidence enough to allow one to embrace with confidence the ‘near 50Hz’ partial discharge cable diagnostic testing technology applied to both new and in-service condition assessment of one's 11-33 kV cable population.

Background to the Technology:
The ‘near 50Hz’ cable diagnostic technology has its origins back in 1980s with Seba KMT in Germany who produced the first patented commercial such equipment in 2004. Seba acquired several European based cable testing equipment companies and built up one of the world’s largest centres of research and expertise in cable management technology. Seba KMT was purchased by Megger Ltd in 2012 and Megger has since expanded the former Seba KMT operation, capabilities, and technologies worldwide.

The ‘near 50 Hz PD’ cable diagnostic technology was first delivered to the New Zealand power distribution industry, EDB’s, generation industry, private networks, and contractors, by AVO New Zealand in October 2017 and demonstrated to the market in January 2018. Since that time the technology has been featured at the June 2018 EEA event, the August 2018 AVO NZ International Technical Conference, and attracted very strong interest from all sectors, including the Regulator. The appeal here is the ability of the technology to conduct (for the first time ever) formal, planned, and comprehensive surveys and risk management of the entire 11-33 kV cable population in New Zealand, an endeavour that has not previously been practicable. Its ease of use and its cost-effective application to the task has commended its market acceptance in both New Zealand and, indeed, worldwide.

Currently, the total sales of ‘near 50 Hz’ cable diagnostic equipment worldwide since 2004 has exceeded 1000 pcs and growing rapidly.

International Uptake Status of ‘Near 50Hz PD’ Cable Diagnostic Technology:
Perhaps the best illustration of the argument for the near-term uptake of the technology in New Zealand is by virtue of its now being in preferred use for 11-33 kV cable diagnostic work in the vast majority of mature first world countries, including:
- Netherlands
- Germany
- Spain
- Italy
- Belgium
- Czech Republic
- Slovak Republic
- Romania
- Hungary
- Russia
- Finland
- Poland
- Singapore
- Malaysia
- Indonesia

The latter 3 countries have integrated near 50 Hz PD testing into their cable testing standards.

Emerging markets taking up the technology include:
- Kenya
- Tanzania
- China
- UAE
- Cambodia
- USA
- UK
- New Zealand (1 set sold to date to WEL Networks. It has been approved for use on the Wellington Electricity (WELL) network, and by Transpower. Several more networks are pending their approval after assessment and multiple EDB and Industrial sites have already sought a ‘near 50 Hz PD’ contracted service. 3 contractors to date have registered their confidence in the technology and their willingness to take the service to the NZ market.
- Australia (behind NZ but interest quickly building. Notably, Ausnet Melbourne has recently reported excellent success with the ‘near 50 Hz PD’ Damped AC (‘DAC’) cable diagnostic technology on their in-service HV cables over the past 10+ years!)

Selected Papers to illustrate the Advantages of ‘Near 50Hz PD’ Cable Diagnostic Technology over VLF 0.1 Hz sinus PD Testing:

Early perspectives:
In his thesis published in 2003, Professor Dr. Gunter Voigt (paper available upon request) of The Hochschule Konstanz, (a German university located in Konstanz, Baden-Württemberg, Germany) published a study of findings of other authors. Page 13 Section 2.3.8 complies the findings of some 7 authors on the observation that the PD inception voltage at 50Hz has always been lower than the figure obtained by using VLF sinus equipment. The ranges of that difference are as much as 0.5 times the PDIV at 0.1 Hz. In other words, the sinus 0.1 Hz approach was found to under-represent the severity of the PD problem in each case. The authors cited in the table are also well known for their strong
research in this matter: Ref 13: Pepper and Kalkner; Ref 14: Muhe, Sumereder; Ref 15: Pepper and Kalkner; Ref 18: Colloca et al; Ref 19: Gockenbach Hauschild; Ref 20: Voight, Mohaupt; Ref 21: Voight.

Indeed, in another of his papers from the same year (May 2003): “Partial Discharge Measurements on service aged Medium Voltage cables at different frequencies” by Gunter Voigt, University of Applied Sciences, Konstanz, Germany and Peter Mohaupt, BAUR Prüf- und Messtechnik, Sulz, Austria, Voigt concluded: “Experimental results on service aged cable show that the inception voltage at VLF is slightly higher [in fact 33%!] compared with 50 Hz tests and the number of discharges may be significantly less.”

A pivotal early paper to show the advantage (over 0.1 Hz sinus VLF) of conducting field-based HV cable diagnostics at the IEC ‘Power Frequency’ range of 30-500Hz, was published in 2004 (VWEW Info day seminar, 2004…see ‘Difference PDIV between 50hz and 0.1 Hz’, a paper also available on request) by E-On [a very large European utility company with approx. 120 billion annual revenue at that time and 35 million customers in EU]. E-On commissioned a comparative test of sinus 0.1 Hz PD testing, and 50 Hz testing. The results showed a marked dependence on the rate of change of test voltage (dU/dt) on the PD inception voltage (PDIV) and PD parameters in general. The results of this test showed that PD behaviour was highly dependent on voltage gradient over time…the lower the rate of change of voltage, the lower the PD activity. The matter was particularly sensitive in layered interfaces (accessories…joints and terminations) because of surface discharges/tracking/interfacial discharges. See Megger IEEE T&D paper attached which summarises this work.

The above findings were supported by various scientific publications that followed, a significant one being: N. Jäverberg, H. Edin: “Applied Voltage Frequency Dependence of Partial Discharges in Electrical Trees”, Proc. IR-EE-ETK, Stockholm, Sweden, 2009 (paper on request….see 4.Conclusion, highlighted). This again determined that PD extinguishes at very slow dU/dt and that waveforms in the IEC power frequency range (30-500 Hz) were strongly preferred for PD field testing.

More Recent Perspectives:

A large number of papers now exist to echo the above findings. By way of illustrating a consistent impression of the advantages of ‘near 50 Hz PD’ only, we refer to the following papers:

a) In June 2012 a paper: “Condition Assessment of Wind Farm Medium Voltage Cable Joints” was published by Hans Lavoll Halvorson of the Norwegian University of Science and Technology (Department of Electric Power Engineering) Norway. His findings included the important observation: “…At early stages of aging the PD signals totally disappeared at frequencies below 10 Hz… This means that signs of aging are not visible at lower frequencies unless sufficiently high voltage is used. This could lead to a wrong diagnosis of cable systems tested only with VLF methods…”

b) In their August 24, 2014 paper: “PD and Dielectric. Response Measurements on Service Aged Cable Joints” by Frank Mauseth, Håkon Tollefsen, NTNU [Norwegian University of Science and Technology] and Sverre Hvidsten, SINTEF Energy Research, they also observed that the PD Inception voltage
(PDIV) was dependent on the applied test frequency. They also noted that sinus 0.1 Hz VLF could indicate areas of issue that were not seen at 50Hz which further cast doubt on the ability of an asset owner to trust the information received from a 0.1 Hz sinus VLF PD test.

c) In their paper of July 2017: "Effect of Applied Voltage Frequency of Partial Discharge in XLPE Cable Insulation" by Alhamadi, Malik, Al-Arainy, and Wani of King Saud University (KSU), College of Engineering, Department of Electrical Engineering, Riyadh, Kingdom of Saudi Arabia, they concluded also: “This paper presents an experimental investigation to determine the relation between the test voltage frequency and the behaviour of PD parameters using offline PD testing. The results show that there are some clear differences in the PD characteristics when tested using 60 Hz voltage and VLF voltage of 0.1 Hz”. Again, this finding casts doubt and uncertainty on the reliability of sinus 0.1 Hz VLF PD data in making a condition assessment of cable.

d) In their Sept 2017 paper (attached) based on known reports and papers prior: "Excitation Voltages for Partial Discharge Diagnostics on Medium Voltage Distribution Cables", by Probst, Putter, Petzold, Legler, of Megger USA and Germany outlined 3 case studies. Their conclusion included the following: “...sinusoidal VLF test sets are susceptible to incorrect measurements of PDIV and have repeatedly shown representations of PD rate, PD intensity and PD mapping not comparable to DAC or 50/60 Hz power frequency. This is due to the very slow voltage gradient / rate of change of voltage dU/dt in the region of the zero crossing. These limitations (...of VLF sinus PD test sets...) pose a significant problem for correct condition assessment and monitoring of the cable’s accessories and therefore for precise and confident decision making”. Their case studies include:

   a. ENSO Energie Sachsen Ost—a German utility company in the federal state of Saxony servicing approximately 500,000 customers and earning a revenue of 1.1 billion € per year. In this test sinus VLD PD indicated a weaker and lower PD count than near 50 Hz methods and gave the incorrect impression of being a non-critical situation.

   b. ENRO Ludwigsfelde Energie—a small independent cooperative utility in the federal state of Brandenburg, Germany, servicing the local industrial parks including various factories of critical customers. In this test, whilst some VLF sinus test sites corroborated with DAC and CR near 50Hz methods, overall the sinus VLF PD testing failed to see some defective areas of the cable at all to 1.7Uo. It was clear in this test that sinus VLF PD again demonstrated an unreliable guide to PD risk and severity in HV XLPE cables.

e) The December 2017 paper: ‘Investigating the Effect of Frequency and Wave Shape of Voltage Source on Partial Discharge Behaviour within Cavity in Medium Voltage Cable’ by Gouda, El-Faraskopury, El-Sinary, and Farag (Egypt) their conclusions included the comments:

   • The PD activity in a power cable is dependent on the wave shape and frequency of the applied voltage as the PD level and the numbers of discharges vary with varying of them.
• "It is recommended using cosine-rectangular wave at starting of MV cable diagnosis process as the most of PDs events are ignited at the zone of change of its polarity(reversal); this is benefit in detecting of hidden defects..."

f) In the paper: ‘Comparison of Partial Discharge Measurement Using Different Alternative Voltage Sources on Medium Voltage Cable’ published in 2019 at the Cigre Study Committee B1-10/Cired at the 14th Conference of Slovenian Electrical Power Engineers, by Marko Stanonik, and Vili Bonča of Elektro Gorenjska d.d Slovenia. (paper on request referred to as ‘referat_B1-10’), the authors concluded: “It turned out that the most sensitive is the Slope method, the OWTS [Damped AC] method gives comparable results, while the results obtained with the VLF sin method deviate more.”

Summary and Observations as to Comparative Advantages of ‘Near 50 Hz’ HV Cable Diagnostic Testing by Comparison to VLF sinus Diagnostic Testing:

By way of summarising the above body of comment ranging from 2003 to the present day, one may confidently conclude:

a) PD assessments at a given voltage on an 11-33 kV cable are highly dependent on the rate of change of voltage, dU/dt, at working voltages likely to be encountered in normal operation (to 1.7Uo).

b) PD measurements on an 11-33 kV cable are very comparable in both pulse count and pC level between ‘near 50 Hz’ equipment (working in the 30-500Hz range) and 50 Hz test frequency.

c) Published evidence exits to illustrate that diagnostic PD testing done on 11-33 kV cable by VLF 0.1 Hz sinus test sources is unreliable in representing the true PD risk that one would encounter in real terms at the operating frequency of the cable at the same voltage.

d) The reasons for the latter important observation, as reported in the papers, include:

• VLF sinus PD has been noted to understate PDIV by as much as 50% or more of tests done at the normal operating frequency (or ‘near 50 Hz’) and especially when testing layered interfaces such as joints and terminations. Some papers have even reported that a reverse of this situation might even occasionally be possible, further complicating any ability to second guess the reality of the true PD situation without a comparable 50 Hz test done simultaneously.

• Such variations also apply to observed PD count and pC level for a given test voltage, exacerbating the above observation. Indeed, VLF sinus has been shown to generally significantly under-read on both these measures for a given test voltage below 1.7Uo, in some cases reported either completely missing certain key sites known to be of issue when assessed at 50Hz, or incorrectly indicating there to be no significant issue when in fact the converse was found to be the case when assessed at 50 Hz.

e) Adding to the observations above:

• For reasons of its consistent and trusted behaviour in representing the ‘50 Hz operating condition PD risk’, the ‘near 50 Hz PD’ diagnostic test methods for 11-33 kV cable have largely been embraced in most of the world over the past 16 years or so, and it is particularly the case through Europe, Middle East, and Asia.

• Over 1000 of the near 50 Hz PD testing sources have been taken up by the Industry over that period.

g) By corollary of the above observations, an asset owner presented with data only from 0.1 Hz sinus PD testing would not reasonably be able to accept such readings with confidence in assessing cable condition and in planning mitigations based upon such evidence. Arguably it would be hard to prove this observation anecdotally had evidence from prior work done not been presented in the likes of the representative material presented herein. It is agreed that a cable tested at 0.1 Hz sinus VLF PD might appear sound and might even go on working for a relatively short
period of years but eventually fail and there would potentially be no supporting historical evidence for this occurrence from the earlier 0.1 Hz sinus tests. In reality, had the testing been done at the outset with ‘near 50Hz PD’, the true condition of the cable asset would have been evident at that time and the asset owner might well have taken a decision to intervene in a more informed manner ahead of such a failure actually arising. Drawing from the anecdotes there would be few cable asset managers that, given the choice and technology being realistically available, would deny themselves the best possible appraisal of a pending risk or the actual asset condition.

**Recommendations and Concluding Observations for Deploying ‘Near 50 Hz’ HV Cable Diagnostic Testing:**

Having illustrated above the outstanding merits of a ‘near 50 Hz’ approach to diagnostic HV cable testing, it is a fitting moment to speak briefly as to the application of this technology to the task.

We have spoken of two waveform types commonly used for the purpose, ‘DAC’ [damped AC, a decaying AC pulse of 5-7 cycles with a frequency component of 30-500 Hz nominally to IEEE400.4] and ‘CR’ [Cosine Rectangular VLF continuous waveform, having essentially an identical frequency composition as the DAC]. Both waveforms, when applied to an ‘in service’ HV cable, will result in comparable Partial Discharge patterns (amplitude in pC, and pulse count), also being reflective of the results that would be identified in a 50Hz operating environment but with the advantage that both DAC and CR can be generated from a much more compact and lower cost test set than an off-line 50Hz source.

Typically, for in service cables one would apply a DAC waveform for diagnostic purposes, testing between 0.5Uo, Uo, and up to 1.7Uo. Where one encounters wet joints, CR offers an advantage of ‘drying out’ the joints prior to PD testing.

This technique typically allows diagnostic PD testing of XLPE cable of up to 6-8km, and PILC cables of up to 3km. Longer cables would be tested by measuring from each end.

For commissioning new HV cables, the Industry still calls for a continuous over pressure test for a period of time. These levels of test are determined by IEC 60502-2 and IEEE 400.2. One has the choice of applying a VLF pressure test for up to 60 mins then immediately following it with DAC testing or to combine the VLF test with a ‘monitored PD withstand test’ using the CR waveform. The CR waveform is suited to this but DAC is not, by virtue of it not being a continuous stress test. The Industry internationally has widely embraced the ‘monitored PD withstand testing’ using CR, finding it to also be very time-efficient. Indeed, savings in time of well over 30 minutes per cable are enjoyed, allowing a significantly greater productivity of diagnostic testing in the day and a reduced per cable testing cost.

**So, for an optimal cost-and-time-effective outcome in performing diagnostic ‘near 50 Hz’ testing for HV cables both in-service and under acceptance/commission, one is advised to specify (or seek from your contractor) the use of a test set that offers both CR and DAC waveforms.**

By way of a final observation, a comprehensive diagnostic testing of in-service HV cables only also requires a VLF Tan Delta test, the results ideally being presented along with the stated recommendations from IEEE400.2. For such cables, one should specify this test in conjunction with the near 50 Hz PD diagnostic testing.

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TREVOR LORD, AVO New Zealand and LORD Consulting: Trevor Lord is Managing Director of both LORD Consulting (a respected power systems asset management consulting company trading internationally) and AVO New Zealand (New Zealand’s leading supplier of power testing, measurement, and monitoring equipment and training). A third generation in his family to be involved in the Industry, he holds a Master’s Degree in Electrical and Electronic Engineering from the University of Canterbury, NZ. He was a co-founder of Cigre New Zealand, and has worked with the power and electrical Industries for 41 years in a wide variety of roles. As a passionate advocate for his work in both LV ‘testing for safety’, and in the wider field of power systems asset management, he has earned the respect of the Industry internationally as a true ‘mover and shaker’. He is known and respected for his efforts to support this vision via engineering expertise, training, and information programmes, and particularly his implementation of innovative and strategically-focussed technical solutions for Industry reliability and performance problems, and his regular industry Conferences and newsletters aimed at raising and unifying the level of best practice. He brings a wealth of practical knowledge and experience to the critical important emerging field of on-line monitoring of electrical network assets and holds two patents in asset management areas.