

ONLINE TRANSFORMER BUSHING MONITORING

Traditional offline testing techniques have proven to be very effective in detecting and identifying defects that involve *slow* diffusion of moisture and air, *slow* accumulation of particles and oil aging products, and the occurrence of faults that can develop over *many years*. This is not the case when defects rapidly progress over months or weeks. Beside the obvious economic benefits of online diagnostics, online monitoring of HV bushings and current transformers permits the user to significantly improve the capability to detect more problems with apparatus at an earlier stage of development. ZTZ Services pioneered the online bushing monitor nearly 40 years ago. This makes ZTZ the most experienced provider with the most highly refined system for detecting failure modes in Bushings, CCVTs, CT, and GIS-AIS transitions.

WHY?

TRANSFORMER MONITORING SYSTEMS FOCUSED ON THE BUSHINGS IS THE PRIMARY BUSINESS OF ZTZ SERVICES - A SPECIALIST ENTERPRISE NEARING FOUR DECADES OF EXPERIENCE.



One detection method will not catch all failures. However, irrespective of different diagnostic responses of defective units, relative PF ratio at operating voltage has been successful in practically all typical cases of developing failure.

An online method is required because of the erratic and sometimes rapid nature of HVCT and bushing failures.

For instance, at 10% of rated voltage, the PF of two bushings is practically the same. That means that an offline Power Factor test will not show any defect in the bushings. With the increase of applied voltage, the PF of the defective bushing rapidly grows. The higher applied voltage reflects in higher PF magnitude.

Online measuring exploits the advantages of PF testing under *real operating conditions* (at rated voltage, at variable operating temperature). These advantages include the ability to record the changes of PF with temperature, with voltage, with time, as well as correlation between PF, capacitance, sum current, and leakage current – in the case of an internal fault involving short-circuits between layers.

ZTZ engineers took this capability to the next level in 1990 with two new test methods, then a third in 2012 and fourth in 2018:

1. The External Reference Method
2. Direct Method using PT as external reference voltage source
3. CCVT Poly-Phasor Method
4. GIC Disturbance Method

Online Transformer Bushing Monitoring, But from Who?

A good and reliable system has some stringent requirements.

1. The bushing sensor (sometimes called a tap-adapter) must be designed as a perfect replacement for the OEM grounding cover. From the mechanical perspective, the threads, thread depth, material, sealing surfaces, sealing gasket and interface to the flexible conduit must all be considered and be built without blemish.
2. From the electrical perspective, the connection and interface to the C1 connection prong must be flawless, as close to the OEM grounding cover design as possible. The material for the tang must be considered for the lowest contact resistance, compatibility with the prong metal, corrosion resistance and temper stability, for a firm reliable grip on the prong for the life of the system.
3. From the safety perspective, the bushing sensor must limit the voltage potential output to a safe level in case of contact with personnel from accidental damage of cabling. This limiting circuitry must be located within the bushing sensor, built with the finest electronic parts, and be twice redundant.
4. From the overall reliability perspective, all unnecessary removeable electrical connectors must be deleted. The bushing sensor cable must be continuous from the sensor internal circuitry all the way to the shorting switches in the monitor cabinet.
5. The installation of the sensors to the bushings – there can be 3, 6, 9, or even 12 sensors per transformer, must be done by experienced field personnel. Extreme care must be exercised when working with older bushings to avoid any damage to them and to ensure a perfect weather-tight seal is attained for each sensor. Turnkey installation by trained and experienced field engineers is the best way to ensure long-term reliability with all the other requirements being met.

These guidelines for quality are only just the beginning. There are many other nuances which come from our experience that is nearing four decades. Only ZTZ Services can offer this.



Experience With Online Tests of HV CTs and Bushings

In 1989, the experience of more than 1,000 units of 330 kV and 750 kV CTs in Europe proved the method to be very successful.

In one utility, 43 defective units were identified. In another, 14 violent failures were prevented during the period 1990-1999.

The availability of monitored data recorded during the maximum temperature of the HVCT in summer enabled the detection of many defective units having symptoms of dielectric overheating, presumably due to excessive aging of oil-paper bulk.

Alabama Power Philosophy for Condition Based Maintenance

Alabama Power made a decision to go with online monitoring of transformer bushings based on the then 25-year experience of ZTZ Services. The proven ZTZ monitoring system requires the installation of sensors to the bushing capacitor taps.

One of the most important features of the ZTZ system is the design integrity of the bushing sensors and how the sensor maintains personnel safety while maintaining the ground connection of the capacitor tap.

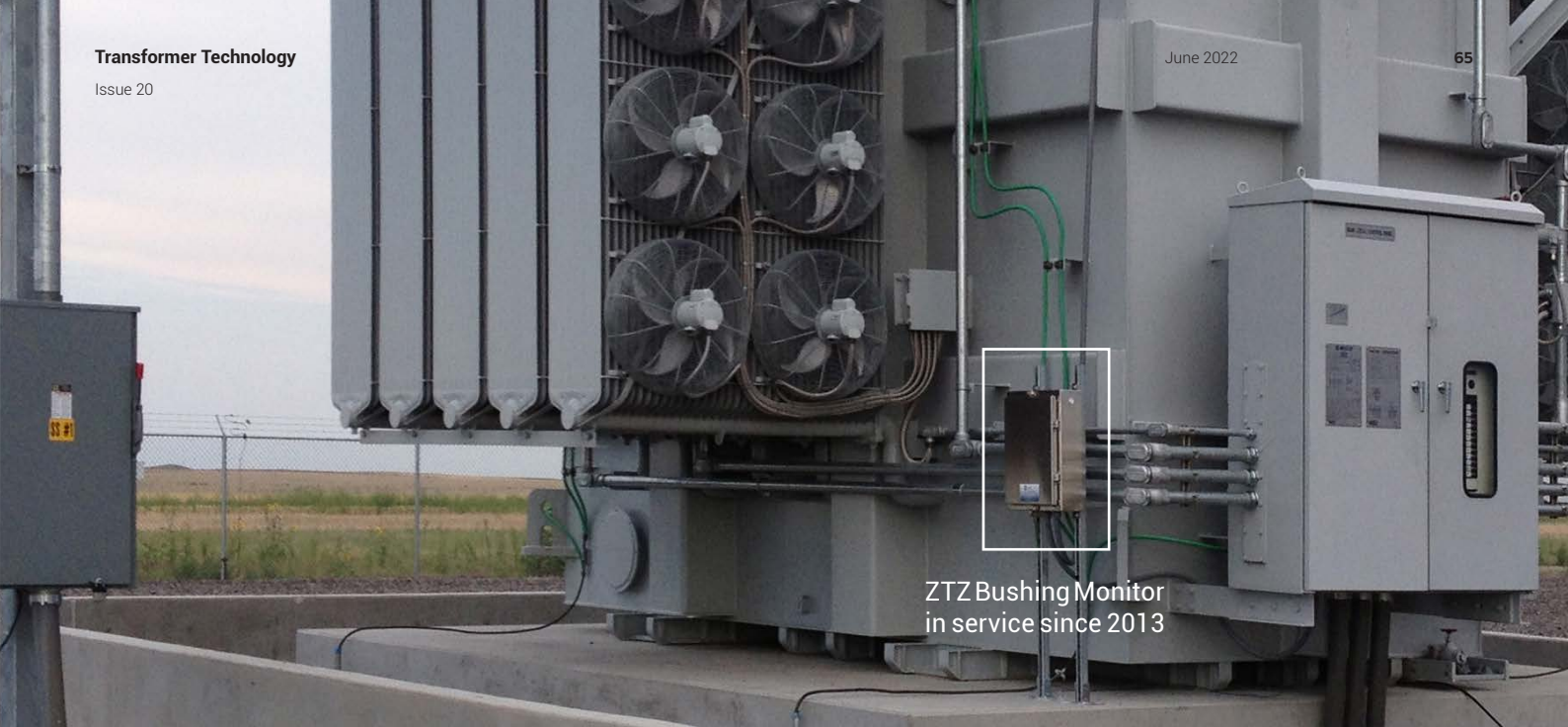
Budget cuts and manpower reductions during the 1980s did not change the need for providing reliable service. There was a need to reduce the number of outages due to failure or planned outages for offline testing.

Alabama Power moved from all time-based maintenance to condition assessment using the ZTZ Services bushing monitor but also applied to CCVTs and PTs. Alabama Power has installed ZTZ monitors on transformers ranging in size from 115/12 kV, 230/115 kV 250 MVA to 500/230 kV 400 MVA auto banks. More than 600 ZTZ monitoring systems are in service at the three operating companies of Southern Company.

The online bushing test data combined with DGA of both the main tank and LTC compartment has allowed Alabama Power to move from a six-year maintenance interval to strictly condition based interval, possibly as long as ten to twelve years.

As mentioned above, the ZTZ system allows for online monitoring of CCVTs and Potential Transformers. Offline testing of this equipment often requires a bus outage with manpower involved in switching and disconnecting.

In the first three years, Alabama Power found two CCVTs that were in the failure mode. The benefit of finding these two before failure greatly outweighed the initial cost of the equipment. The last CCVT failure on APCo property cost \$250,000 (\$750,000 in 2022 dollars) just for PCB cleanup, in addition to loss of revenue caused by additional equipment damage.



ZTZ Bushing Monitor in service since 2013

30+ Years Onward

With more than 5,000 transformer bushing monitors in service, ZTZ Services is the most experienced supplier, having achieved an unmatched level of refinement, including a lifetime warranty. There has never been a reported false alarm by a ZTZ Bushing Monitor. Used ZTZ systems are never found on eBay™ as are the competitors', which is a testament to the long useful life of ZTZ monitoring systems and high customer satisfaction.

ZTZ Services has become very popular with renewables operators. The problems they face with transformers are similar to those faced by investor-owned utilities (IOU). However, whereas IOUs can tolerate an occasional transformer failure by switching the network around, a renewable operator is in trouble. There is usually no replacement nearby and every sunny day means hundreds of thousands of dollars in lost revenue while waiting for the new transformer to arrive.

At \$100 MW/hr, a renewable operator cannot afford to risk a catastrophic failure. The **ZTZ TRANSMAX2000** system offers the utmost in bushing condition awareness and is fully installed on a turnkey basis by trained ZTZ factory field engineers. The TRANSMAX2000 represents very low-cost insurance against transformer failure – usually the installed cost is far less than one day of lost revenue.

Transformer bushings can fail on either the low voltage side or the high voltage side. Solar sites have the characteristic of going from cold to full-on at dawn and full-off at dusk, day after day. This is shown in the plot below by the power factor shape of a saw-tooth pattern. The power factor is shown to be affected by ambient temperature. This transformer use is called "Rough Service", and it is one of the most severe applications for the bushings. In April of 2022, a 200 MW solar site main transformer monitor produced the four-month power factor plot shown in Figure 1.

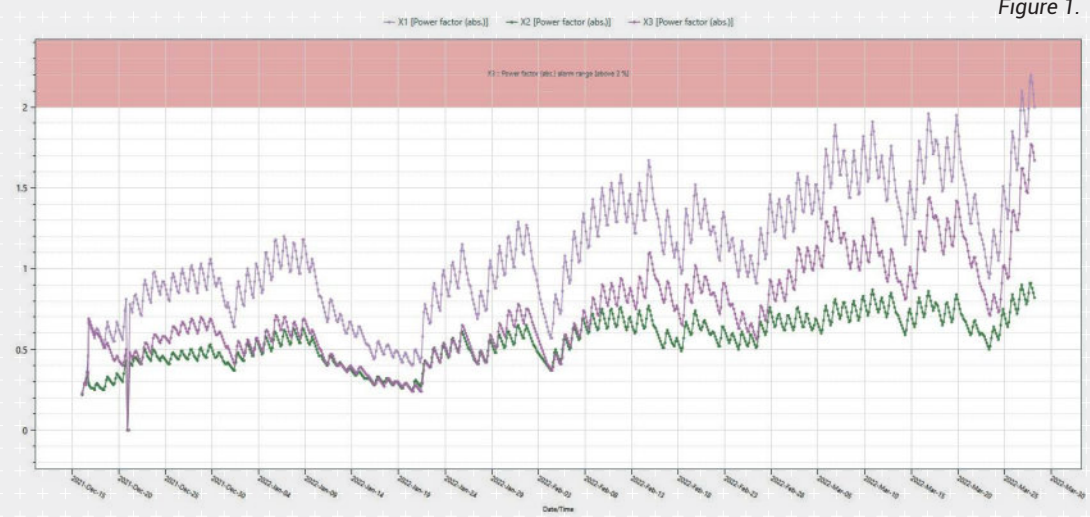


Figure 1.



RENEWABLE
OPERATORS
ENJOY OVER
200 YEARS
OF UTILITY
EXPERIENCE
OFFERED BY
ZTZ SPECIALIST
ENTERPRISE
ON THE

TOPICS OF
TRANSFORMER
OIL, TESTING,
BUSHINGS AND
FORENSICS.
THIS
EXPERTISE IS
MADE FREELY
AVAILABLE
TO ALL ZTZ
SYSTEM USERS.



The purple traces represent the measured power factor of the X1 and X3 bushings (the low voltage side) facing the voltage converters. The plot shows data from December 2021 to March 2022. The power factor increases from nominal to alarm stage during this time. Obviously, if the transformer was on a five-year test cycle with traditional measuring tools, it is likely the problem would have gone to full failure – which would mean a \$240,000 revenue loss per day for this site.

The online measured power factor is not the only way that ZTZ monitoring systems verify a problem. There are other exclusive algorithms that are applied to the measured data which are used to corroborate and add confidence to the alarm status. No system operator wants to receive false alarms and ZTZ monitoring systems do not give them.

Renewable operators enjoy over 200 years of utility experience offered by ZTZ on the topics of transformer oil, testing, bushings and forensics. This expertise is made freely available to all ZTZ system users.



ZTZ HAS ONLY
ONE FOCUS - TO
FULLY SUPPORT
THE USER
OF THE ZTZ
TRANSFORMER
MONITORING
SYSTEMS.



Renewable operators are choosing ZTZ because it is a specialist enterprise. Transformer monitoring systems focused on the bushings is the primary business of ZTZ Services. ZTZ is also a highly stable, privately held U.S. company. There are no "cut corners" to increase "shareholder value". Customer service resources are not shared between multiple corporate pursuits/acquisitions and originate from the ZTZ factory in the Eastern U.S. Time Zone – not Europe or Canada.

ZTZ has only one focus – to fully support the user of the ZTZ transformer monitoring systems. ZTZ supports the customer with as-needed consultative services, field training, formal training at ZTZ headquarters, and full turnkey system installations – all for maximizing up-time of the transformer. ZTZ presently has four installation teams located at the Miami, Florida headquarters.

Into the Future

Offshore wind is growing in significance and remote offshore substations and interconnecting cables require monitoring. ZTZ Services supplies the **Hydrocal H1008 Offshore DGA System**. Extreme ruggedization sets the H1008 apart from any other online DGA system. In the picture above, the device is shown at the Hornsea-Two offshore substation, world's largest offshore wind farm.

As older renewables sites are repowered, up-rated, and improved; ZTZ monitoring systems will provide the systems which keep a careful watch on the most important part of the system – the main step-up transformer. With the transformer supply chain presently suffering long delivery delays, the preservation of this critical asset becomes even more important.