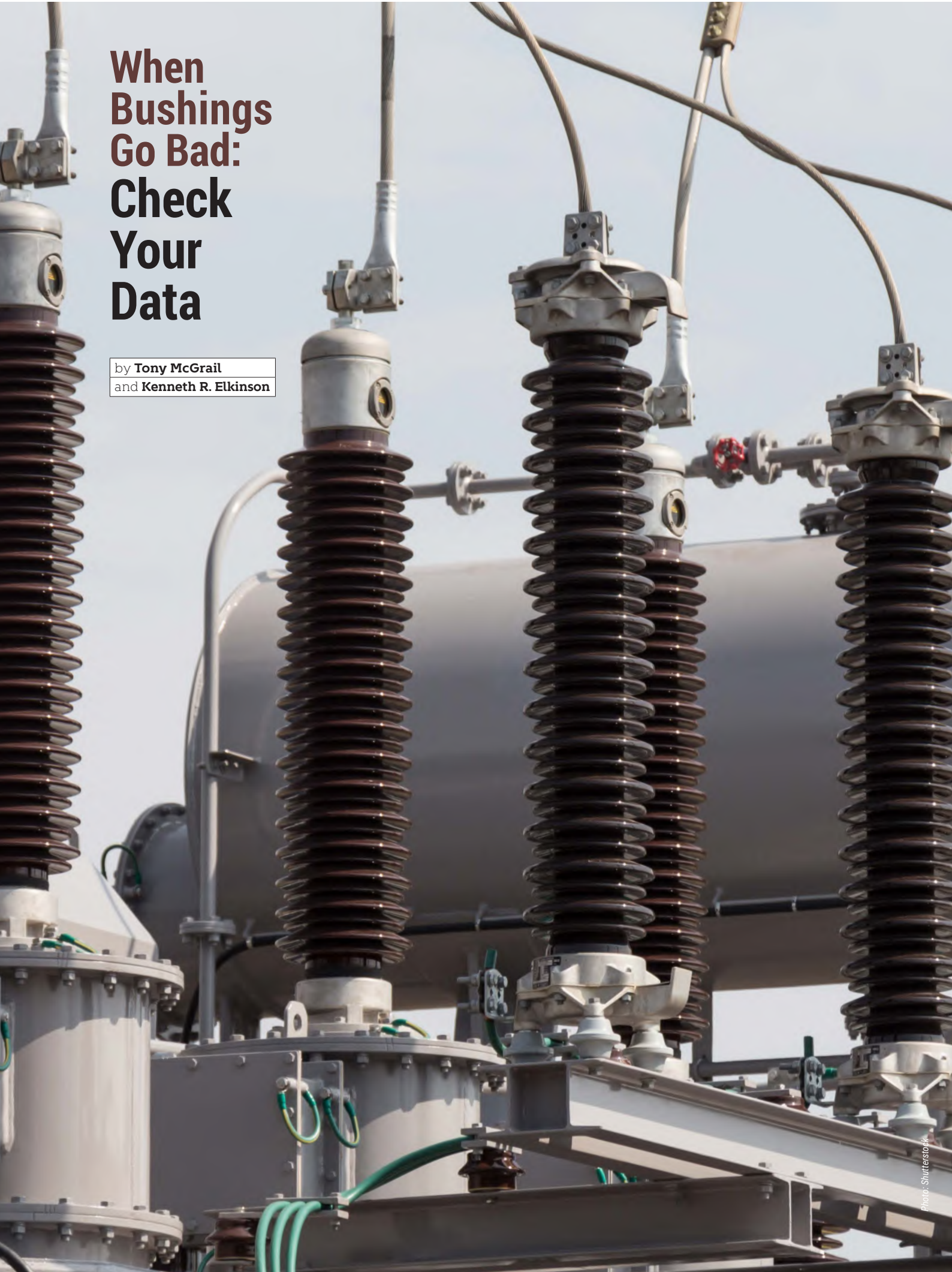


# When Bushings Go Bad: Check Your Data

by **Tony McGrail**  
and **Kenneth R. Elkinson**



*In bushing monitoring it is very important to be aware of all available data – the raw phase angles and rms leakage currents for each individual bushing are often as useful as the derived power factors and capacitances in terms of deterioration detection, investigation and diagnosis.*

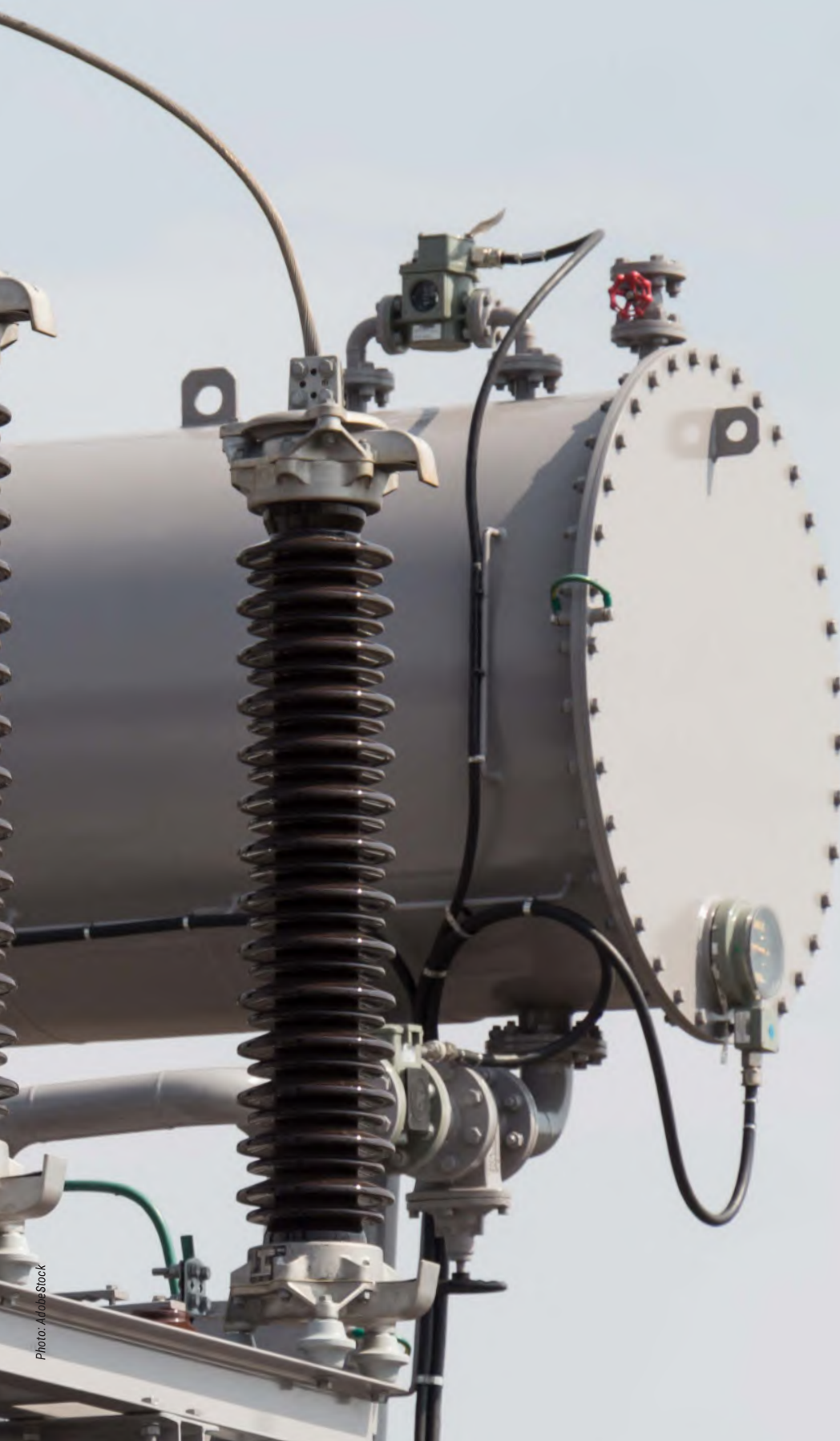


Photo: Adobe Stock



**Tony McGrail** is Doble Engineering Company's Solutions Director for Asset Management & Monitoring Technology, providing condition, criticality and risk analysis for utility companies. Previously Tony has spent over 10 years with National Grid in the UK and the US; he has been both a substation equipment specialist and subsequently substation asset manager, identifying risks and opportunities for investment in an aged infrastructure. Tony is a Fellow of the IET, a member of the IEEE, CIGRE, ASTM, ISO and the IAM, and is currently active on the Doble Client Committee on Asset and Maintenance Management and a contributor to SFRA, Condition Monitoring and Asset Management standards. His initial degree was in Physics, supplemented by an MS and a PhD in EE followed by an MBA.



**Kenneth Elkinson, P.E.**, received his Bachelor of Science in Electrical Engineering degree from the University of Massachusetts at Lowell. Kenneth has held a number of positions at Doble Engineering, as Field Engineer, Client Service Engineer, and now Apparatus Analytics Engineer. Previously, Kenneth worked with National Grid in the US as a Substation Engineer. Mr. Elkinson is a licensed Professional Engineer in the state of Massachusetts, and is an active member of IEEE, CIGRE, and the NSPE.

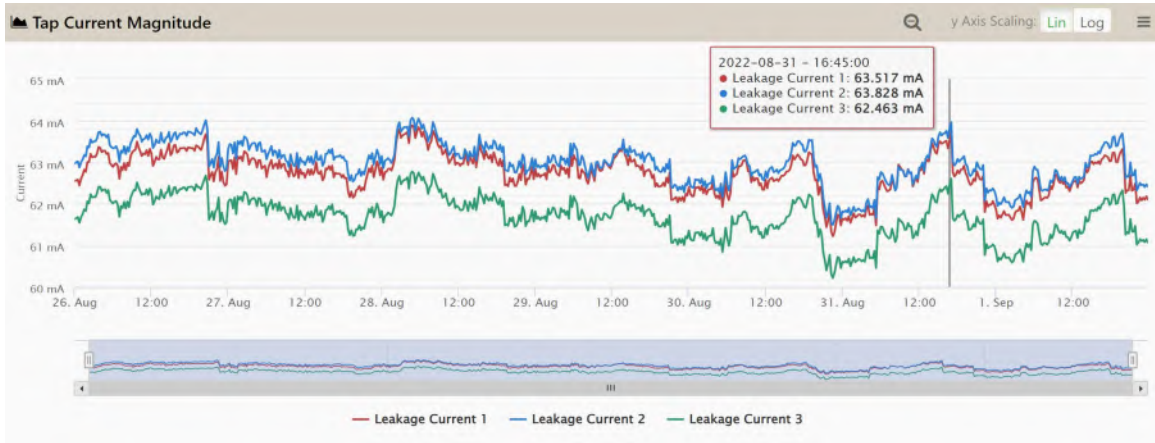


Figure 1. Showing the variation in leakage current magnitude for three GSU bushings over 7 days in 2022

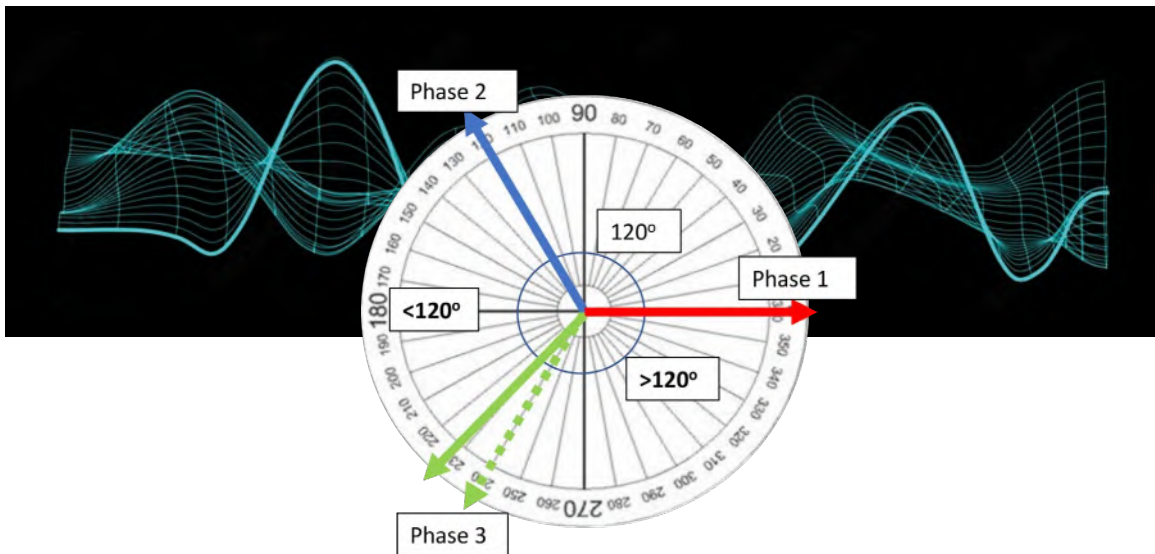


Figure 2. Exaggerated phase angle change for Phase 3 bushing showing Phase 1-to-2 staying unchanged

Bushings are usually reliable assets – a failure rate, per year, of no more than about 0.5% is usual [CIGRE]. Power factor and capacitance are good indicators of deterioration in offline bushing tests and are commonly used [Doble]. In addition, it is generally found that:

- it is not common for two bushings in a set of three to 'go bad' simultaneously;
- a rising power factor is a significant indicator of insulation deterioration.

These two findings are also useful in online measurements where raw current waveforms are recorded, from which we can calculate relative phase and rms magnitudes for the leakage current of each bushing; from these values we can calculate the individual bushing power factors and capacitances (TT). Leakage current varies with both bushing condition and system voltage providing a lot

of 'noise' in the measurements, as shown in Figure 1.

As a result of the 'natural' variation in leakage current, it is usual to put some averaging into the resulting power factors to avoid false positives from sudden system variations: phase angle variation due to bushing deterioration start at  $\sim 0.1^\circ$ , but system variation may be above  $1^\circ$  to  $1.5^\circ$  and vary minute by minute, making it difficult to detect the bushing deterioration. At Doble we calculate daily, weekly and monthly trends for power factor and capacitance, but also instantly respond to sudden changes if they exceed a user set threshold.

Power factor and capacitance have been used to detect and prevent failure in many bushings, of many different types, from Westinghouse, ABB, Trench, GE and others (Doble) using only the individual bushing leakage currents for diagnostic purposes. The addition of a voltage reference

provides far greater capability and will be discussed in a separate article. For now, we have three bushings, with three leakage currents and an interest in diagnostics.

In Figure 2, we show the three phasors associated with the three leakage currents from a set of bushings which, in an ideal balanced system would all be  $120^\circ$ . We have added a very large change in the Phase 3 bushing – a change 100 times greater than expected from bushing deterioration – so we can easily see the effect on the relative phase angles:

- Phase 3-to-1 increases
- Phase 3-to-2 decreases by the same amount that 3-to-1 increased
- Phase 1-to-2 stays the same

Consequently, if we were to plot the data over time, Phase 1-to-2 should stay constant if just bushing 3 is deteriorating. Also note that the sum of the three phase angles is always  $360^\circ$ .

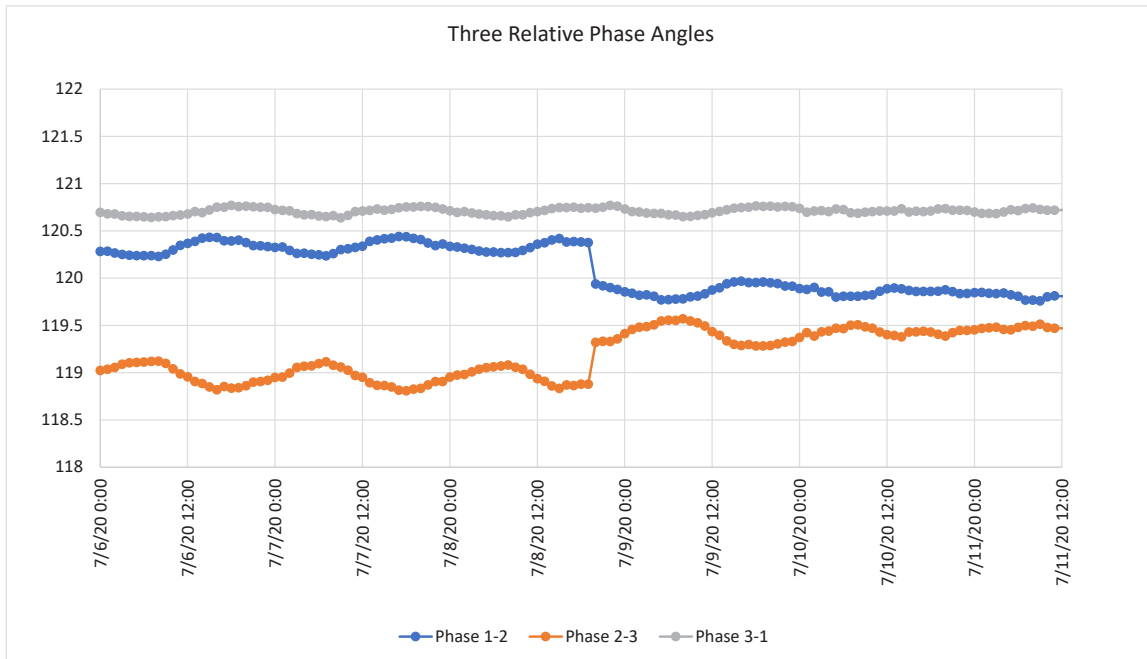


Figure 3. Step change in phase angle for Phase 2 bushing

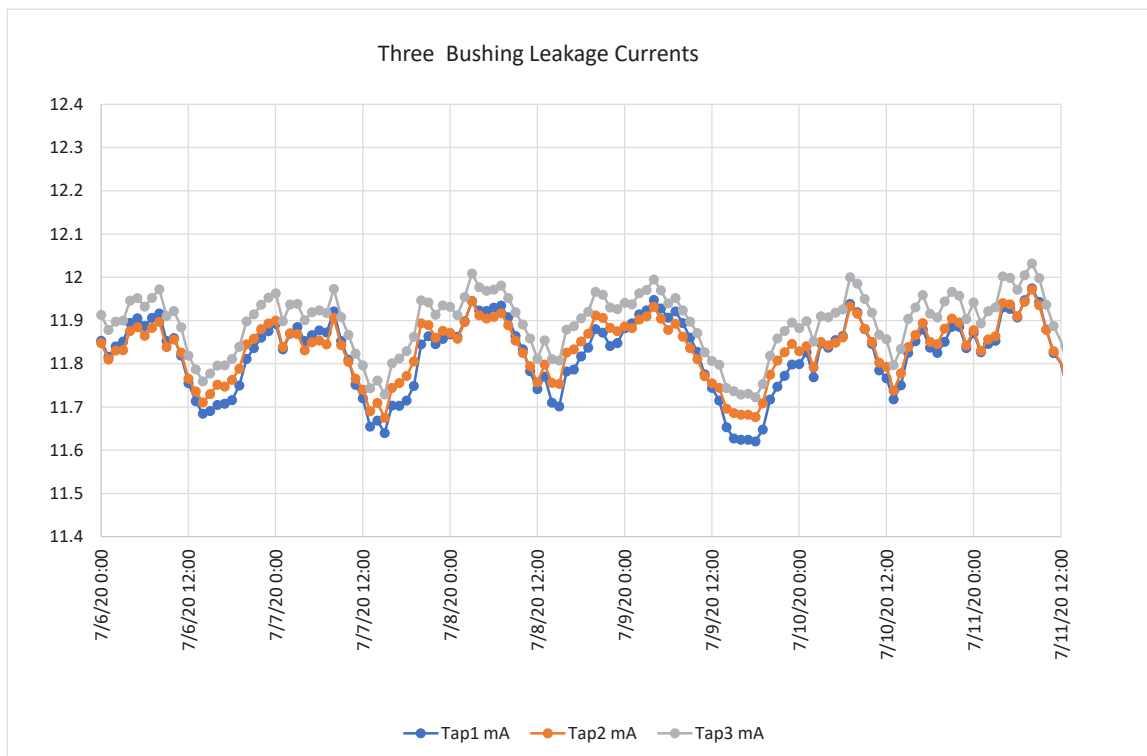


Figure 4. Leakage current magnitude for the three bushings

In Figure 3 we can see example results where both traces involving the phase 2 bushing show a sudden change in angle. Note that the remaining trace is relatively constant, indicating that it is just one bushing deteriorating. As expected in Figure 3, the sum of phase angles at any point is 360°, and the traces involving the deteriorating bushings

show reflections of the variation, as expected: the increase in one is the same as the decrease in the other.

At the same time as recording the phase angles, we can also look at leakage current magnitude for the three bushings, shown in Figure 4. The natural variation in current magnitude, following a daily cycle

shows no particular disturbance at the date/time of the anomaly in Figure 3.

In Figure 5 we can see the relative phase angles for three low voltage bushings recorded over several months. The changes recorded in Figure 3 were small, as expected, but in Figure 4 we are seeing changes of several degrees.

*Power factor and capacitance have been used to detect and prevent failure in many bushings, of many different types, using only the individual bushing leakage currents for diagnostic purposes.*



*The addition of a voltage reference provides far greater capability and will be discussed in a separate article.*



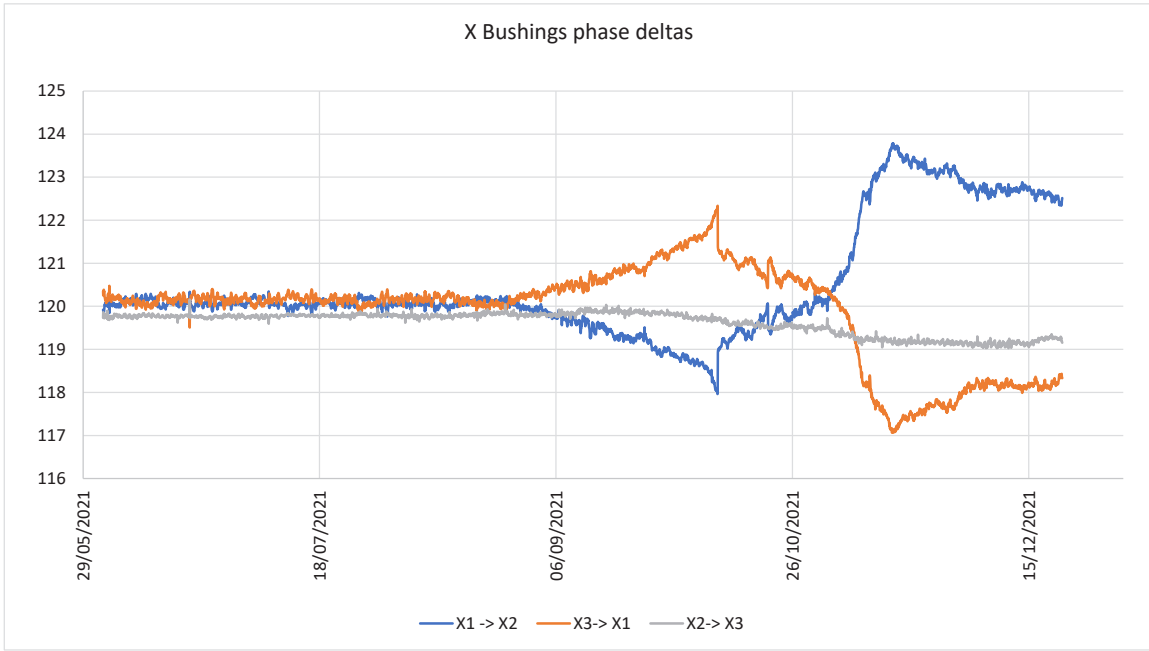


Figure 5. Relative phase for 3 bushings

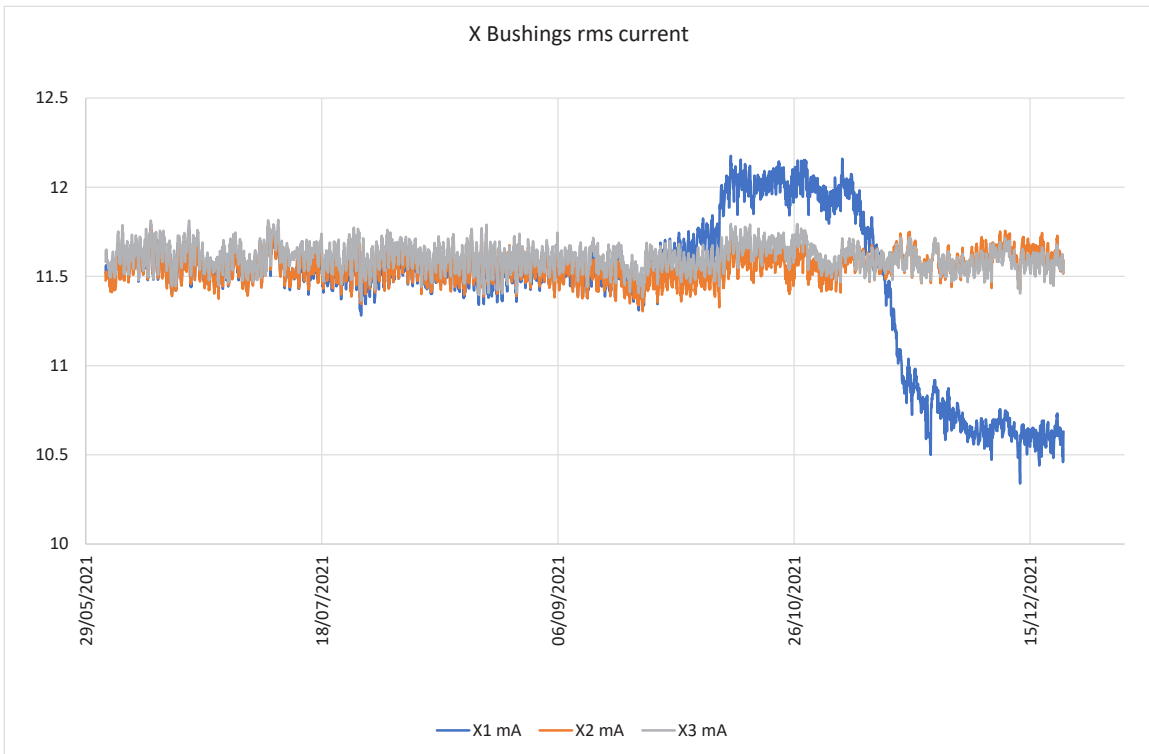


Figure 6. Leakage current magnitude for three bushings

In Figure 5, none of the traces show a constant value, indicating that more than one bushing is deteriorating. The two traces with large changes in phase angle both include the X1 bushing, which is thus the suspect bushing. In addition, the fact that for the X1 bushing the phase angle heads in one direction then reverses implies that the power factor has increased then decreased again. This is an uncommon effect where a bushing shows the effect of internal tracking within the bushing due to

contamination or moisture ingress and can eventually lead to a negative power factor being recorded. The effect of tracking can also be seen in the leakage current magnitude over the same time period, as shown in Figure 6.

A rising current is typical of deteriorating bushing, but here the current rises, and then subsequently falls – again, an uncommon event, and one which relates to internal tracking within the bushing.

It is very important in bushing monitoring to be aware of all available data – the raw phase angles and rms leakage currents for each individual bushing are often as useful as the derived power factors and capacitances in terms of deterioration detection, investigation and diagnosis. A voltage reference is recommended when possible, as this helps to remove the effects of system variation and can focus investigation on to an individual bushing.