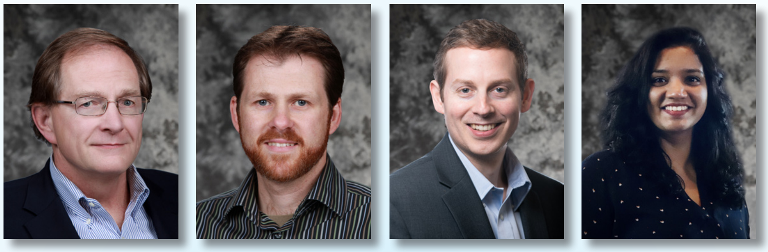
Initial Experience with the ARENA Cable/Motor Test Bed



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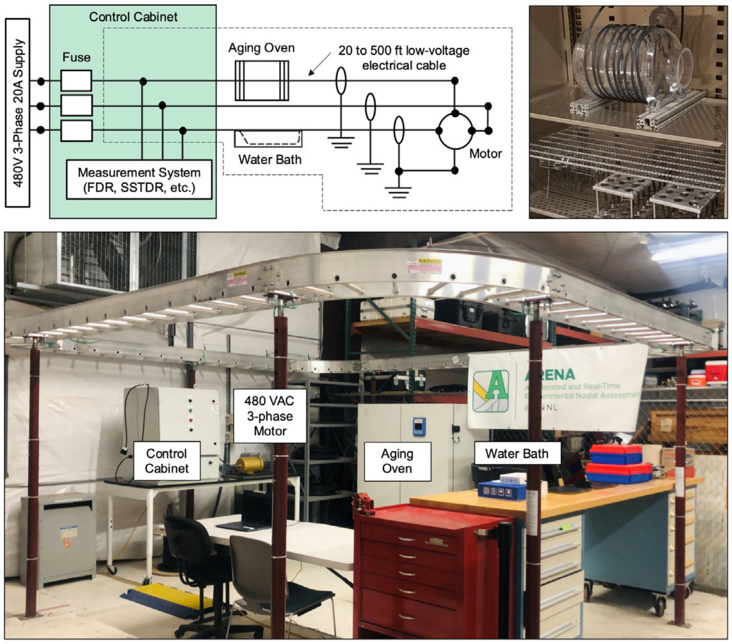
Degradation of installed electrical cables within nuclear power plants is known to occur as a function of age and operating environment. With more than 1,000 km of power, control, and instrumentation cables typically found in nuclear power plants, complete cable replacement is a severe cost burden. To reduce this cost, methods are needed to nondestructively assess degradation of cable materials. Pacific Northwest National Laboratory (PNNL) is advancing the science of nondestructive cable inspection in our Accelerated Real-Time Environmental Nodal Assessment (ARENA) cable /motor test bed [1]. The ARENA test bed consists of a 480 VAC 3-phase cable and motor system powered through a control cabinet, as shown in Figure 7, which allows damaged and degraded components to operate without challenging the utility supply. It readily supports various online, live-wire, and offline nondestructive examination (NDE) tests to detect and evaluate component damage as well. The ARENA test bed includes a large oven for accelerated thermal aging, a water trough for water exposure, elevated cable trays for supporting lengths of cable that can be undisturbed for extended test durations, and the possibility to introduce phase to phase or ground-faults at various locations between the supply and the motor load. The ARENA test bed is supplemented by an extensive array of standard cable test techniques, plus it has the capability to model and simulate the test arrangement with a finite-element digital twin to improve understanding of the physical measurements.

Figure 7. ARENA cable and motor test bed for 480 VAC 3-phase systems, including thermal and water aging.



Initial studies with the ARENA test bed have included assessments of frequency domain reflectometry (FDR) to detect cable exposure to water [2], and more recently, spread-spectrum time domain reflectometry (SSTDR) to assess ground-faults. FDR measurements require the cable to be disconnected from the live source or de-energized, as observed in Figure 8. A broad-band chirp is injected onto one conductor of the cable with a second conductor serving as a reference or ground. Any impedance changes cause a reflection of the chirp that is processed in the frequency domain, and then transformed to the time domain. Since the propagation velocity of the signal is known, the reflection time can be related to the distance along the cable. SSTDR measurements do not require the cable to be disconnected from the live source allowing measurements on energized cables. As with FDR, SSTDR correlates an injected signal with impedance mismatch reflections in the time domain so any detected reflections can be correlated to the distance along the cable based on wave propagation velocity.

One concern for cables in service is whether being dry or immersed in water can damage

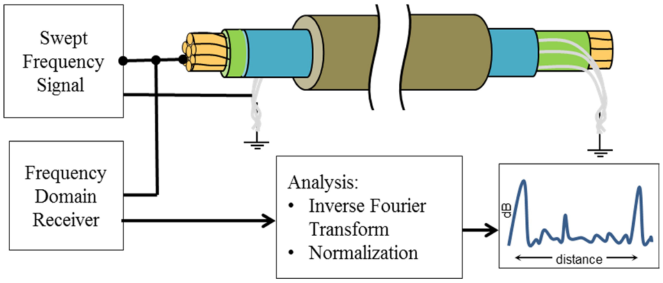


Figure 8. FDR test arrangement. Peaks in the distance response correspond to the time response based on the wave propagation speed in the cable.

the insulation over time. If FDR tests could be extended to determine if and where cables were exposed to moisture, damage could be minimized by selectively drying or lifting the cable above potentially damaging moisture. To assess feasibility of immersion detection, both shielded and unshielded cables were tested for their FDR response with a portion of the cable submerged, as shown in Figure 9, where the presence of water coming into contact with an undamaged and unshielded cable was clearly detected as an FDR peak. This peak was equally detectable with or without a connected motor. The response of the shielded cable to the presence or absence of water was substantially undetectable either with or without the motor connected.

Another concern is the requirement that NDE measurements be taken when the source is offline. Online SSTDR has been shown to detect conductor and insulation damage in rail and aircraft cable systems [3], but has not been extensively explored for nuclear power plants applications. We are exploring the applicability of SSTDR in the ARENA test bed toward nuclear power plants by measuring ground-faults ranging from a complete short circuit to 1k Ω at various lengths along a 100-ft cable. While ground-faults were difficult to detect, they were visible when the baseline signal was subtracted, as shown in Figure 10, thus supporting the usage of this online technique in nuclear power plants. The ARENA cable/motor test bed offers numerous cable test possibilities. Continuing tests with low-voltage FDR and SSTDR for cable faults are planned to expand and address the effect of motors, higher voltage cables, and simulations of test signals in the ARENA cable test configuration.

References

[1] Glass, S. W., L. S. Fifield, and M. Prowant. 2021. PNNL 31415 PNNL ARENA Cable Motor Test Bed Update.

[2] Glass, S. W., M. P. Spencer, A. Sriraman, L. S. Fifield, and M. S. Prowant. 2021. Nondestructive Evaluation (NDE) of Cable Moisture Exposure using Frequency Domain Reflectometry (FDR). PNNL-31934. PNNL, Richland, WA, USA.

[3] Furse, C., P. Smith, M. Safavi, and C. Lo. 2005. "Feasibility of spread spectrum sensors for location f arcs on live wires." IEEE Sensors Journal 5(6): 1445–1450. doi: 10.1109/JSEN.2005.858900.

Figure 9. (left) With the shielded cable, there is no clear indication of the presence or absence of water. (right) With the unshielded cable, there is a clear indication where the cable goes through the water trough.

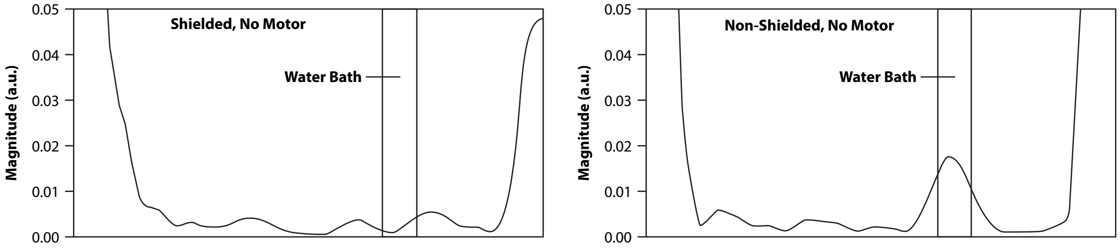


Figure 10. (left) SSTDR raw ground-fault signal where difficult to detect. (right) Baseline-subtracted where clearly seen.