SBIR Transformer Acoustics Pitch

Info

Technology Innovation (3500 characters)

> Explain the core high-risk technical innovation to be researched and developed during a Phase I project. NSF must understand what research and development is required and how this technical innovation differs from and is significantly better than existing solutions. It may also be that the proposed innovation creates a new market. In this case, why will it be adopted? Describing features or benefits of the proposed technology is not sufficient.

Transformers make noise that is a direct reflection of the underlying magnetic flux. This magnetic flux is affected by both the underlying electricity and the transformer mechanics. The underlying electricity is affected by the upstream and downstream equipment that is on the grid.

All of these produce different, sometimes overlapping, electric signatures that become abundantly clear during harmonic analysis. Through the process of magnetostriction (whereby electric power is converted to mechanical, acoustic power), minor changes in the waveform become abundantly clear, and the electric waveform becomes audible; transformers thus function as loudspeakers for the electric grid.

The US Navy and the Intelligence Community already analyze acoustics to understand a system's construction in a limited capacity on sonar recordings from submarines. We are applying the same concepts to understand the ways in which actors on the grid (transformers, inverters, rectifier, and turbine generators) produce their own acoustic signatures.

While the Navy uses the process of detection, classification, and identification, we are introducing a new task of diagnosis. By analyzing a wide array of transformers, inverters, and rectifiers under different stages of degradation, we can identify not just the type of equipment but what kind of problems it may have as well.

There is a small market for transformer monitoring, but there is no market yet for inverter or rectifier monitoring. Many independent power producers have asked for a way to identify faulty inverters, and many utilities have expressed frustration with faulty rectifiers that produce anomalous harmonics that pollute their electricity. And for all three of these cases, monitoring and analysis require high-voltage work and extensive safety procedures to install the equipment or figure out whether further investigation is required.

Acoustic analysis solves this problem by offering a non-invasive, passive, and extremely cheap alternative; the hardware has already been deployed to everyone's pockets: this works on a smartphone — accessibility is why this technology will be adopted.

Existing solutions for holistic transformer monitoring (Oktogrid, Magnefy) combine multiple sensors to assess the health of the transformer. These solutions cost $5-7k/transformer and feed copious amounts of data to SCADA systems. However, none of them attempt to identify — let alone diagnose — different equipment connected to the grid. While there exist solutions for personal homes to identify when different appliances are active, there is nothing that exists at the utility level for larger equipment.

Acoustic analysis is the form factor that focuses on accessibility and enables mass adoption; identification and diagnosis is the nascent technology that will open doors for entire industries of repair, enabling utilities to maximize grid capacity, maximize the lifespan of their assets, and minimize waste of unneeded electricity.

Technical Objectives and Challenges (3500 characters)

> Clearly explain the specific research and development required to prove that the foundational technology works and address the associated challenges explicitly with a high level description of how each will be managed. This section must convey how the proposed work is technically innovative and demonstrate that you have an understanding of the core research and development tasks necessary to prove out the technical innovation.

This work is innovative because very few people have explored the mapping of the flow of electricity into the acoustic space; the novelty here is not the concept of transformer or inverter fault diagnosis, but rather the accessibility of acoustic analysis. What doors open up when the hardware to analyze a transformer is in everyone's pocket? What happens when the full fleet of transformers is actually assessed for problems?

The conversion of electrical energy into mechanical acoustic energy is underexplored, and there are two ways to explore the space: theoretical and mechanical.

The theoretical path involves building a computer model of a grid actor (transformer, inverter, rectifier). The model will focus on the generation of the magnetic flux, and that flux's interaction with nearby ferromagnetic material. This will build on top of academic work that has been done to model various pieces of the grid actor. Then, examples of that theorized problem will be sought after through our catalogue of grid actor recordings. When a severe case is found, we will then work with the owner to have a repair team validate our claim.

Academic literature on transformer acoustics is unified in saying that real-world transformers have very different properties from laboratory transformers, which means that a part of this path involves accumulating a large amount of real-world transformer recordings. We have spent the past year building relationships with electric utilities in the US and Europe and growing a catalog of transformer recordings. As this project continues, we will be able to get more recordings.

The mechanical path involves buying and deforming many different grid actors and then recording the sound before and after the degradation. As a laboratory space, we will build a low-/medium-voltage lab. From there, we will buy many small transformers, inverters, and rectifiers and incrementally degrade them. While this laboratory environment will be significantly different from the real-world environment, the physics are the same and we expect to learn many things (even if not everything). To make our laboratory environment more like the real world, we will also generate our own AC and place anomalous harmonics in the current.

Our team has the programming expertise to take academic models and turn them into structures that are useful for our modeling. And given our backgrounds as nuclear engineers for submarines, we are able to construct and manage a voltage lab for cataloguing defects.

Market Opportunity (1750 characters)

> Explain the value of the technological innovation including the potential uses and those who will benefit (who is the customer) and demonstrate a high-level understanding of the competitive landscape and why this innovation has the potential to compete.

Urban passenger rails are powered via DC rectifiers in confined substations. The bus bars are typically in protective ducts and are sometimes insulated. For these reasons, high-voltage work is often difficult to perform. In addition, their transformers cross-connect phases, which makes standard monitoring equipment difficult to install. A low-cost handheld tool that can be used by untrained personnel allows for monitoring in this unusual situation without putting personnel at risk.

Utilities, as the grid operator, are invested in maintaining the continuity of electricity, which requires knowing how all of the grid actors are behaving. The benefit of diagnosing different grid actors connected to a transformer is that you can diagnose issues on equipment that you don't own. With Bellwether's acoustic analysis tool, utilities could identify misbehaving equipment and address their owners before a protective trip occurs.

Utilities are required to maximize reliability and decrease costs. With the ability to quickly identify transformers that have high internal losses, they can replace inefficient transformers that are consuming extra electricity: this instantly adds capacity to the grid and minimizes costs that are passed on to the consumer. For industrial transformer owners, internal losses eat directly from their profits; they are incentivized to replace their transformers when the inefficiencies are more than the cost of a new one.

The real advantage of our product is that it is significantly cheaper than the competition. Oktogrid and Magnefy cost ~\$7k/transformer, which means a fleet of 200 transformers will cost \$1.4M to instrument. Our product costs \$3k/user/year; a 6-person team would cost only \$18k/year.

Company and Team (1750 characters)

> Explain the team's suitability to successfully execute the project based on the proposed innovation and approach to R&D. Provide information on plans to address gaps in the team.

Ari Brown is a former US Navy submarine officer. He is a certified nuclear engineer for submarines under the Department of Energy and Naval Reactors. As a qualified submarine officer, he is also a sonar analyst. He received a bachelor's degree in computer science from the University of Michigan in 2014 and has been a programmer for 20 years, with multiple open-source coding contributions before graduating high school. He has been featured in the National Rural Electric Coop Association's Startup Alley and has spent the past 1.5 years building connections in the utility space in America and Europe.

Matthew Dods has identical submarine qualifications to Ari Brown. He received a bachelor's degree in mathematics from the United States Naval Academy in 2018, and a master's degree in mathematics from the Naval Postgraduate School in 2019.

One of the remaining gaps in the team is specific knowledge on the construction of inverters and rectifiers. With NFS funding, we will be able to hire part-time help to do physics modeling:

Tim Smith is a professor of physics at Dartmouth College, specializing in quarks and intermediate energy physics. He has also worked as a computer modeler for fusion energy at Commonwealth Fusion.

Yorke Brown is a professor of physics at Dartmouth College and is a ham radio operator. He has taught amateur radio and circuitry for the past 15 years.

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