

BELLWETHER, LLC

October 22, 2026

Research Partnership

Electric Grid Analysis via Smartphone

1 Overview

Bellwether is using transformer acoustics as a way to gain insight into the electric grid. We aim to be able to diagnose mechanical and electrical issues in transformers, inverters, rectifiers, and inverters. This diagnostic tool is called **Bellwether Canary**, serving as a canary for a failing grid.

In order to obtain these insights, we need to obtain acoustic recordings and associate them with the qualitative and quantitative information of the transformer.

2 Partnership

A research partnership is comprised of three steps:

1. **Substation visits**, where we visit each available substation
2. **SCADA data collection**, where the partner provides the data in section 4
3. **Follow-on report**, where Bellwether shares a report of grid deficiencies

3 Recording Process

The smartphone is placed on the ground at the corner of the transformer, as close to the transformer as possible. A 30-second video is available demonstrating the process. The transformer is not touched.

3.1 iPhone Recording

Each recording is approximately 10 minutes long, taken on an iPhone app ("Canary") that allows for immediate uploading to the cloud for further review.

Any smartphone voice memo app can capture a usable recording that can later be uploaded, so the partner can also submit their own recordings later.

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4 SCADA Data — Transformer Qualities

4.1 Quantitative Power Attributes

All quantitative attributes of the power should be provided to as fine a granularity as is available (regarding decimal place and **how frequently it is measured**, i.e. 1-minute or 1-second intervals). Table 1 describes the quantitative attributes of the power quality associated with the **individual phases**.

It is understood that not all of this information is available; Bellwether would appreciate as much of it as possible.

Values are requested per-phase and as an average over the time period.

Table 1: Phase Power Qualities

Quality	Notes
Neutral current (A)	Provided to the hundredth of an amp
High voltage (kV)	Measured high voltage side; provided to the single volt
Low voltage (kV)	Measured low voltage side; provided to the single volt
Frequency (Hz)	Provided to the hundredths place
Primary current (A)	Provided to the single amp
Secondary current (A)	Provided to the single amp
Secondary loading (kVA)	Provided to the single VA
Power factor	-
Total harmonic distortion	-
Harmonic presence	Percentages of 2nd – 15th current harmonics; only one per phase is required, not one every second

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4.2 Transformer Metadata

The following qualities capture the requisite qualitative metadata:

Table 2: Transformer Metadata

Quality	Notes
Manufacturer	-
Class	-
Insulation type	-
Installation date	-
Dissolved Gas Analysis results	Precise figures are not necessary
Known issues	-
Historical issues	-

4.3 Unavailability of Data

In many cases, all the requested data might not be available. We ask that the unavailability not be a deterrent — value can be gained even with a limited amount of data.

5 Follow-on Report

After the SCADA data has been delivered, we are able to conduct an early-stage analysis of each transformer.

For each transformer, we analyze the circuit that it's on and report the following:

- Grid frequency
- Transformer efficiency
- Phase imbalance
- Inverter presence and frequency
- Rectifier pulse deficiencies
- Corona

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5.1 Grid Frequency

Grid frequency can be estimated to the $1/1000^{\text{th}}$ Hz.

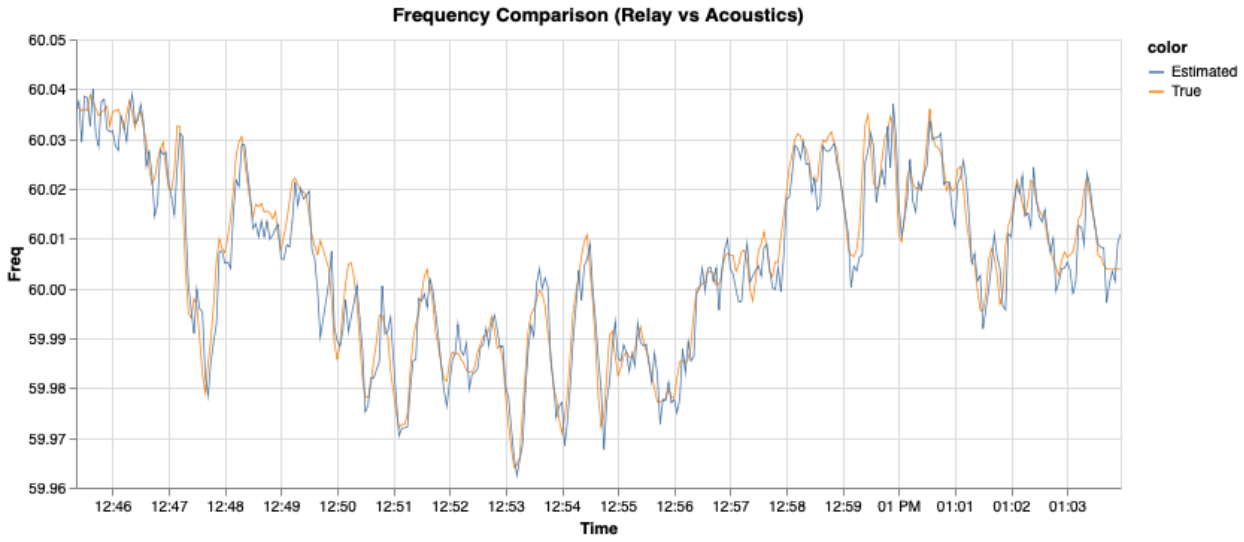

Figure 1: *Frequency:* Comparison of the grid frequency (y axis) as read by an SEL-735 relay ("True") and Canary's acoustic algorithm ("Estimated") over 19 minutes.[1]

5.2 Transformer Efficiency

Transformers are 95-99% when they are first built. However, that efficiency declines after many years of continuous service. In some cases, a transformer may degrade faster than expected, resulting in a fleet where certain transformers are significantly less efficient than the rest.

We have identified an acoustic signature that correlates to the overall transformer efficiency. This allows us to report a **single number that represents the amount of electricity that is lost at that loading**.

[1] Recording #333

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5.3 Phase Imbalance

Phase imbalance in transformers is the result of improper loading of the feeders. A certain amount of imbalance is expected and unavoidable.

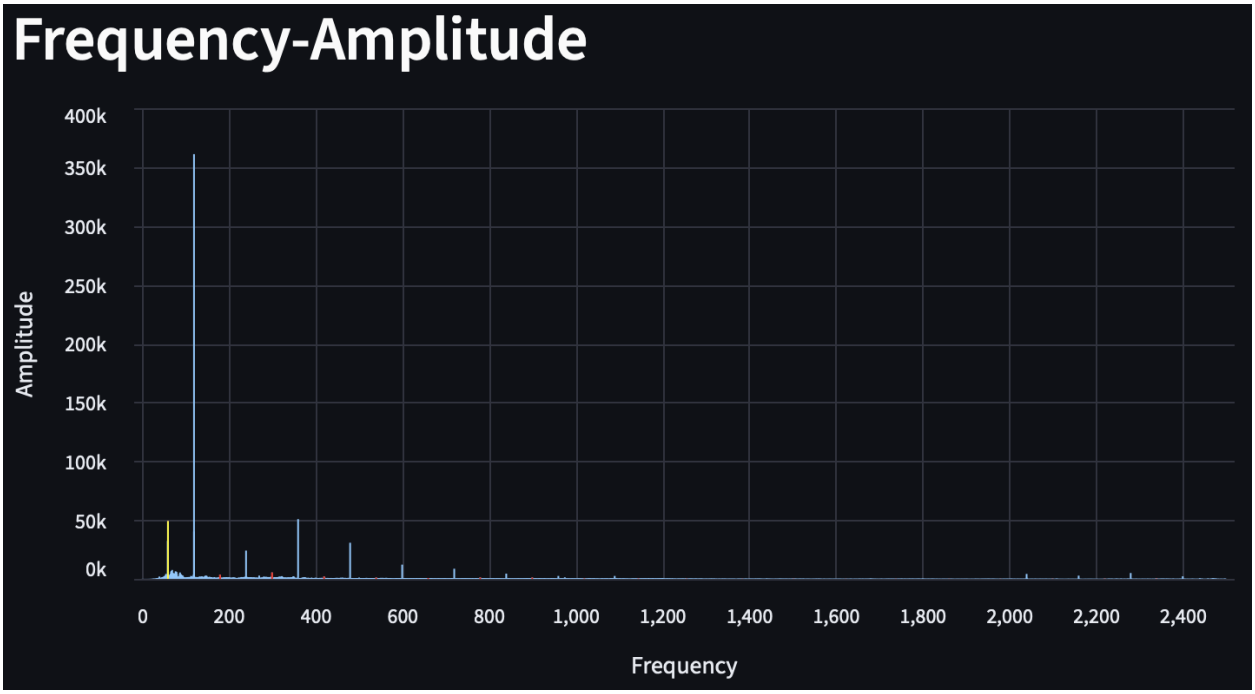

Figure 2: *Phase imbalance:* The presence of the yellow bar, representing 60 Hz, indicates DC bias in the magnetic field.[2]

The yellow bar in figure 2 is the 60 Hz tone, which is only seen in the case of DC bias, which is the result of phase imbalance.

[2]Recording #85

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5.4 Inverter Presence and Frequency

Grid circuits will sometimes be in parallel with renewable generators, who produce electricity via inverters. These inverters have distinct electric signatures, which we can then detect in the acoustics.

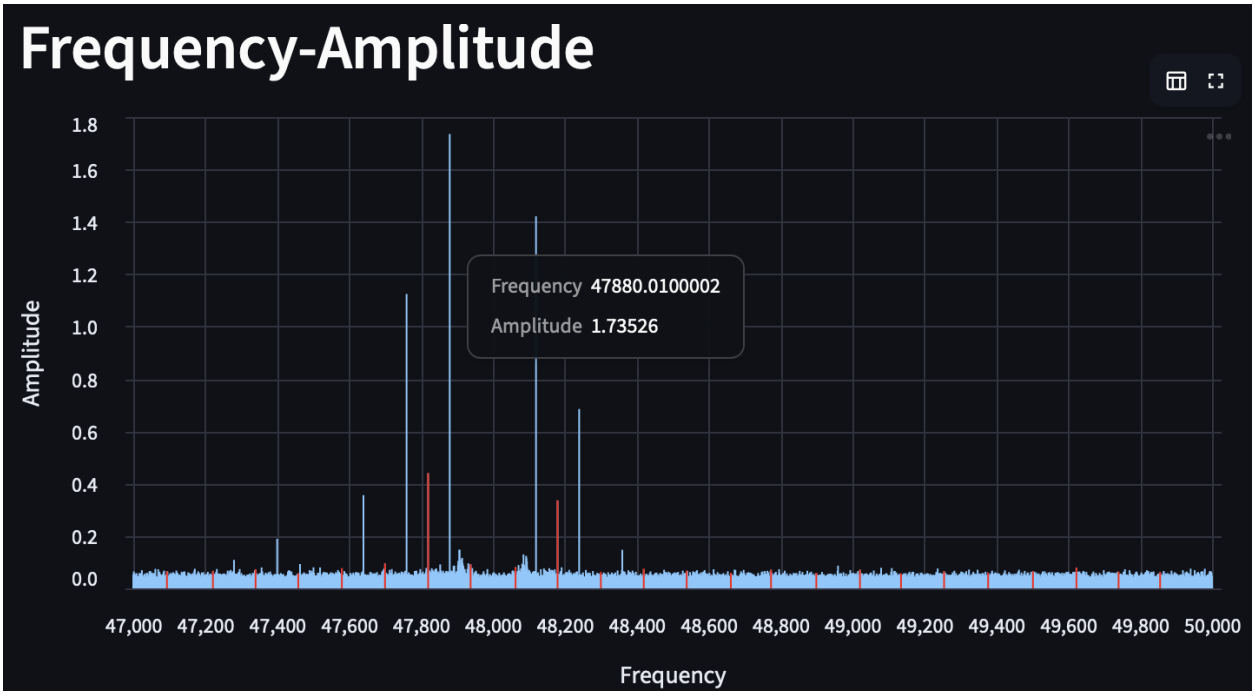

Figure 3: *Inverter harmonics:* These harmonics are in the ultrasonic range (exceeding 20 kHz) and are from an inverter on this grid circuit. The red harmonic is from a misfiring component within the inverter.

In figure 3, certain harmonics are highlighted in red, which are the odd harmonics of 60 Hz. Given the nature of magnetostriction, **a healthy inverter should never produce this**. However, it is present because of failing electronic components in the inverter.

[2]Recording #473

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5.5 Rectifier Pulse Deficiencies

Rectifiers are most commonly 6-pulse designs, which means they have two strings of 3 pulses. These strings need to be perfectly timed to be 180° off. However, if one of the pulses has degraded, then it will no longer be in sync with the remaining five, and it will produce an even harmonic. This even harmonic in the electricity produces a half-harmonic in the acoustics and is easily identifiable, as evidenced by figure 4.

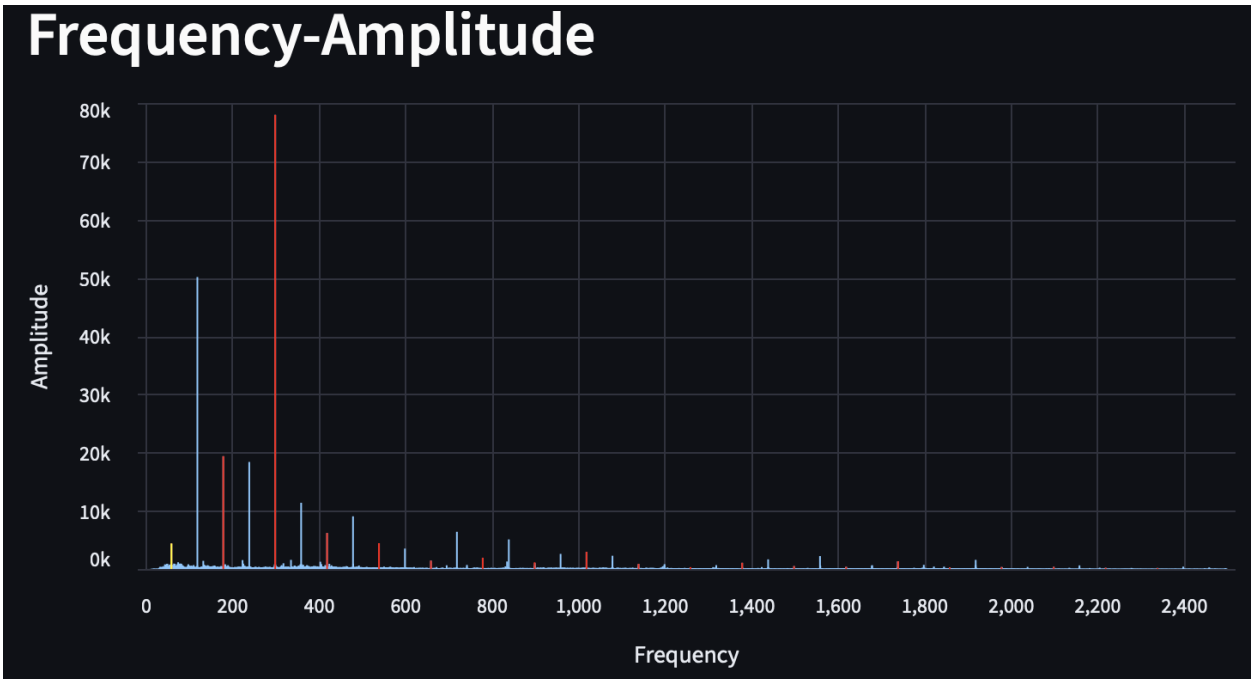

Figure 4: *Rectifiers:* The large red harmonics (odd 60 Hz harmonics) correlate to 6th-12th even harmonics, which are the result of mistimed thyristor pulses.[3]

5.6 Corona

We are also able to detect corona through the presence of 11-22 kHz broadband noise. Along with the graphs, we deliver a percentile, stating how irregular the corona recorded is when compared to the entire population of recordings.

[3] Recording #444

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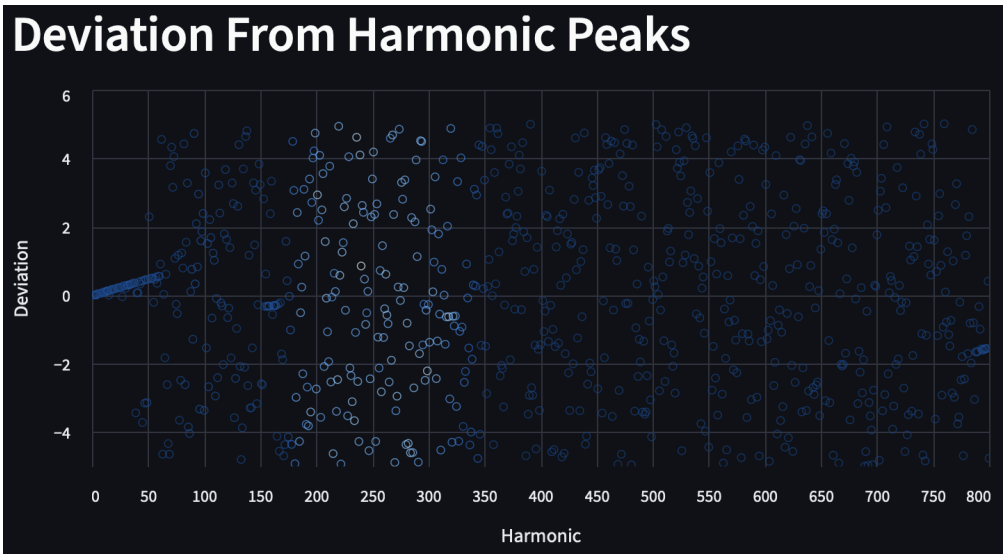

Figure 5: *Corona:* Assessment of broadband noise by assessing the deviation of the actual harmonics from the predicted harmonics. Lighter circles indicate louder harmonics.[4]

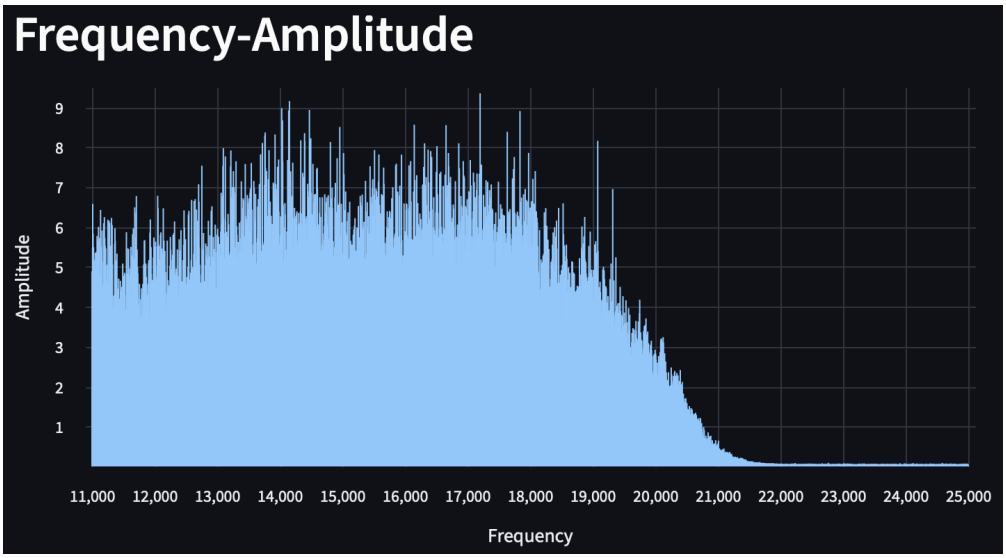

Figure 6: *Corona:* The curve of broadband noise of corona that occurs at 11-22 kHz, above the audible range for adult humans (which is generally around 15 kHz).[5]

[4]Recording #473
[5]Recording #473

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5.7 Future Reportings

With continued research, we will be able to offer more detailed assessments and diagnoses on transformers, inverters, and rectifiers:

1. Transformer winding looseness
2. Transformer winding turn-to-turn shorting
3. Specific diagnoses on inverters
4. Specific diagnoses on rectifiers
5. Turbine generator health
6. Partial discharge readings

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