DETECTING POWERLINE NOISE WITH LOW-COST NOISE SENSORS FOR POWER OUTAGE MITIGATION

Scientific Use of Machine Learning on Low-Power Devices

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AFRICAN REGIONAL WORKSHOP ON SCITINYML
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OBJECTIVE
Mitigate/Reduce Power Outages, Particularly at Community Health Care Facilities

EXPLORATION
Possibility of Low-Cost Noise Sensors Detecting Aberrant Powerline Noise

COMMON SOURCES OF PROBLEMS
Common Sources of Power-Related Problems

POSITING SOURCES OF NOISE
Positing Potential Sources of Power-Related Noise

EXPERIMENT SETUP & RESULTS
Audio analyzers & power line noise & spectrogram results

SOME COMMON MISCONCEPTIONS UNVEILED
Some Unexpected Results & Possibilities
OBJECTIVE:

MITIGATE/REDUCE POWER OUTAGES, PARTICULARLY AT COMMUNITY HEALTH CARE FACILITIES THAT DO NOT HAVE ROBUST RESILIENCY BUDGETS
The Load increased dramatically during Covid-19

Community Health Centers Engaged in Low-Cost Preventative Measures

HEAT KILLS CORONAVIRUS

COVID 19 MITIGATION

BASED ON VARIOUS STUDIES
Many community health centers operated with the guidance that many viruses won’t survive in temperatures over 60°C

WASHER AND DRYERS
Many viruses won’t survive in temperatures over 60°C
Increased Load

Dramatically load increased

The widespread usage of devices in unanticipated areas resulted in unexpected load issues.

Power Outage

Power Outages Increased

During unusually high-power demand, overload situations have resulted in power outages.

Medical Equipment Unable to Function Properly
Both cables supplying electrical power to a prestigious hospital failed.

Power out from 8:30am to 6:30pm

A large university hospital forced to cancel surgeries since the primary generator only lasted for 30 minutes.

Power outage in the medical center communication going offline and internal phones between departments become inoperative for hours.

This was beyond the National Fire Protection Association 110 Standard and National Electrical Code, which requires emergency power restoration to healthcare and critical-care facilities within 10 (ten) seconds of an outage.
POWER OUTAGES MITIGATION ON HOSPITALS

Historically, it has been found that even if backup power systems at hospitals and health care facilities are employed, they are not always reliable.

The backup generators at certain hospitals did not have fuel to last through the sustained outage. Electric Power Research Institute (EPRI) asserted that there is a 20%-30% failure rate for the start-up of hospital generators.

Substantive portion of all UPS back-up system power failures are battery related and non-detectable, and detectable battery failures account for a significant portion of UPS failures during short outages.

Hospital backup systems do not activate instantaneously. It is that short lag time that is the root of many malfunctions of sensitive medical equipment, as they attempt to power recycle.
The monitoring of key power equipment for aberrations can help increase energy resiliency, improve efficiency, and enable greater self-sufficiency for hospitals and health care facilities.

- The monitoring of the incoming current and voltage channels for power aberrations
- Thermal
- Spark detection
- Good combination to contend with false positives/negatives
- Noise

Hospitals can significantly increase operational efficiency with real-time data and round-the-clock monitoring.
THE EMI/RFI PARADIGM

The National Institutes of Health (NIH) have reported that several medical-related devices have had operational issues due to Radiofrequency Interference (RFI).

This phenomenon revealed a dual opportunity, via monitoring EMI/RFI Paradigm.

THE DUAL OPPORTUNITY 1

A baseline understanding should be obtained regarding the environs within which sensitive medical equipment must be operated. In many cases, hospitals expand quickly and are not in accordance with the original design/architecture.

THE DUAL OPPORTUNITY 2

There is the opportunity to detect aberrant powerline activities, which serve as an early indicator and warning of potential power reliability and stability issues. We are looking for low-cost opportunities for the community health facilities.
EXPLORATION:

POSSIBILITY OF LOW-COST NOISE SENSORS DETECTING ABERRANT POWERLINE NOISE
DEFENSE-IN-DEPTH PARADIGM FOR POWER ABERRATION DETECTION
TIMING CONSIDERATIONS

The issue of powerline noise comes with the opportunity of leveraging it as an early indicator and warning for power outage mitigation. The practicality as pertains to the utilization of low-cost noise sensors (segueing to scalability & extensibility) is examined.

CORRECTIVE ACTIONS DIRECTLY AFFECT THE PERFORMANCE INDICES OF ELECTRIC POWER SYSTEM RELIABILITY, SUCH AS

- **SAIFI**
  System Average Interruption Frequency Index

- **SAIDI**
  System Average Interruption Duration Index

- **MAIFI**
  Momentary Average Interruption Frequency Index

- **CAIDI**
  Customer Average Interruption Duration Index

EXAMINED HOW LOW-COST NOISE SENSORS MIGHT PROVIDE AN OPPORTUNITY FOR COMPREHENSIVE COVERAGE & DETECTION OF CERTAIN POWERLINE NOISE ABERRATIONS AT THE “EDGE” AGAINST A SET OF COMPILED HEURISTICS.
PRIMER ON **POWERLINE NOISE**

**High Frequency Hissing** -> **Hard to Detect (Potentially, for some cases)**

**Low Frequency Humming** -> **Easier to Detect (Potentially, for some cases)**
BACKGROUND INFORMATION ON POWERLINE NOISE

PERIODIC SIGNALS

TIME-DOMAIN

FREQUENCY-DOMAIN

CURRENT

VOLTAGE
LEXICON PRIMER ON
POWERLINE-RELATED NOISE

INCIDENTAL EMITTERS
No specific limits on the conducted or radiated emissions.

UNINTENTIONAL EMITTERS
Intentionally generate an internal radio signal, but not radiate RF energy.

INTENTIONAL EMITTERS
Transmitters that intentionally radiate RF energy.

ELECTRICAL GRID EQUIPMENT
MICROPROCESSORS, SWITCHED-MODE POWER SUPPLIES
LOW-COST SENSORS
REMOTE READING METERS THAT SEND DATA
HIGH-COST SENSORS
PROBLEMS:

COMMON SOURCES OF POWER-RELATED PROBLEMS
The Common Sources of Noise Stemming from Electric Utility Equipment

Given the distance to ground level, distribution powerline noises are the most readily detectable by human observers equipped with, for example, a spectral analyzer and directional microphone where the sensors can also be placed on the towers and/or poles.
PO S I T S:

POSITING POTENTIAL SOURCES OF POWER-RELATED NOISE
# Image Classification: Likelihood of Arcing

<table>
<thead>
<tr>
<th>Electric Utility Equipment</th>
<th>Weather Conditions</th>
<th>Fair Weather</th>
<th>Light rain/Fog</th>
<th>Heavy rain/Wet Snow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bell Insulator</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lightning arrestor</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Poorly wrapped/Insulated tie wire</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other connected equipment</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Other nearby, non-connected equipment</td>
<td></td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>Electric Utility Equipment</td>
<td>Weather Conditions</td>
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<tr>
<td>Corona Discharge Noise</td>
<td>Fair Weather</td>
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</tr>
<tr>
<td></td>
<td>Light rain/Fog</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Heavy rain/Wet Snow</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

- **Fair Weather**
  - X

- **Light rain/Fog**
  - ✓

- **Heavy rain/Wet Snow**
  - ✓

- **Dry Snow**
  - X
## Spectrogram Results

<table>
<thead>
<tr>
<th>Voltage Level</th>
<th>Light Rain/Fog</th>
<th>Heavy Rain/Wet Snow</th>
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</thead>
<tbody>
<tr>
<td>.12 kV</td>
<td><img src="image" alt="Light Rain/Fog .12 kV" /></td>
<td><img src="image" alt="Heavy Rain/Wet Snow .12 kV" /></td>
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<tr>
<td>2.4 kV</td>
<td><img src="image" alt="Light Rain/Fog 2.4 kV" /></td>
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<tr>
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</tr>
<tr>
<td>765 kV</td>
<td><img src="image" alt="Light Rain/Fog 765 kV" /></td>
<td><img src="image" alt="Heavy Rain/Wet Snow 765 kV" /></td>
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</tbody>
</table>
The research focused on whether it can be demonstrated that powerline noise can be used as an early indicator and warning of impending potential power reliability and stability issues. The problem of powerline noise can be influenced by the corona release factor and whether equipment is installed incorrectly. Powerline noise also depends on high and low frequencies.

- **Powerline Noise Disadvantages**
  
  Directly affects the performance indices of electric power system reliability, such as SAIFI, SAIDI, MAIFI, and CAIDI.

- **The Opportunity of Powerline noise**
  
  Detection of certain aberrations at the edge, as an early indicator and warning for potential power reliability and stability issues (i.e., power outage mitigation).

- **Low-cost Noise Sensors**
  
  Low-cost noise sensors might provide an opportunity for detection of certain powerline noise aberrations at the “edge” against a set of compiled heuristics.
EXPERIMENT: EXPERIMENTAL SETUP AND RESULTS
HUMIDITY RATES AND THE EFFICACY FOR CORONA DISCHARGE DETECTION

- District A: 85.27%
- District B: 75.14%
- District C: 81.83%
- District D: 82.00%
- District E: 90%

HOSPITAL A: 87.6%
In fact, at the SEZ hospital, the humidity was at 90% in comparison to the surrounding area (thereby providing the most favorable conditions for corona discharge detection). In essence, the charge density in the approximate vicinity of the corona wire increased with an increase in humidity. Indeed, the humidity directly affects the corona inception voltages. It has been found that the peak-to-peak values of audible noise pulses and the amplitude of corona current pulses have a one-to-one relationship in time.

Powerline frequencies estimated by audio analyzers enhanced with directional microphones for various powerline voltage levels can establish a set of compiled heuristics over time, via various machine learning approaches. In fact, in areas of high humidity, the higher frequency spectral components are more pronounced than the lower frequency components. The advantage of this phenomenon resides in the fact that the lower frequency components are, potentially, principally undesirable background noise for some cases.
EXPERIMENTAL SETUP

EQUIPMENT
MSI GS63 7RE Stealth Pro laptop and Nubwo M22 Pro directional microphone

AUDIO ANALYZER
Visual Analyser, ARTA, and Friture.
EXPERIMENTAL RESULTS

Powerline Frequencies Estimated by Audio Analyzers for Various Powerline Voltage Levels

Powerline Frequencies Estimated by Audio Analyzers Enhanced (E) with Directional Microphones for Various Powerline Voltage Levels
POWERLINE FREQUENCIES ESTIMATED BY STANDALONE AUDIO ANALYZERS AS WELL AS ENHANCED WITH DIRECTIONAL MICROPHONES FOR VARIOUS POWERLINE VOLTAGE LEVELS
The powerline frequency of the 138 kV disconnecting switch under non-arcing conditions (orange line) and under arcing conditions (blue line). Under normal “non-arcing” conditions, the frequency range is 961-1298 Hz; however, at the time where the arcing occurred, the frequency spiked to 3123 Hz.
UNANTICIPATED FINDINGS:

SOME COMMON MISCONCEPTIONS UNVEILED
OBSERVATIONS

Powerline noise mitigation involves eliminating of an arc of some type, which can occur for several reasons including loose hardware, a cracked insulator, corrosion between two pieces of metal, a loose tie wire, carbon tracking (i.e., carbon-rich prior arc path), etc.

HELICAL SPRING

Helical spring washers actually might not prevent loosening and can be shown to actually speed up the rate of loosening in many cases. Hospitals in hot weather areas are, for some cases, at higher risk.

POLYMER INSULATOR

Vise-Top “polymer” insulators are far superior to tie wires, which can cause arcs when loose, especially in cases involving polyethylene covered line wire.

POWERLINE ARCING

Weather conditions (e.g. freezing can cause hardware to loosen) can aggravate the situation and accelerate the process towards potential arcing. Hospitals in cold weather areas are, for some cases, at higher risk.
CONCLUSION

Closing

EXPERIMENTAL RESULTS
It is indeed possible to obtain results addressing common misconceptions (e.g., corona discharge are infrequently the source of powerline noise).

EXPERIMENTAL RESULTS
It is indeed possible to obtain evidence-based results that challenge existing best practices (e.g., helical springs may actually accelerate loosening).

SPECTROGRAMS AND 3-D LINE CHARTS
It is possible to achieve higher detection certainty as pertains to abnormal arcing and noise for electricity equipment.

LOW-COST NOISE SENSOR
Hence, it is indeed possible to utilize a low-cost noise sensor paradigm for detecting abnormal powerline noise.
CONCLUSION CONT’D

POWERLINE NOISE
Generally speaking, much powerline noise is from loose hardware and small arcs, and powerline noise is usually stronger on lower frequencies.

POWERLINE NOISE
Powerline generated noise will typically not vary with the time of day.

LOW-COST SENSORS MAY HAVE THE ADVANTAGE OF NOT EMITTING RF ENERGY

WE HAVE, POTENTIALLY, ASCERTAINED SOME INTERESTING HEURISTICS TO FACILITATE IMAGE/AUDIO CLASSIFICATION

LOTS OF POSSIBILITIES FOR TINYML!
RECOMMENDATIONS

(1) adherence to the recommended IEEE Std 1-2000 (R2011) (Revision of ANSI/IEEE Std 1-1986) with regards to the evaluation of electrical insulation

(2) adherence to the recommended IEEE Std 99-2007 (Revision of IEEE Std 1-1980) with regard to the thermal evaluation of insulation systems for electrical equipment

(3) better estimation of the hyper-locale aging and degradation of the involved components as well as adapting maintenance plans as appropriate

(4) more optimal deployment/placement of specialized high-telemetry sensors for enhanced monitoring.
THANK YOU

FOR YOUR TIME AND ATTENTION!