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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Mitigate/Reduce Power Outages, Particularly at Community Health Care Facilities

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SOME COMMON MISCONCEPTIONS UNVEILED

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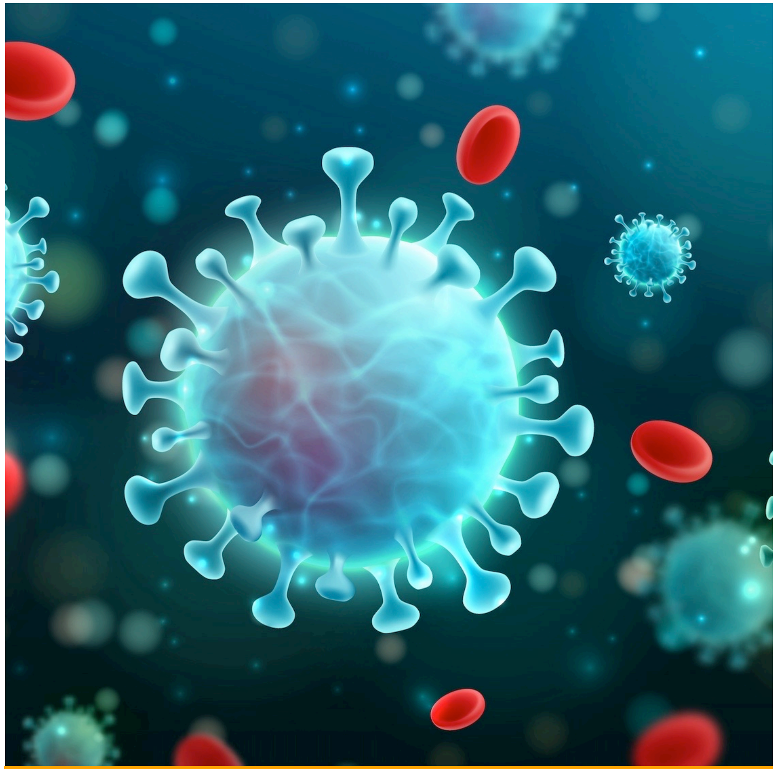
OBJECTIVE:

MITIGATE/REDUCE POWER OUTAGES, PARTICULARLY AT COMMUNITY HEALTH CARE FACILITIES THAT DO NOT HAVE ROBUST RESILIENCY BUDGETS

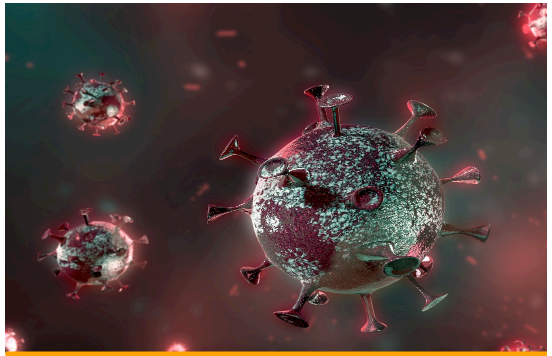
SOME BACKGROUND INFORMATION…

The Load increased dramatically during Covid-19

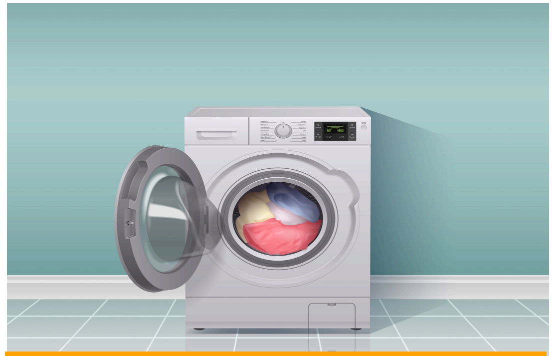


SARS-CoV-2

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

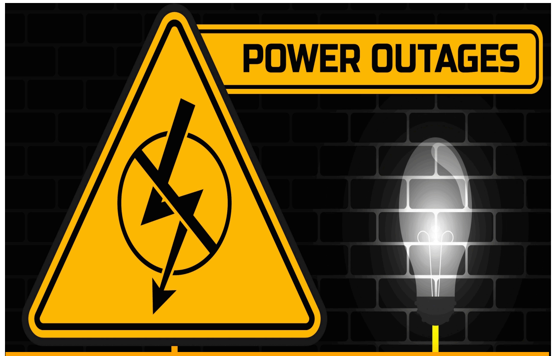
Many viruses won’t survive in temperatures over 60°C

COLLEAGUES REQUESTED ASSISTANCE…

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

HISTORICAL POWER OUTAGE EVENTS IN HOSPITALS

2017

POWER OUTAGE IN THE MEDICAL CENTER COMMUNICATION GOING OFFLINE AND INTERNAL PHONES BETWEEN DEPARTMENTS BECOME INOPERATIVE FOR HOURS

2018

A LARGE UNIVERSITY HOSPITAL FORCED TO CANCEL SURGERIES SINCE THE PRIMARY GENERATOR ONLY LASTED FOR 30 MINUTES

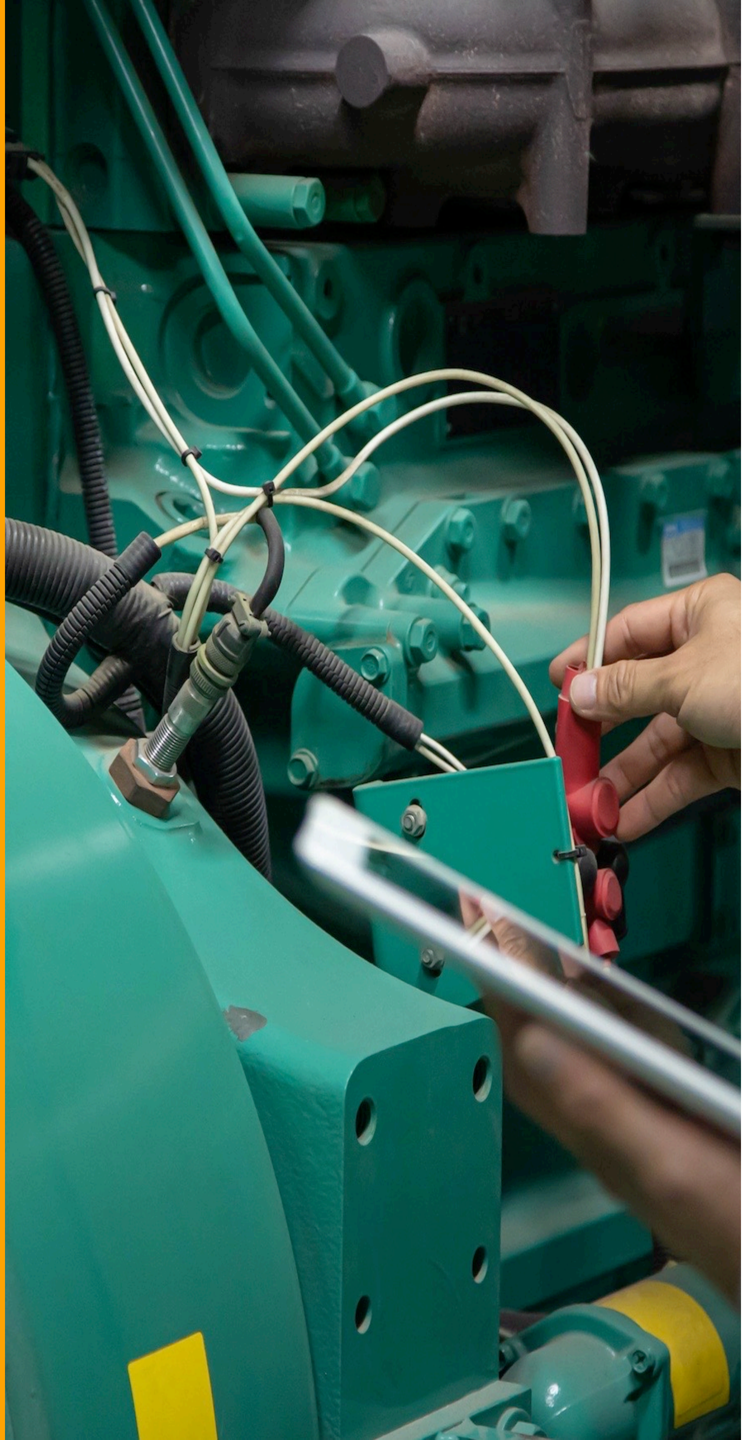
2020

BOTH CABLES SUPPLYING ELECTRICAL POWER TO A PRESTIGIOUS HOSPITAL FAILED. POWER OUT FROM 8:30AM TO 6:30PM

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.

QUASI-REAL TIME MONITORING

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
- NOISE

GOOD COMBINATION TO CONTEND WITH FALSE POSITIVES/NEGATIVES

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 I

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.

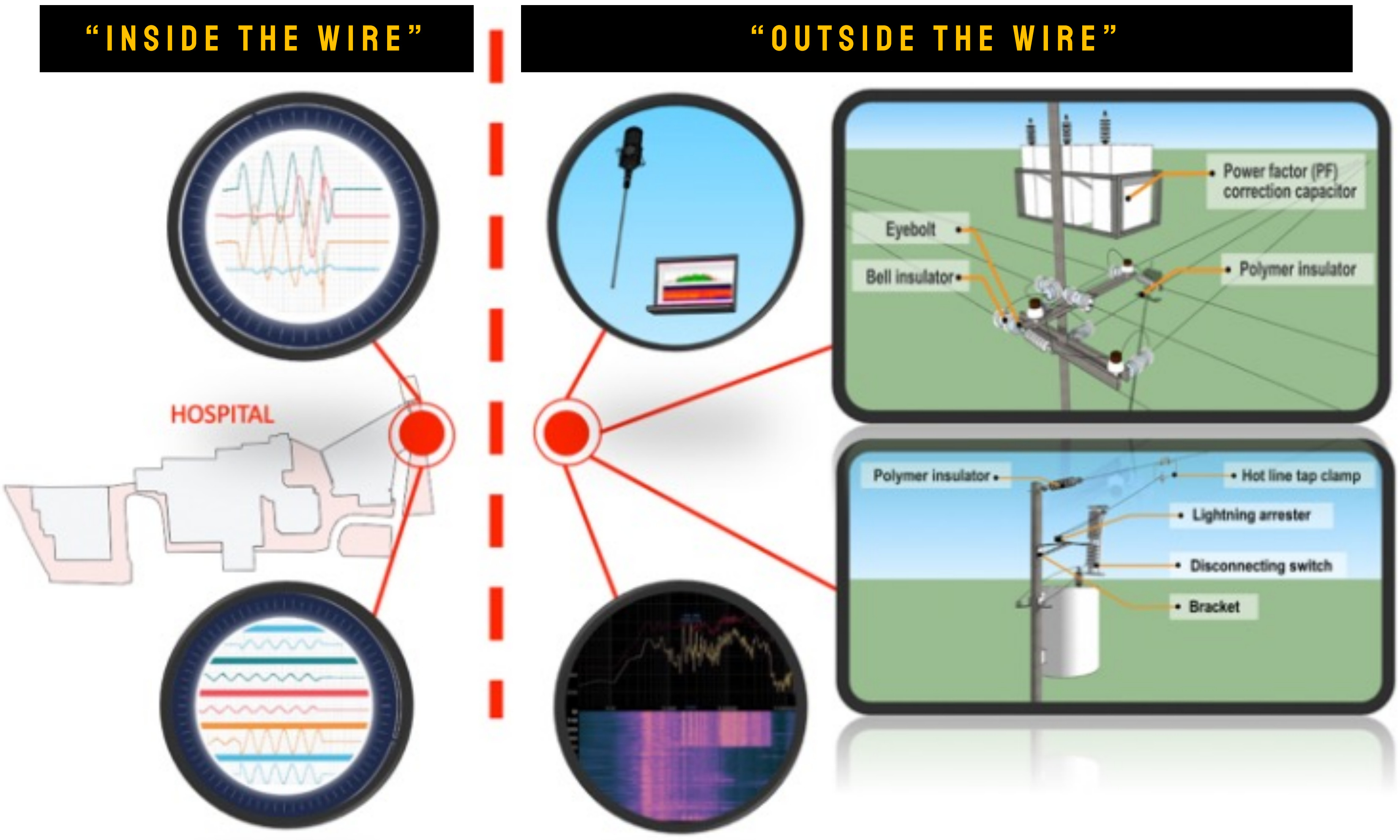
THE DUAL OPPORTUNITY 2

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

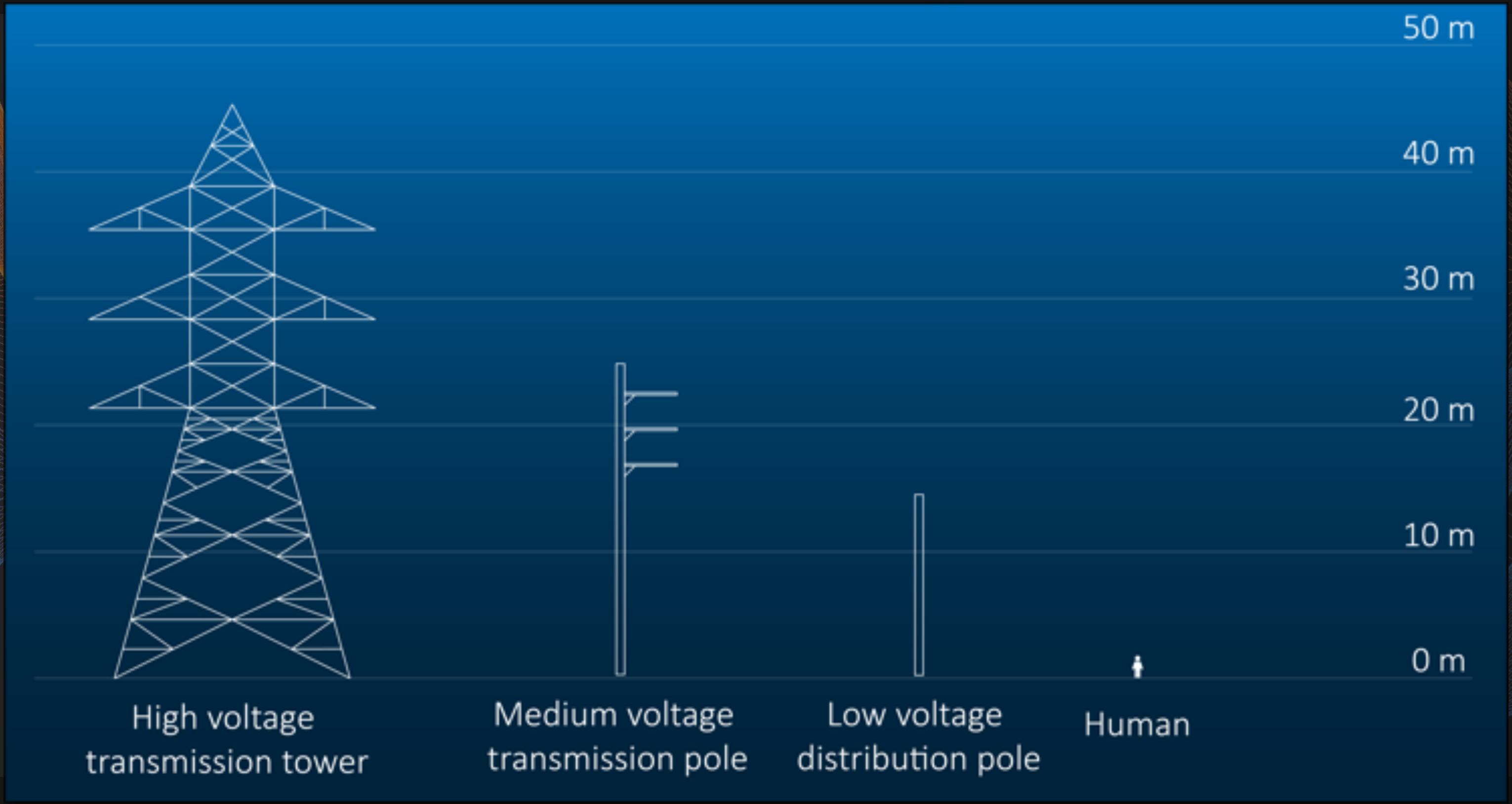
SAIDI
System Average Interruption Duration Index

MAIFI
Momentary Average Interruption Frequency Index

CAIDI
Customer Average Interruption Duration Index

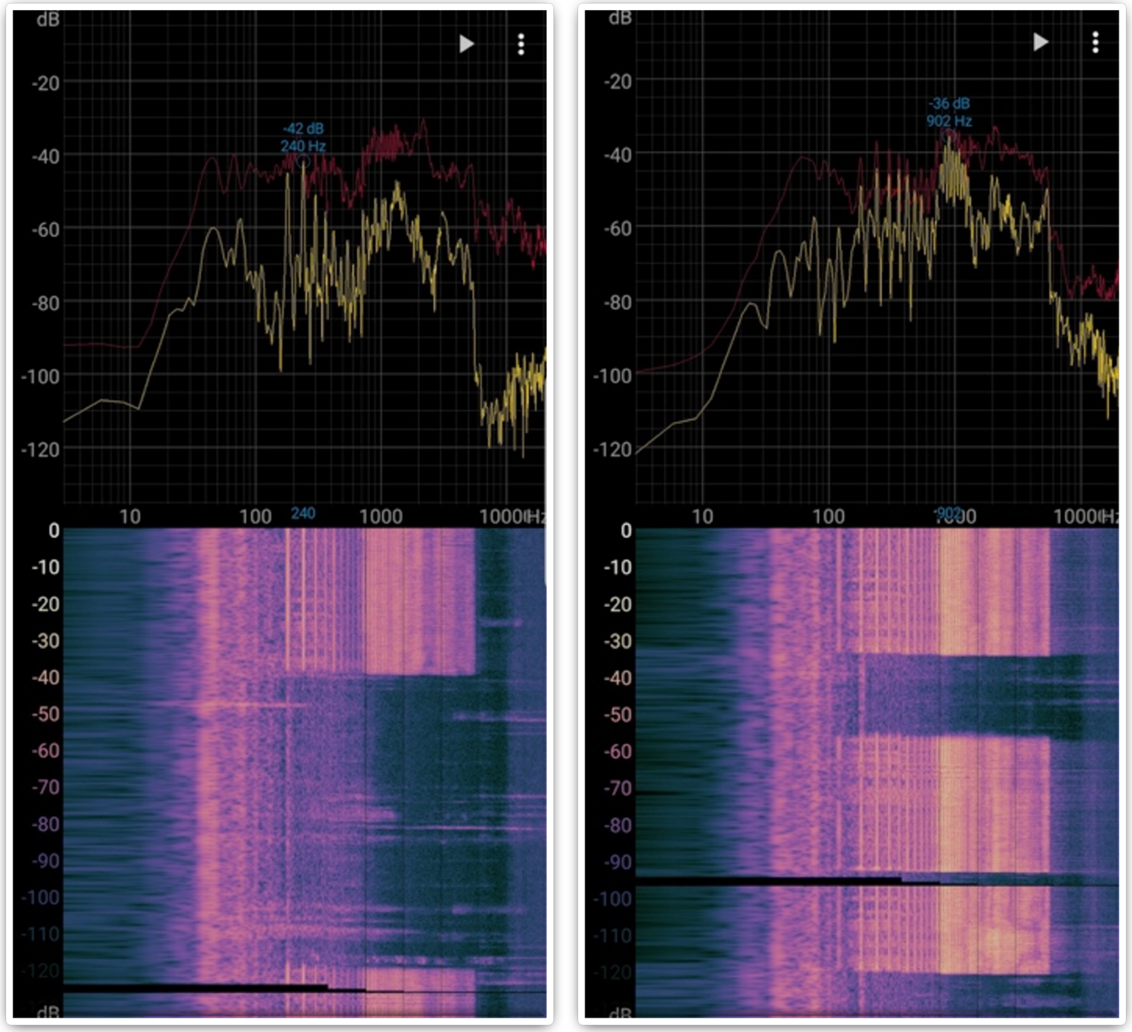
EXAMINED HOW LOW-COST NOISE SENSORS MIGHT PROVIDE AN OPPORTUNITY FOR COMPREHENSIVE COVERAGE & DETECTION OF CERTAIN POWERLINE NOISE ABERRATIONS AT THE “EDGE” AGAINST A SET OF COMPILED HEURISTICS.

PRIMER ON POWERLINE NOISE

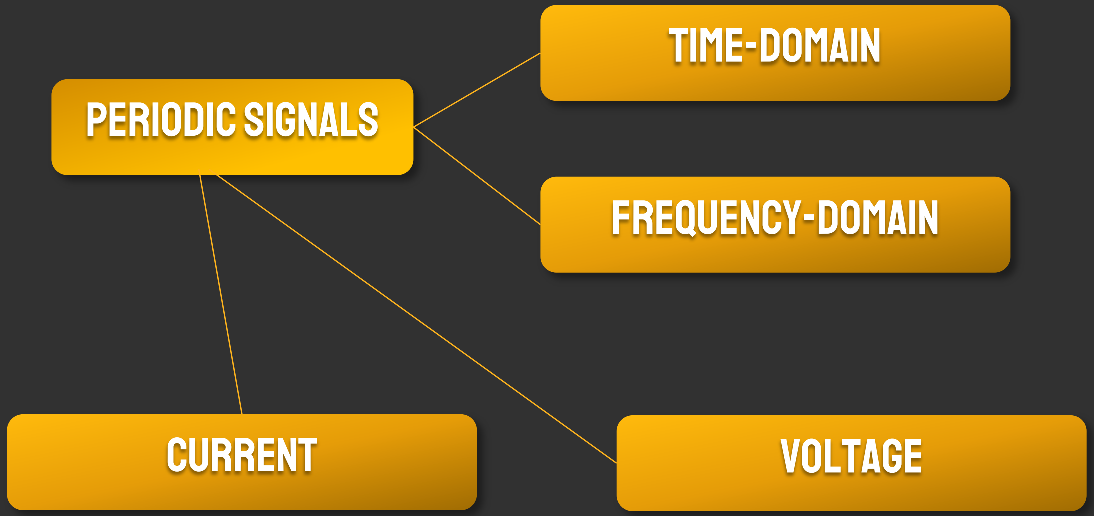


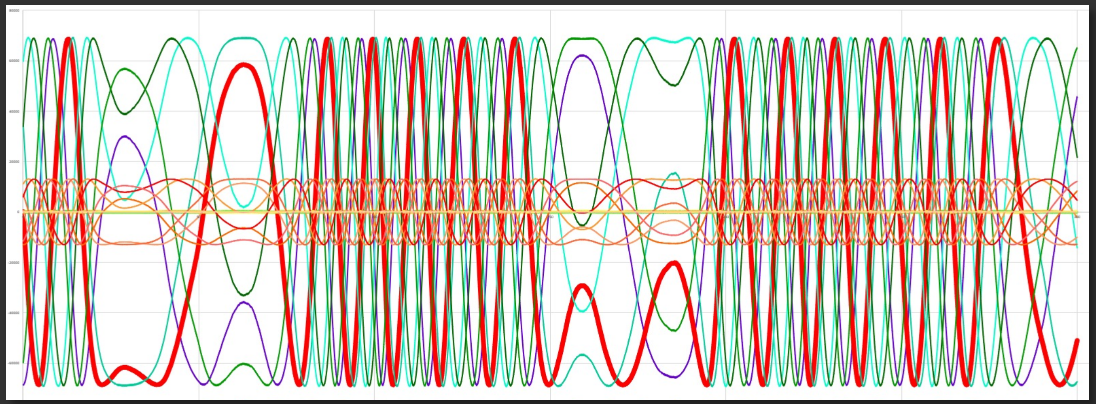
HIGH FREQUENCY HISSING -> HARD TO DETECT (POTENTIALLY, FOR SOME CASES)

LOW FREQUENCY HUMMING -> EASIER TO DETECT (POTENTIALLY, FOR SOME CASES)



BACKGROUND INFORMATION ON POWERLINE NOISE





LEXICON PRIMER ON

POWERLINE-RELATED NOISE

INCIDENTAL EMITTERS

No specific limits on the conducted or radiated emissions.

ELECTRICAL GRID EQUIPMENT

UNINTENTIONAL EMITTERS

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

MICROPROCESSORS, SWITCHED-MODE POWER SUPPLIES

LOW-COST SENSORS

INTENTIONAL EMITTERS

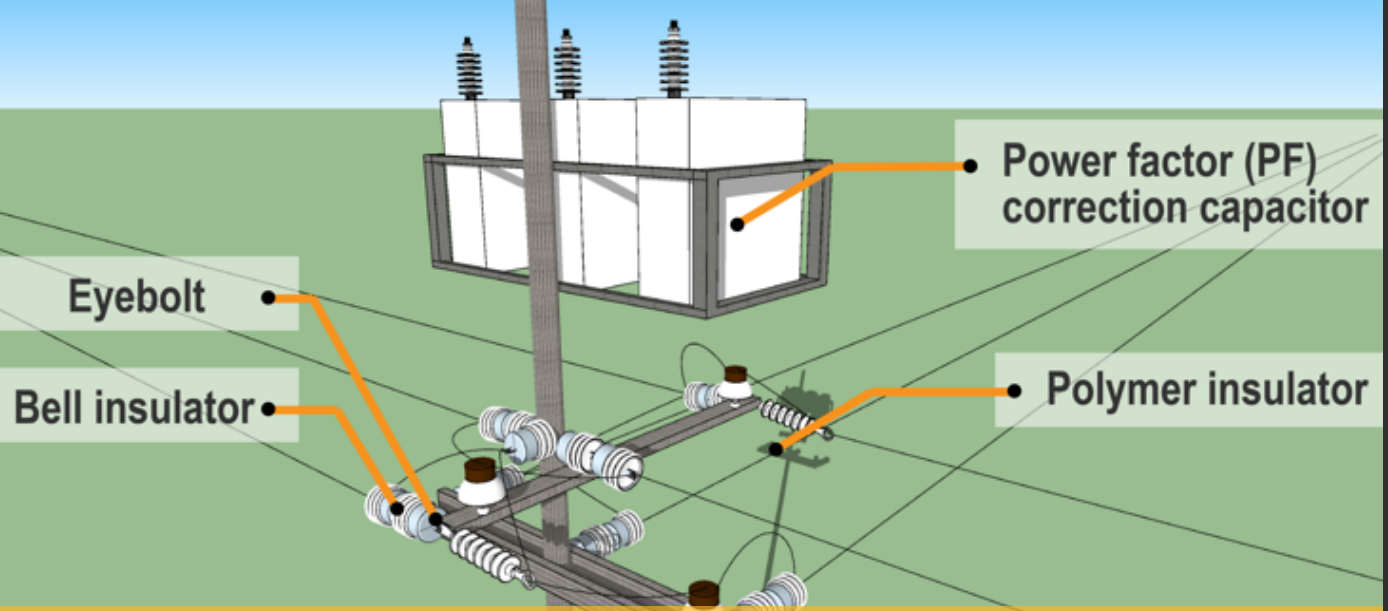
Transmitters that intentionally radiate RF energy.

REMOTE READING METERS THAT SEND DATA

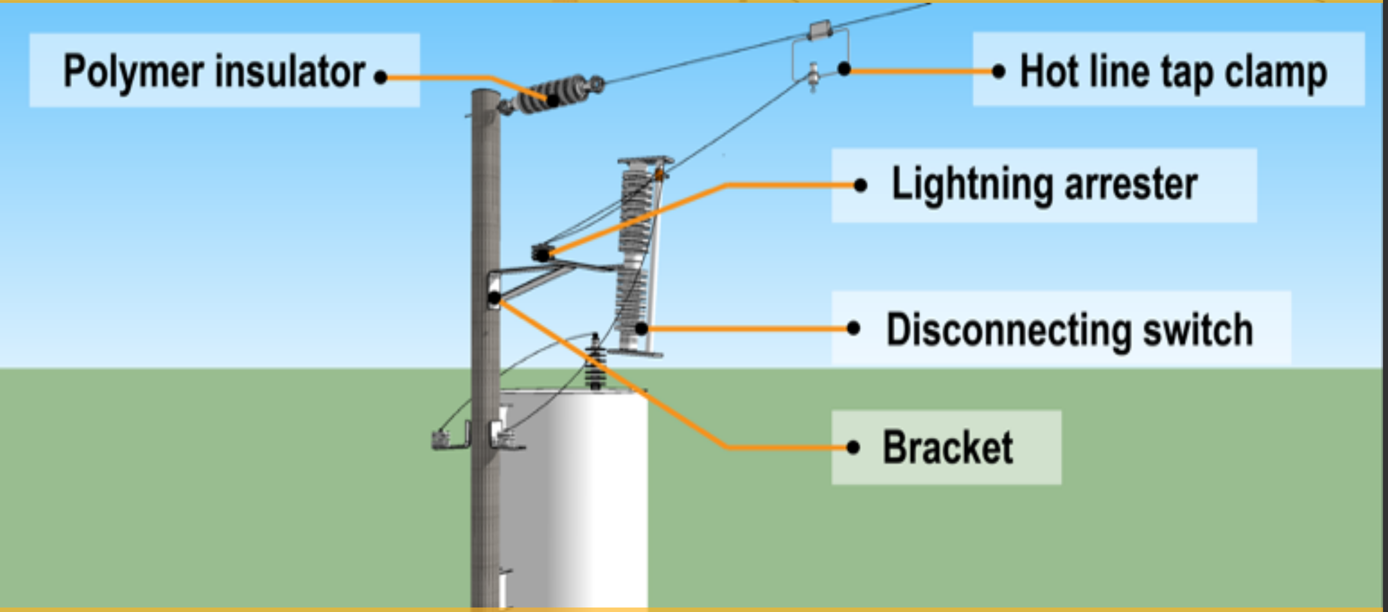
HIGH-COST SENSORS

PROBLEMS:

COMMON SOURCES OF POWER-RELATED PROBLEMS



PROTOTYPICAL DISTRIBUTION POLE (PDP)



PDP WITH POLE-MOUNTED TRANSFORMER

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.

POSITS:

POSITING POTENTIAL SOURCES OF POWER-RELATED NOISE

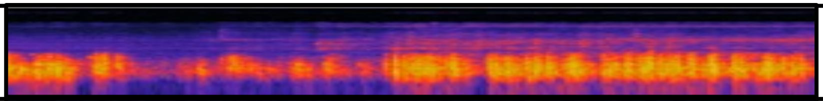
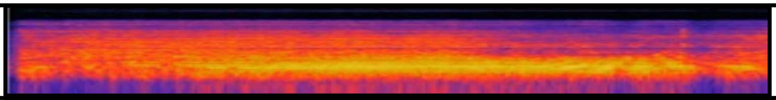
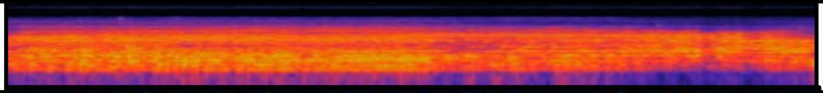
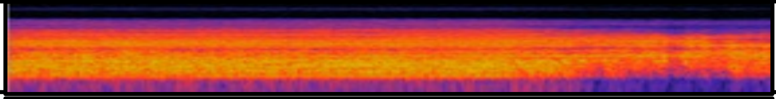
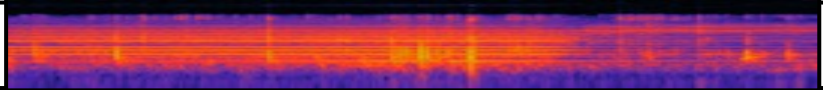
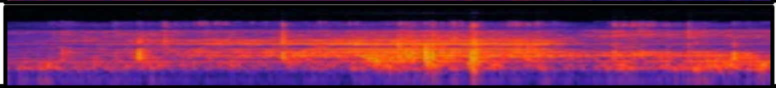
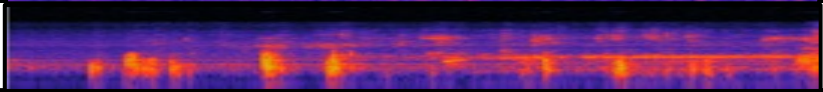
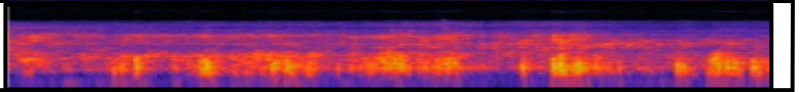
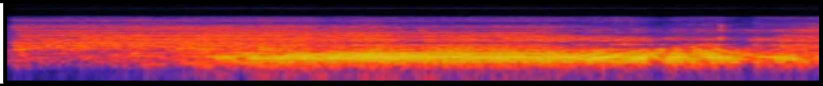
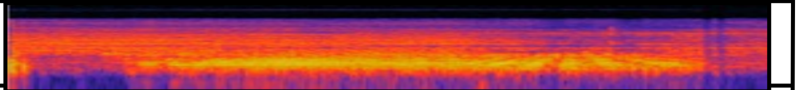
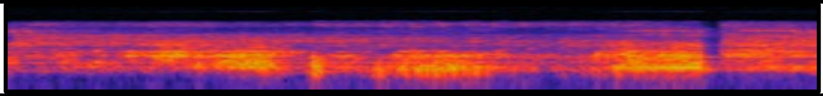
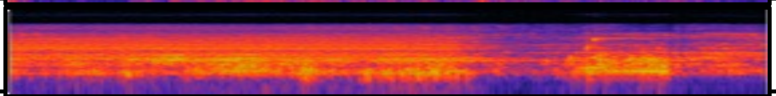
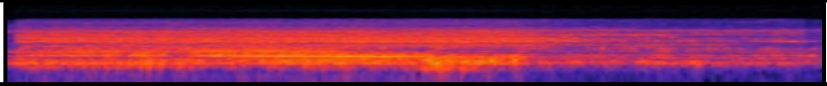
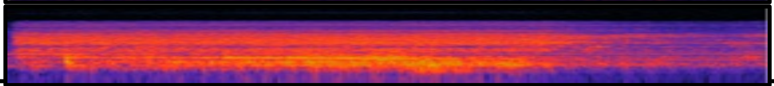
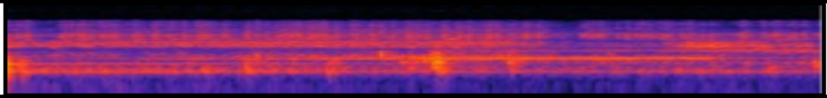
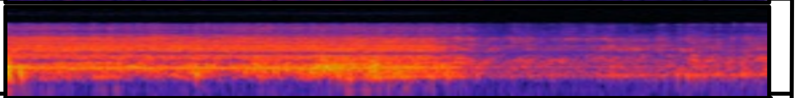
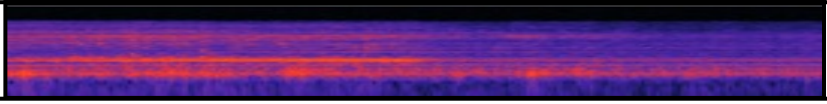
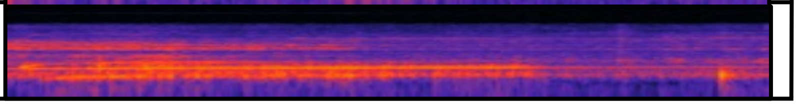
IMAGE CLASSIFICATION: LIKELIHOOD OF ARCING

	Weather Conditions		
Electric Utility Equipment	Fair Weather	Light rain/Fog	Heavy rain/Wet Snow
Bell Insulator	✓	✗	✗
Lightning arrestor	✓	✓	✓
Poorly wrapped/Insulated tie wire	✓	✗	✗
Other connected equipment	✓	✓	✓
Other nearby, non-connected equipment	✓	✗	✗

AUDIO CLASSIFICATION: LIKELIHOOD OF NOISE

	Weather Conditions			
Electric Utility Equipment	Fair Weather	Light rain/Fog	Heavy rain/Wet Snow	Dry Snow
Corona Discharge Noise	✗	✓	✓✓	✗

SPECTOGRAM RESULTS

VOLTAGE LEVEL	LIGHT RAIN/FOG	HEAVY RAIN/WET SNOW
.12 KV		
2.4 KV		
12 KV		
33 KV		
150 KV		
220 KV		
400 KV		
750 KV		
765 KV		

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

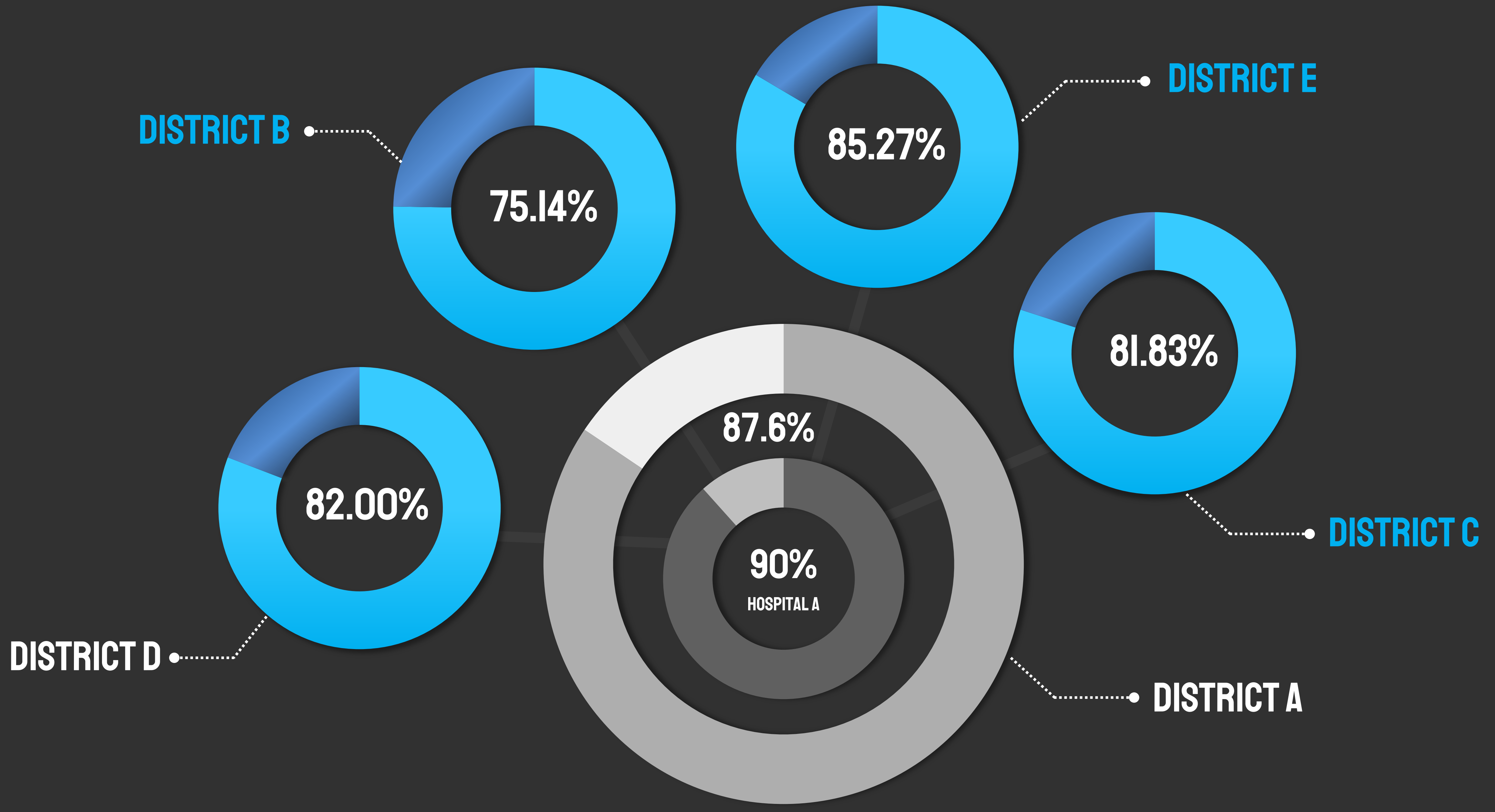
Low-cost noise sensors might provide an opportunity for detection of certain powerline noise aberrations at the "edge" against a set of compiled heuristics.

Research Focus

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.

EXPERIMENT:

EXPERIMENTAL SETUP AND RESULTS



HUMIDITY RATES AND THE EFFICACY FOR CORONA DISCHARGE DETECTION

• EXPERIMENT CONDUCTED IN HIGH HUMIDITY AREAS

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

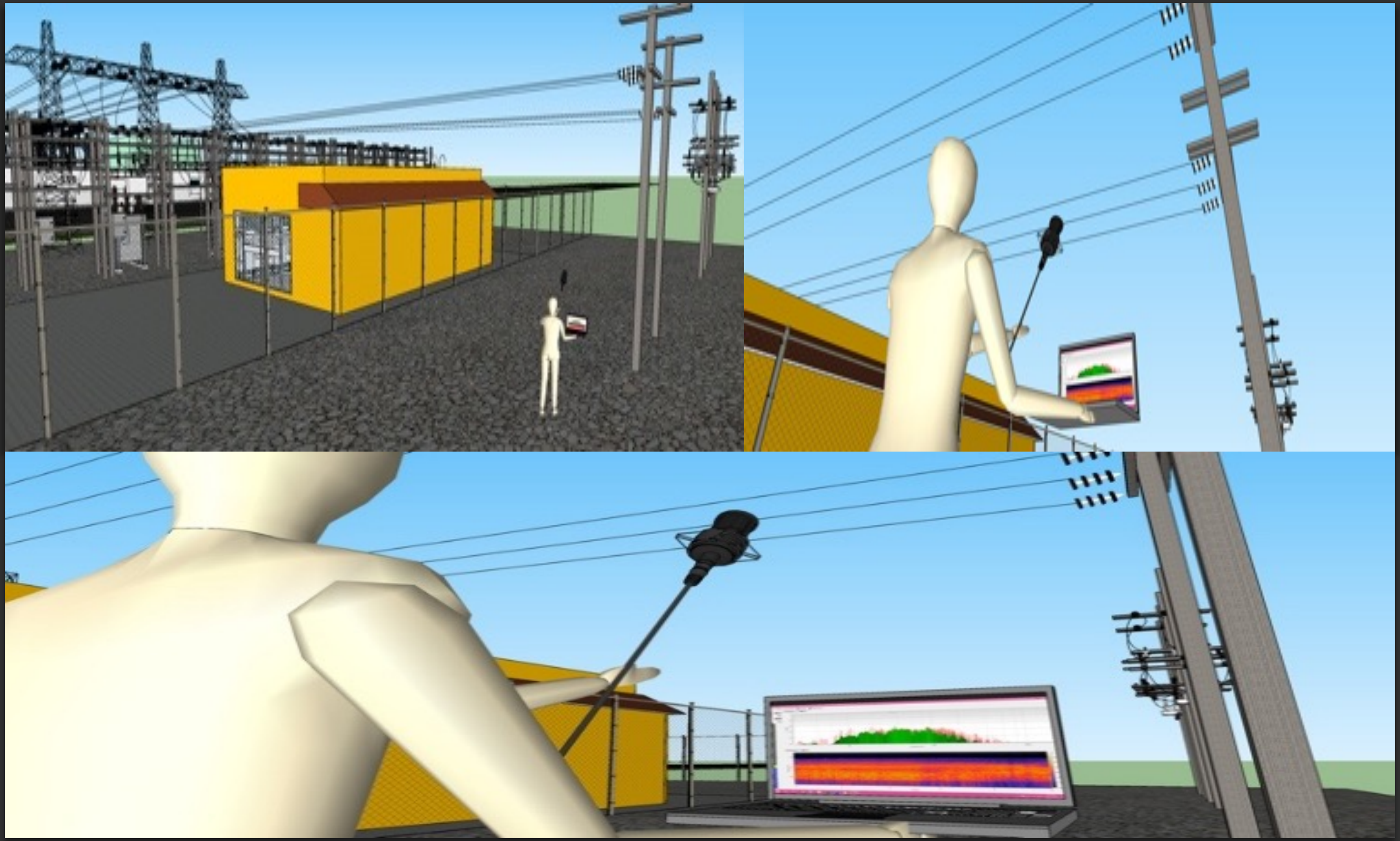
EXPERIMENTAL SETUP

EQUIPMENT

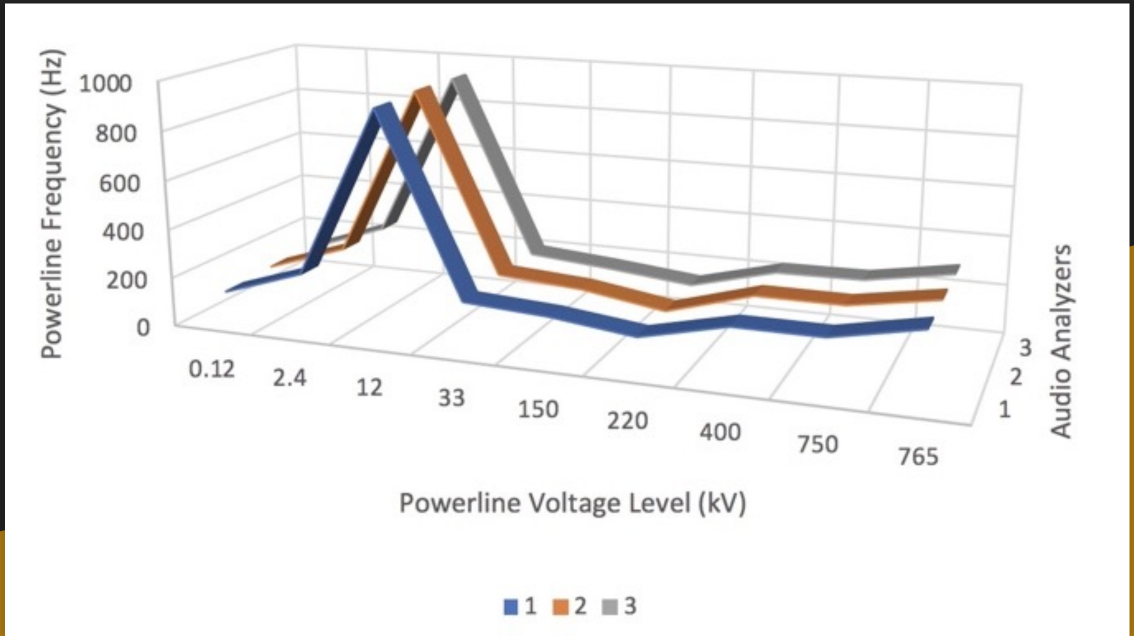
MSI GS63 7RE Stealth Pro laptop and Nubwo M22 Pro directional microphone

AUDIO ANALYZER

Visual Analyser, ARTA, and Friture.

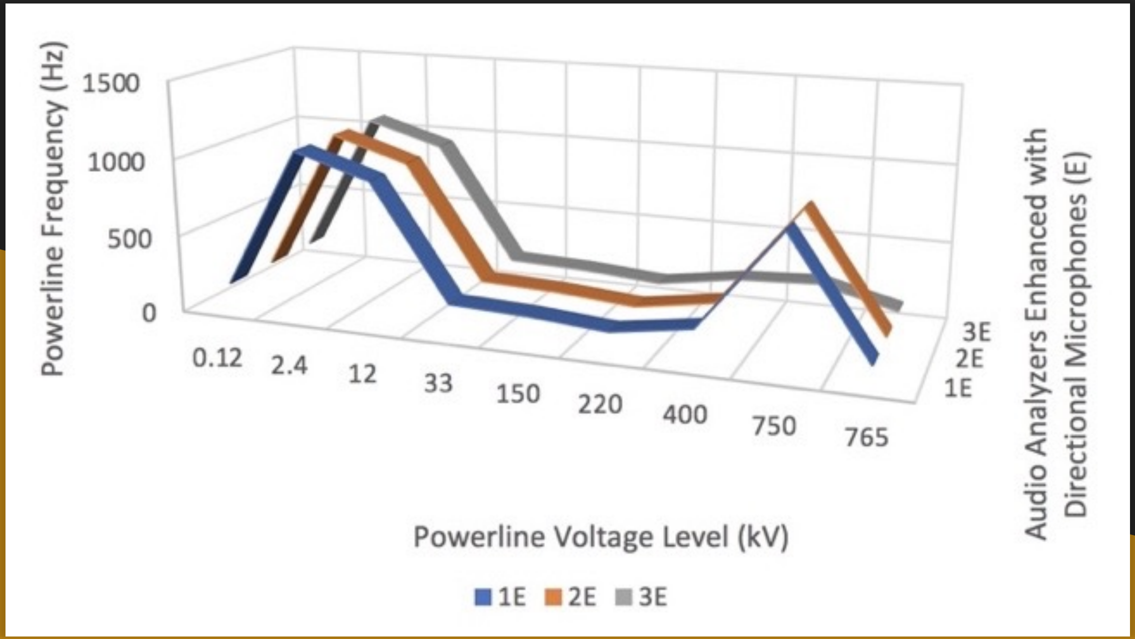


EXPERIMENTAL RESULTS



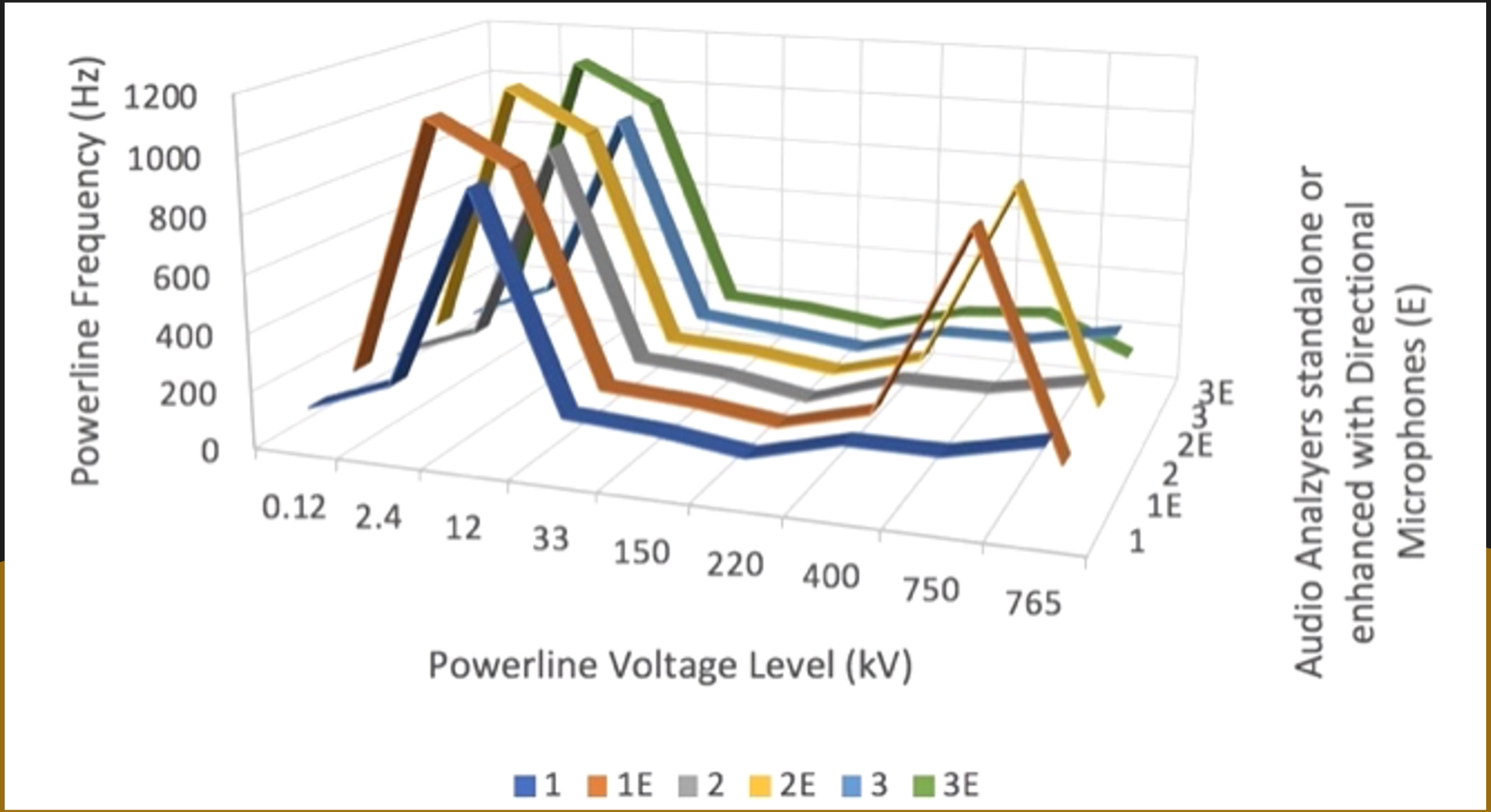
VISUAL ANALYZER ARTA FRITURE

Powerline Frequencies Estimated by Audio Analyzers for Various Powerline Voltage Levels

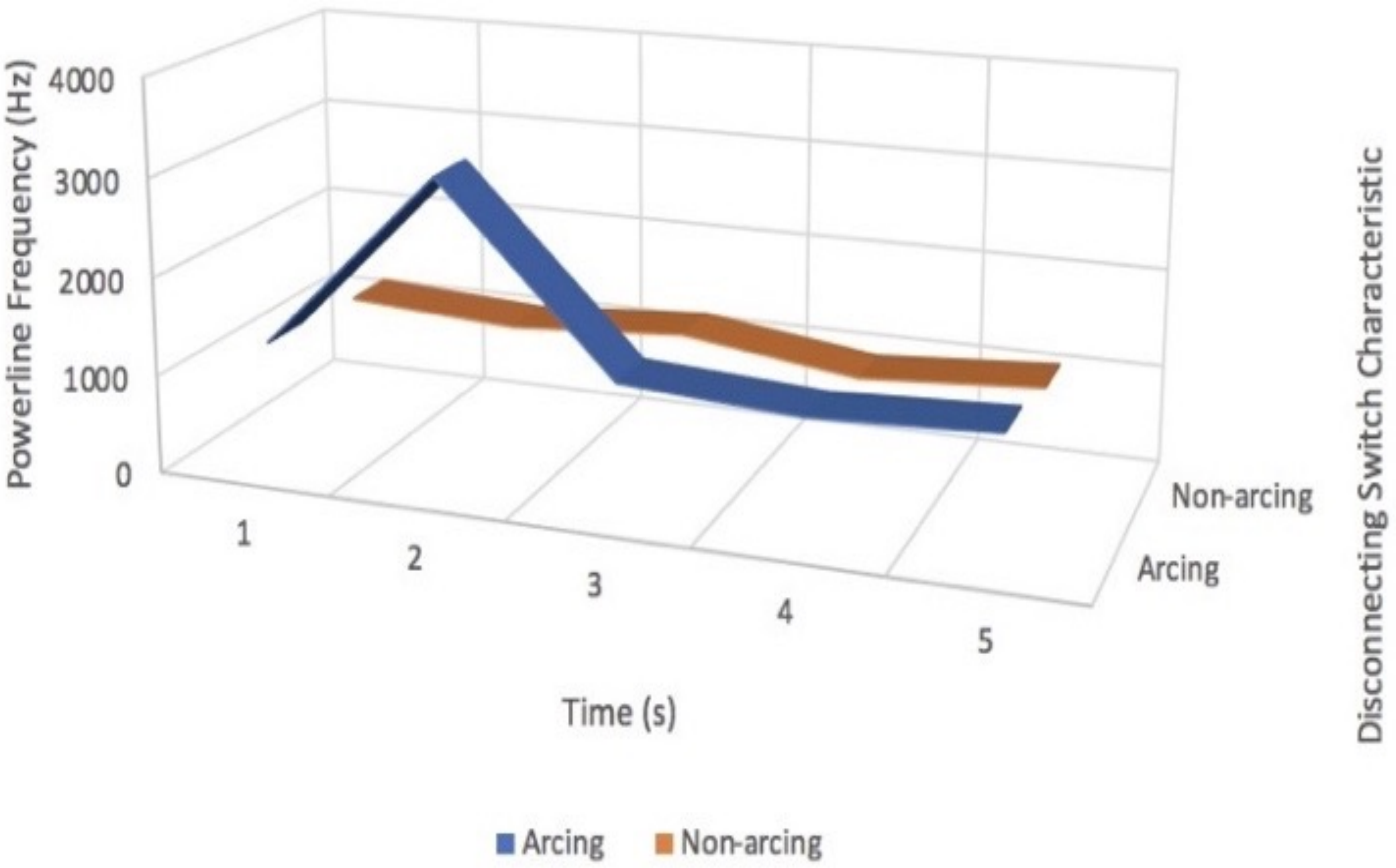


VISUAL ANALYZER+DM ARTA+DM FRITURE+DM

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.

NORMAL FREQUENCY OF DISCONNECTING SWITCH CONTRASTED WITH ABNORMAL ARCING FREQUENCY NOISE

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.

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.

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.

Closing

CONCLUSION

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!