2017 ADMS Program
Steering Committee Meeting

Sensing Electrical Networks Securely and Economically (SENSE)

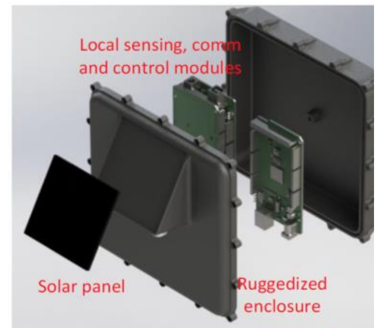
Prof Deepak Divan, Member NAE, Fellow IEEE
Center for Distributed Energy, Georgia Tech

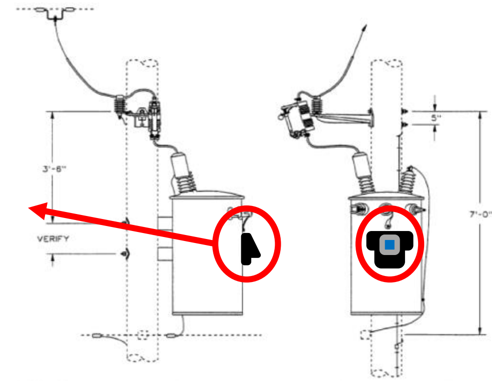
October 12th 2017

Sensing Electrical Networks Securely and Economically (SENSE)

Objectives & Outcomes

- To develop and demonstrate secure ubiquitous low-cost sensor networks for distribution service transformer monitoring.
- Field evaluation of sensors on two distribution feeders located with utility partner.
- Business model for the deployment of such low-cost sensors, providing an ROI basis for utility users





Technical Scope

- Develop low cost sensors using techniques compatible with volume production.
- Integrate flexible energy management, communications, advanced functionality, data storage, cloud connectivity, cybersecurity, analytics, machine learning, and user interface into sensor design
- High-risk non-contact sensing can reduce cost of deployment dramatically.

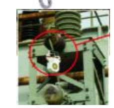
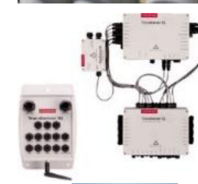
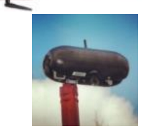
Life-Cycle Funding Summary ($K)

FY18, authorized	FY19, planned	FY20, planned
$581k	$583k	$709k

Partners:
Georgia Tech – Center for Distributed Energy (lead)
Oak Ridge National Laboratories
Southern Company

Low Cost Sensors for Distribution Systems

- The Smart Grid is predicated on increased visibility and awareness across the entire grid infrastructure
- Sensors and Phasor Measurement Units (PMU) on the transmission system have added tremendous value
- The promise of increased visibility across the typically ‘blind’ distribution grid is attractive as it can provide improved controllability, diagnostics and prognostics, and can minimize downtime and improve operational SAIDI/SAIFI indices
- Many utility sensors are available commercially and should be seeing broad deployment
- However, with the exception of specific instances where there is a corporate or regulatory mandate, utilities have been unable to justify wide deployment

Wireless Sensor for Overhead Lines (SEL)[4]	
Lighthouse MV Sensor (Tollgrade)[5]	
Powerline Sensing using Backscatter (EPRI, SwRI, TVA) [6]	
UNC, TVA and EPRI [7, 8]	
Transformer IQ (Gridsense/ Incon) [9]	
GS200/250 Line Sentry (Grid Sentry) [10]	
MM3 (Sentient energy) [11]	
OptaNODE Distribution Transformer Monitor (Grid 20/20) [12]	
Coresense (ABB) [13]	

Current Approach: Utility Distribution Monitoring

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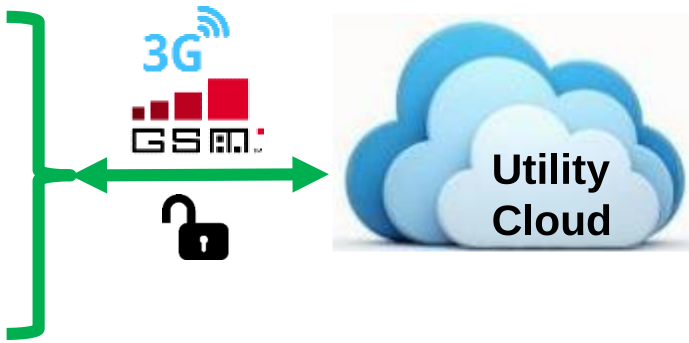
Cellular COMMs/Pvt. Network



"There is no ROI in using a $1000 sensor to monitor a $1000 transformer" – *utility engineer*

Transformer cost - $1500
Sensor costs $600 - $1500
Commission/install - $150
Operating costs - $30/year

➡ **Utilities rarely monitor assets**
Replace assets when they fail!!
Reduces system reliability

Challenges
- Good in principle - **BUT**
- Expensive, poor ROI, high customization
- Already overloaded w/data (AMI, DA)
- Complex comms and backhaul infrastructure
- Cyber-security, comms technology migration for low cost sensors
- Sensor life & replacement costs

Many companies have offered transformer monitoring but have struggled with economic viability

Wireless Transformer Asset Monitoring

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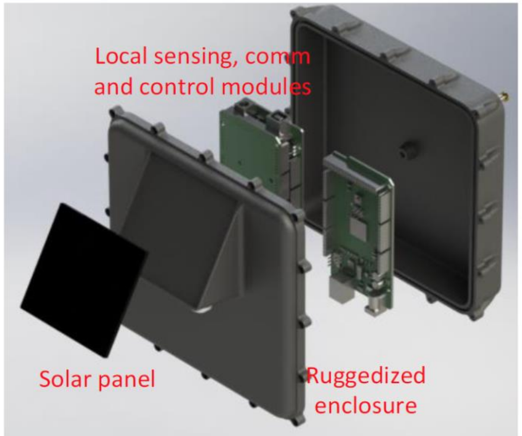
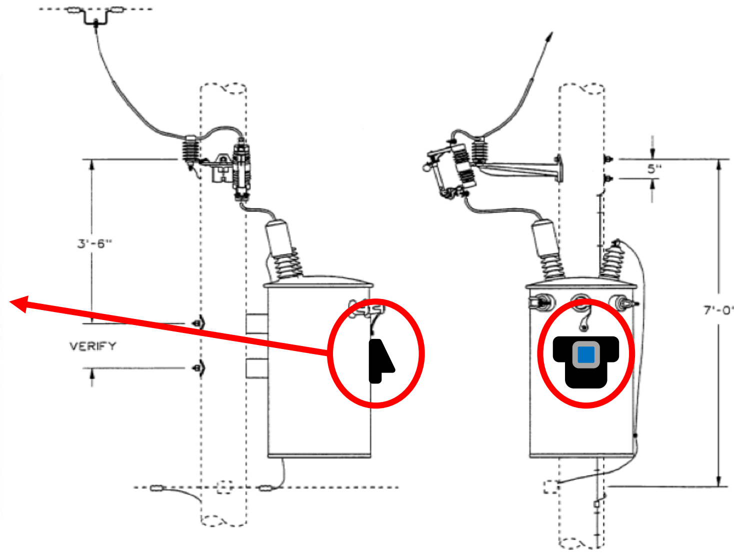
Wireless Sensing
Event Based Monitoring





- Target cost $25-100 (depending on capabilities)
- Stick-on sensor – deployable with hot-stick with minimal install time and cost
- Multiple sensing modalities – current (flux sensing), temperature and voltage (field sensing or wired)
- Sensing resolution: 32/cycle; RMS values stored every minute; reported every 15 minutes; time synchronized
- Flexible energy management – target >10 year life; PV, flux-based; Li-Ion battery
- Smart sensor – GPS, transformer life and health, volt/current recording, adaptive
- Flexible communications – on-demand (cellular) for event reporting; and zero-cost peer-peer based delay-tolerant-network (DTN) for asset health reporting
- Data management – 6 month on-sensor data storage; 'cloud' based customer-specific analytics and reporting
- Power sources: Battery/Solar Panel/Wireless Energy Harvesting
- Data analytics – Post-analysis of time-synced sensor data; outage alerts; overlay on distribution feeder data; simple visualization for end-customer
- Cybersecurity – end to end AES 128 bit encryption; monitoring for attacks; DNP3 for interoperability
- Business model – monthly base charge of $2/asset/month with upcharges for additional data-based services

Flexible Communication Architecture

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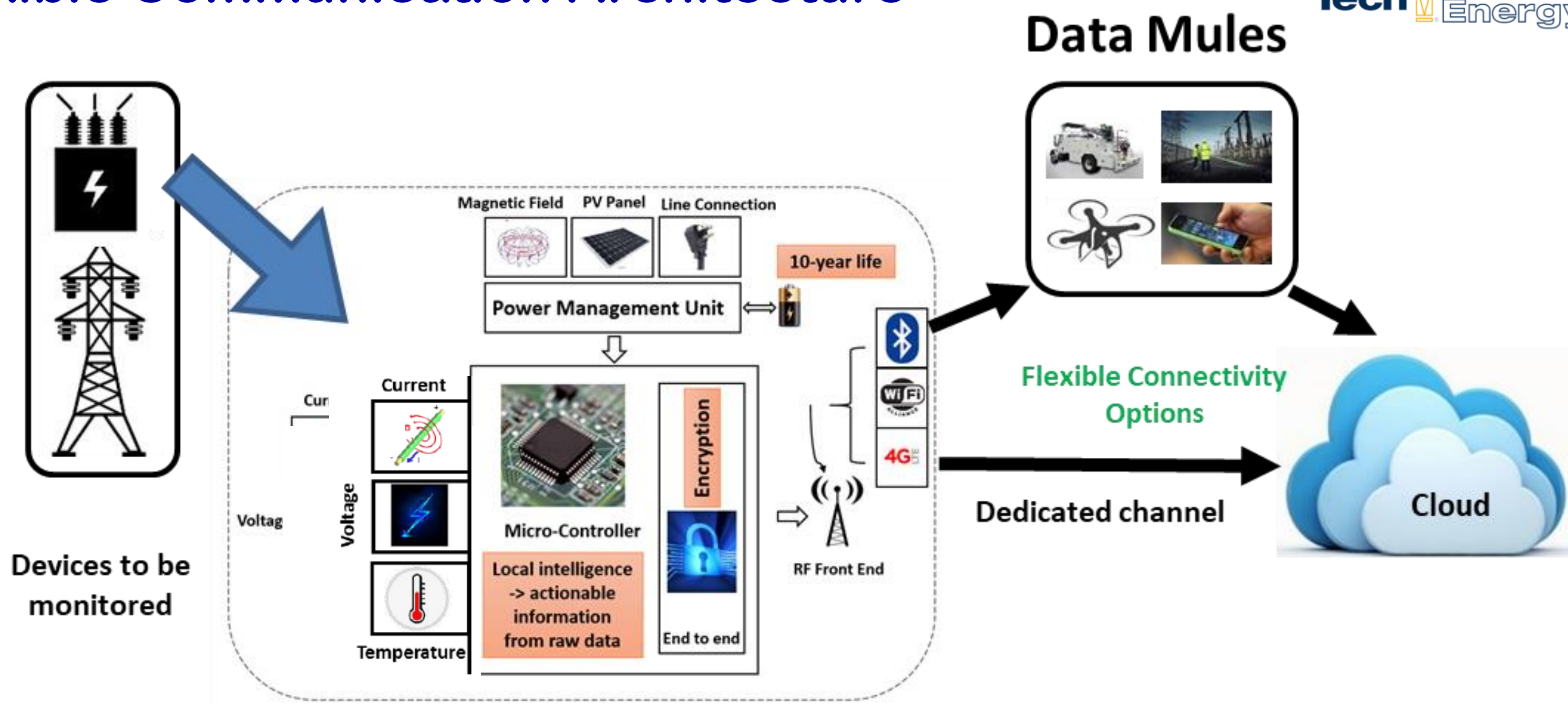

- Asset class requiring condition monitoring where intermittent connectivity is acceptable:
  - Devices which can work autonomously & with delayed communications
  - New approach to Device to Cloud connectivity can be realized
- Assets needing continuous sensing require a dedicated backhaul:
  - Can be more expensive
  - Have to deal with issues like certification & updates
  - Poor coverage/sparse areas: No access points, need own private network, which is expensive

Wired sensing → Wired power (high), complicated install → On demand COMMs
Wireless sensing → Wireless power (low), easy install → can use DTN → Condition Monitoring

Advanced Cloud Data Analytics

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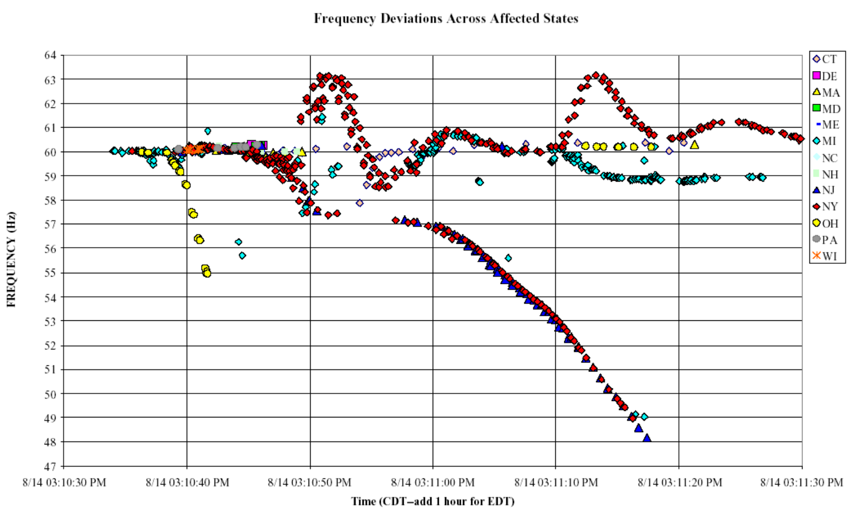
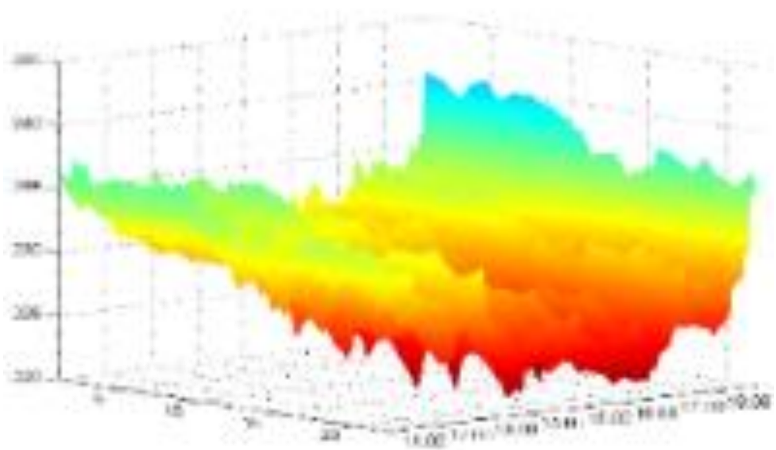
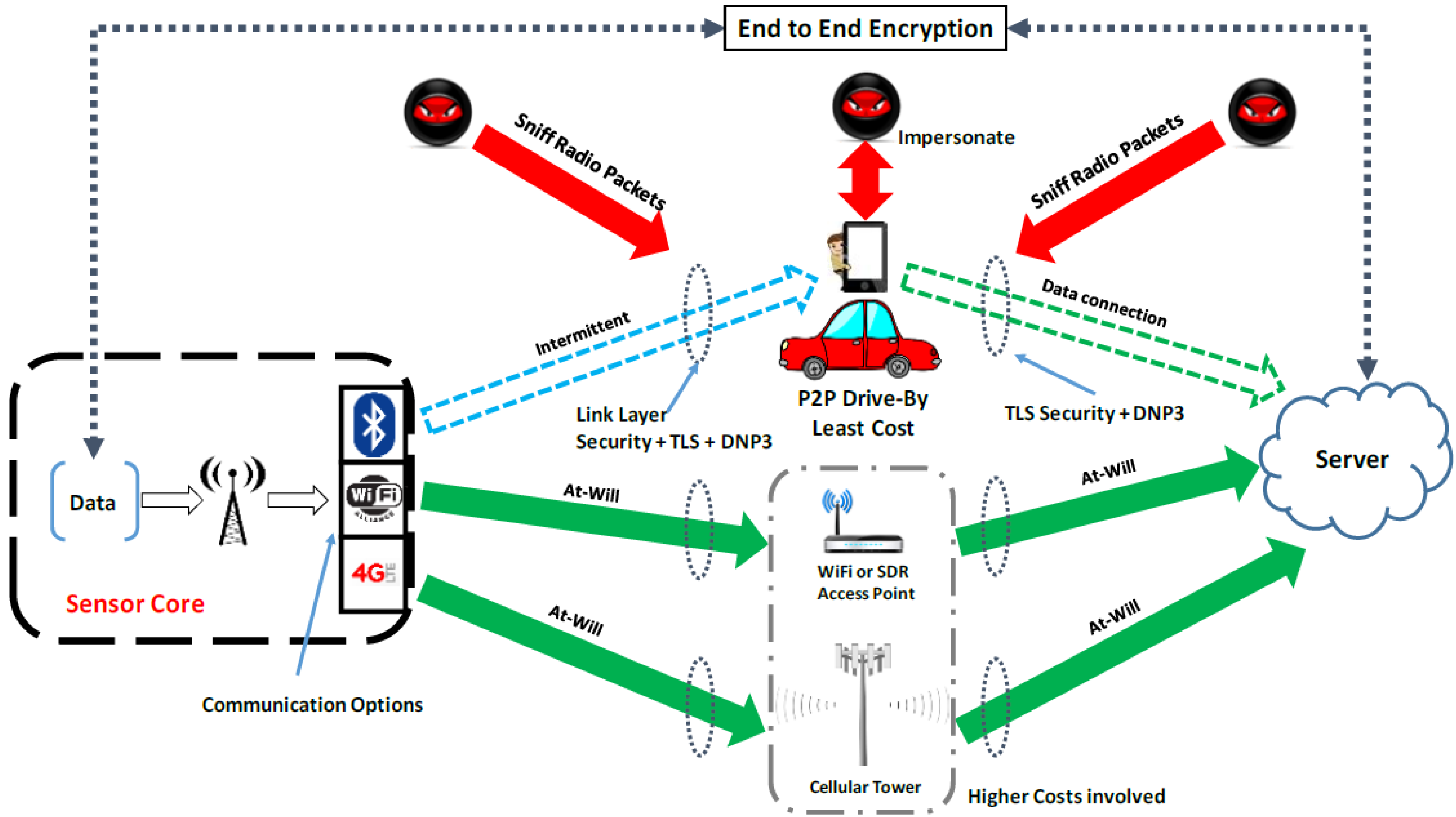
- Sensors with on-board self learning AI to extract key actionable information or significant change in sensor environment (indicative of a change in asset status)
  - Transformer degradation
  - Overloading
  - Connection topology
  - Equipment failure, etc.
- Feeder-level analytics based on individual asset data





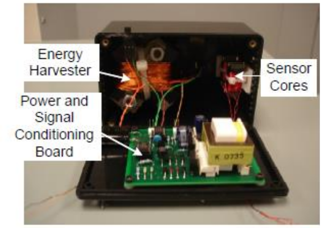
Possible Attack Vectors – Cybersecurity Baked In



Previous Relevant Work

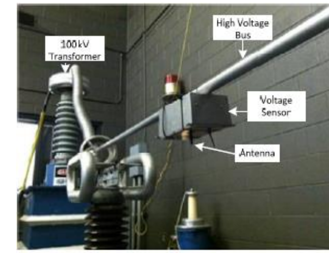
- Wireless Current Sensing

R. Moghe, F. Lambert, and D. Divan, "A novel low-cost smart current sensor for utility conductors," IEEE Transactions on Smart Grid, vol. 3, pp. 653-663, 2012

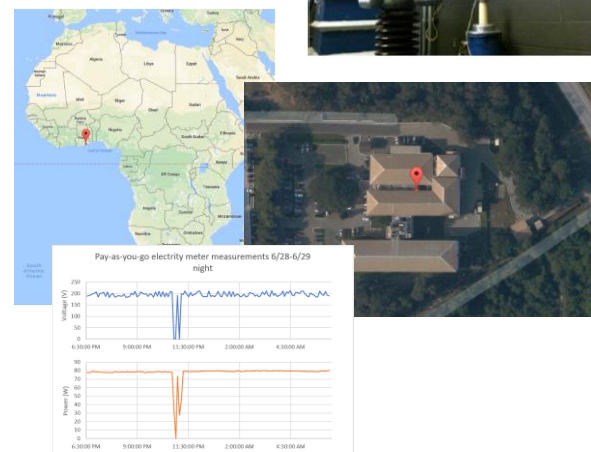


- Wireless Voltage Sensing

R. Moghe, A. R. Iyer, F. C. Lambert, and D. M. Divan, "A low-cost wireless voltage sensor for monitoring MV/HV utility assets," IEEE Transactions on Smart Grid, vol. 5, pp. 2002-2009, 2014.



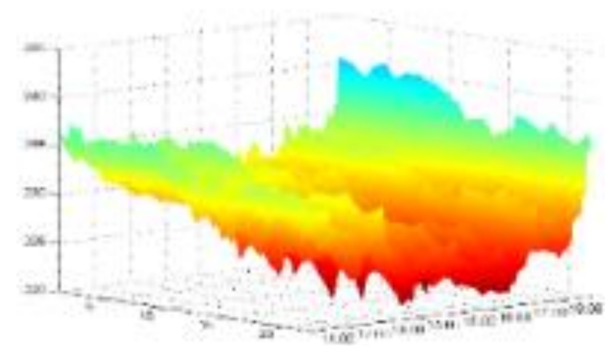
- Data-Mule Based Delay Tolerant Networks



- Grid-edge data shows volatility, enables high PV penetration

D. C. f. D. E. Prof Deepak Divan, Member NAE, Fellow IEEE, "Grid Edge Control – Extracting Value from the Distribution System," ed: DOE – Quadrennial Energy Review Panel Presentation, Atlanta, GA, May 24, 2016.

- Sensor level AI for dynamic thermal rating of transmission lines



Y. Yang, D. Divan, R. Harley, and T. Habetler, "Real-time dynamic thermal rating evaluation of overhead power lines based on online adaptation of Echo State Networks," in 2010 IEEE Energy Conversion Congress and Exposition, 2010, pp. 3638-3645.

Potential Risks

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- Inability to measure voltage with 5% accuracy based on flux sensing
  - For asset monitoring low accuracy is acceptable, but to achieve good accuracy line connection is possible without significantly lengthening installation time
  - Will use continuous tuning based on local measurements and cloud data
- Inability to realize sensor functions with 3D printing
  - Other, more expensive manufacturing methods may be needed
- Flexible communication pathways encountering range and/or energy budget constraints
  - Create range extender that allows communication with data-mules

Project Significance

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- CEA Technologies study: of a population 400,000 power transformer units, about 4000 units (1% of total population) failed per year
- More than 50 million distribution transformers in service in North America (one million new added service points annually)
- Result: 500,000 transformer failures every year (including 1800 catastrophic failures) annually without incipient failure monitoring, resulting in an annual **cost tag of millions of dollars**, and over **3 million hours of lost service** for millions of customers

Key Tasks and Milestones

Task#	Key tasks	Key Milestones	Start Date	End Date	Verification Method
1	Project Management and planning		Oct 1 2017	Oct 1 2020	Quarterly Reports
3.1	Sensor design	Build and test MVP	Oct 1 2017	Feb 1 2018	Quarterly Reports
3.2	Communication modules		Oct 1 2017	Oct 1 2019	Quarterly reports & Demo
3.3	Analytics		Oct 1 2017	Feb 1 2020	Quarterly Reports
3.4	Sensor build and test	Test and verify "Bronze" prototype	Feb 1 2018	Oct 1 2019	Quarterly reports & Prototype testing
4	Prepare Functional Specification for Golden Prototype		Oct 1 2019	Jan 1 2020	Utility approved document
5	Prepare Test Plan for Field Demonstration of Sensor Technology Solution	Acceptance of Field Demonstration Plan by utility host	Jan 1 2020	Feb 1 2020	Utility approved document
6	Field Demonstration of Sensor Technology Solution	Build and test ruggedized "Gold" Prototype: 100 units	Jan 1 2020	Oct 1 2020	Prototypes & Quarterly Reports
7	Commercialization	Opportunity Assessment Report	Oct 1 2018	Oct 1 2020	Quarterly Reports & OAR report

Project Deliverables

Task #	Deliverable	Completion Date	Submission Method
1.0	An updated Project Management Plan (PMP) shall be submitted within 30 days of award.	Nov 1 2017	Report
2.1.1	A Data Management Plan (DMP) shall be submitted within 90 days of award.	Jan 1 2018	Report
2.1.2	An Interoperability Plan shall be submitted within 90 days of award.	Jan 1 2018	Report
2.1.3	A Cybersecurity Plan shall be submitted within 90 days of award.	Jan 1 2018	Report
3.1.1	Preliminary specifications document developed.	Jan 1 2018	Report
3.4.1	A MVP sensor model built and verified.	Feb 1 2018	Physical prototype
3.4.2	Fully integrated “Bronze prototype” verified for functionality	Oct 1 2019	Test results for sensing, communications, energy harvesting and other functionalities
3.6.1	Final report – Phase I	Oct 1 2020	Report
6.4.1	Demonstration Summary Report	Oct 1 2020	Report

Project Team

Organization	Name	Role
GT CDE	Deepak Divan	PI
GT NEETRAC	Frank Lambert	Co-PI
GT	Raheem Beyah	Co-PI
GT	Nagi Gabraeel	Co-PI
GT CDE	Prasad Kandula	Technical contact
GT CDE	Szilard Liptak	Technical contact
GT CDE	Suresh Sharma	Entrepreneur in house
GT CDE	Shreyas Kulkarni	PhD Student
GT CDE	Eric Myers	MSc Student
GT CDE	Lalith Polepeddi	Research Scientist
ORNL	Dominic Lee	
ORNL	Mark Buckner	
ORNL	Kofi Korsah	
ORNL	Thomas King	
Southern Company	Joe Schatz	

Budget Breakdown

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Budget Summary

	Federal	Non-Federal	Total
Year 1	$449,867	$131,198	$581,065
Year 2	$421,403	$161,588	$582,991
Year 3	$543,908	$164,909	$708,817
Totals	**$1,415,178**	**$457,694**	**$1,872,872**

Budget Categories

	Year 1	Year 2	Year 3	Total
a. Personnel	$166,491	$174,739	$245,722	$586,952
b. Fringe Benefits	$26,398	$28,103	$42,646	$97,148
c. Travel	$1,360	$1,360	$3,780	$6,500
d. Equipment	$0	$0	$0	$0
e. Supplies	$20,000	$20,000	$10,000	$50,000
f. Contractual	$133,000	$133,000	$163,000	$429,000
g. Construction	$0	$0	$0	$0
h. Other	$78,248	$78,248	$78,248	$234,744
i. Total Direct Charges (sum of 6a-6h)	$425,498	$435,451	$543,397	$1,404,345
j. Indirect Charges	$155,567	$147,540	$165,420	$468,527
k. Totals (sum of 6i-6j)	**$581,065**	**$582,991**	**$708,817**	**$1,872,872**

Summary

- Proposed project is showing a novel holistic approach to realizing ultra-low-cost sensors for distribution networks
- Worked with Southern Company to create preliminary specification for proposed sensor
- Reduces cost of sensor, installation, commissioning, customization, operation – allows a service model
- Enables higher level of services that are data based, providing advanced diagnostics and prognostics capability
- Sensors will be installed on two distribution feeders to validate the value proposition and to show economic feasibility
- Economic use case and service model will be explored for the sensors in utility applications, such as transformer monitoring

Thank you for the attention

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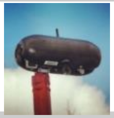
Commercially Available Sensors

Product (Company)	Quantities Measured and Target Applications	Specifications and Physical Attributes	Communication Channels	Image
Wireless Sensor for Overhead Lines (SEL)[4]	Current, Temperature, Fault Threshold, Outage History on Overhead Conductors	Fault Sensing range 50 to 1200A, Voltage range 4.16 to 34.5kV; Wt: 570g	Reports to SCADA through a radio network	
Lighthouse MV Sensor (Tollgrade)[5]	Current, Voltage, Conductor Temp., Faults and Sags, Power Quality, Power Factor, Waveform capture on Overhead Conductors	Operating Voltage 4-35kV, 0.5% accuracy, operating current 12-600A; Dim: 152mm x 305mm x 127mm; Wt: 3.8kg	GSM or WiFi based	
Powerline Sensing using Backscatter (EPRI, SwRI, TVA) [6]	Current, Temperature, Peak Current, Peak Temperature on Overhead Conductors	Applicable for lines which are 2 inches in diameter	Radio backscatter	
UNC, TVA and EPRI [7, 8]	Surface temperatures, phase differences, ambient temp. on Transformers, Circuit Breakers, Transformer bushings	Stick on Sensor	WSN meshed network topology with 1 access point	
Transformer IQ (Gridsense/ Incon) [9]	Voltage sag/swell, harmonics, fault phase indication, magnitude, duration, temperature monitoring on Pole/Pad-mounted Distribution Transformers	Retrofit for small transformers, Current and Temperature sensors are accessories	Cellular (3G/CDMA), WiFi, Ethernet, Landys/Gyr/Silversprings radio	
GS200/250 Line Sentry (Grid Sentry) [10]	Line Current, Temp, Waveforms, Harmonics on Overhead Conductors	Hotstick Installation on cables upto 1.14 inches, 1% error; Dim: 31cm x 14cm; Wt: 1.6kg	Cellular, WiFi, DNP3; VPN with TCP/IP backhaul to the server and SCADA	
MM3 (Sentient energy) [11]	Current, Temp, Voltage presence, Waveform capture on Overhead Conductors	Current upto 800A, Waveform @ 130 samples/sec, Operating Voltage upto 35kV, hotstick installation; Dim: 8in x 4.5in x 5.5in; Wt: 3kg	Local COMMs is secure Bluetooth, backhaul is Cellular (LTE/4g, 3G, 2G, GPRS/GSM), CDMA or Silversprings Pvt network, GPS with timestamp	
OptaNODE Distribution Transformer Monitor (Grid 20/20) [12]	Current and Voltage on Distribution Transformers	IP65 Rated, Connection to hot (X1,X3), Clip on sensor; Dim: 32cm x 19cm x 12cm; Wt: 2kg	RF Mesh, GSM, WiFi enacting DNP3 over IP, ANSI C12.22, Data is CSV Files	
Coresense (ABB) [13]	DGA for Transformer Gases (H2 and Moisture) in cooling oil in any Transformer	Maintenance free for 15yrs; Dim: 39.2cm x 26.4cm x 15.8cm; Wt: 8kg	RS485/Ethernet/Optical Ethernet/IEC61850 all with DNP3 and Modbus	

Targeted Sensor Performance Metrics

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Sensor Attribute	Performance Target	Current Value	Assumptions
Deployment Cost - Estimated Capital Cost	<$100	$1,800	
Deployment Cost - Estimated Installation Cost	$100	$400	Assumptions for Performance Target: • Installation: Hotstick • Installation Rate: 15 Integrated Sensor Packages/Day • Daily Equipment Cost: $250 for Truck Roll • Daily Labor Cost: $1200
Ease of Deployment - Time Required to Deploy Sensors	15		
Ease of Deployment - Hot Stick Capability	Hot Stick Capable		Sensor package hotstickable or capable of being installed with hotstick without de-energizing equipment
Calibration	Self calibration		Self calibration with verification from cloud data
Calibration	No additional cost		
Calibration Frequency	Continuous self calibration from cloud data		
Calibration Longevity	> 5 years		
Maintenance	Not required		Replace if found faulty. No field repairs will be conducted.
Maintenance	Not required		Replace if found faulty. No field repairs will be conducted.
Maintenance Cycle	Not required		Replace if found faulty. No field repairs will be conducted.
Life Expectancy	10 years		
Power Consumption	< 1 W	15	
Limit of Detection	Voltage < 48V Current < 40A		
Response Time	20ms		
Environmental	60 to -40 ºC		Operating Temperature Range for the Integrated Sensor Package
Case	IP66		
Tamper Proof Packaging	Sealed GPS location		Sealed packaging and ability to detect movement based on GPS location helps in identifying theft
Cybersecurity	Cyber secure		Cybersecurity throughout components and systems, utilizing open standards and other cybersecurity best practices

Task#	Key tasks	Key Milestones	Start Date	End Date	Verification Method
1	Project Management and planning	M 1.1, M1.2, M1.3	Oct 1 2017	Oct 1 2020	Quarterly Reports
3.1	Sensor design	M 2.1	Oct 1 2017	Feb 1 2018	Quarterly Reports
3.2	Communication modules	M2.2, M3.2, M4.2, M7.3, M4.3	Oct 1 2017	Oct 1 2019	Quarterly reports & Demo
3.3	Analytics	M3.3, M7.2, M10.3	Oct 1 2017	Feb 1 2020	Quarterly Reports
3.4	Sensor build and test	M3.1, M4.1, M5.1, M6.1, M7.1	Feb 1 2018	Oct 1 2019	Quarterly reports & Prototype testing
4	Prepare Functional Specification for Golden Prototype		Oct 1 2019	Jan 1 2020	Utility approved document
5	Prepare Test Plan for Field Demonstration of Sensor Technology Solution	M 10.2	Jan 1 2020	Feb 1 2020	Utility approved document
6	Field Demonstration of Sensor Technology Solution	M 10.1, M 11.1, M12.1, M12.3	Jan 1 2020	Oct 1 2020	Prototypes & Quarterly Reports
7	Commercialization	M7.4, M12.2	Oct 1 2018	Oct 1 2020	Quarterly Reports & OAR report

Milestone No.	Description	Planned Completion Date	Verification Method
M1.1	Submission of Data Management Plan	Jan 1 2018	Report
M1.2	Submission of Interoperability Plan	Jan 1 2018	Report
M1.3	Submission of Cybersecurity Plan	Jan 1 2018	Report
M2.1	Develop preliminary specifications document	Feb 1 2018	Report
M2.2	Define flexible comms architecture and protocol	Feb 1 2018	Report
M3.1	Build MVP for demonstration of core functionality.	Jun 1 2018	Physical prototype
M3.2	Identify security layer at device level	Jun 1 2018	Report
M3.3	Identify algorithms to extract value from sensed data using machine learning	Jun 1 2018	Report
M4.1	Test MVP for demonstration of core functionality	Oct 1 2018	Test results for voltage, current and temperature sensing
M4.2	App to enable delay tolerant network using mobile phone data mules developed	Oct 1 2018	Demonstration of App working on phone
M4.3	Standard comm. Protocols (DNP3) developed and tested	Oct 1 2018	Report of experimental results
M5.1	Identify manufacturing techniques (3D printing, other) to build low cost sensor	Jan 1 2019	Report
M6.1	Build “bronze” prototype with 3D printing techniques with integrated sensing, communication, controller, energy harvesting modules	Feb 1 2019	Physical prototype
M7.1	Test and verify “Bronze” prototype for sensing, local intelligence and secure communication functionalities ad environmental conformance.	Oct 1 2019	Test results for sensing, communications, energy harvesting and other functionalities
M7.2	Develop data analytics in the cloud for data from multiple distributed sensors	Oct 1 2019	Report
M7.3	Develop utility-end interface basic framework	Oct 1 2019	Framework demonstration report
M7.4	Evaluate economic value that can be derived by utilities	Oct 1 2019	Report
M8.1	Acceptance of Functional Specification (or equivalent) for sensor by electric distribution utility demonstration	Jan 1 2020	Utility approved document
M9.1	Release golden prototype specification to vendor partner	Jan 1 2020	Purchase order
M10.1	Build ruggedized “Gold” product: 100 units as per functional specification	Feb 1 2020	Physical prototype
M10.2	Acceptance of Field Demonstration Plan by electric distribution utility demonstration host	Feb 1 2020	Utility approved document
M10.3	Develop improved device monitoring using Change-point detection algorithms	Feb 1 2020	Report
M11.1	Installation and functional testing	Jun 1 2020	Report of test results
M11.2	Collect initial field data and demonstrate value from sensor and aggregated sensor data	Jun 1 2020	Report
M12.1	Completion of Field Demonstration at Electric Distribution Utility Demonstration Host	Oct 1 2020	Utility approved document
M12.2	Generate opportunity assessment report (OAR)	Oct 1 2020	Report
M12.3	Publication and presentation of results/progress	Oct 1 2020	Report