Online Assessment of Capacitor Banks Using Circuit Health Monitoring Technology

Jeffrey Wischkaemper (Presenter)
B. Don Russell
Carl L. Benner
Karthick Muthu Manivannan
Texas A&M University

College Station, Texas 77843-3128
jeffw@tamu.edu, 979-575-7213

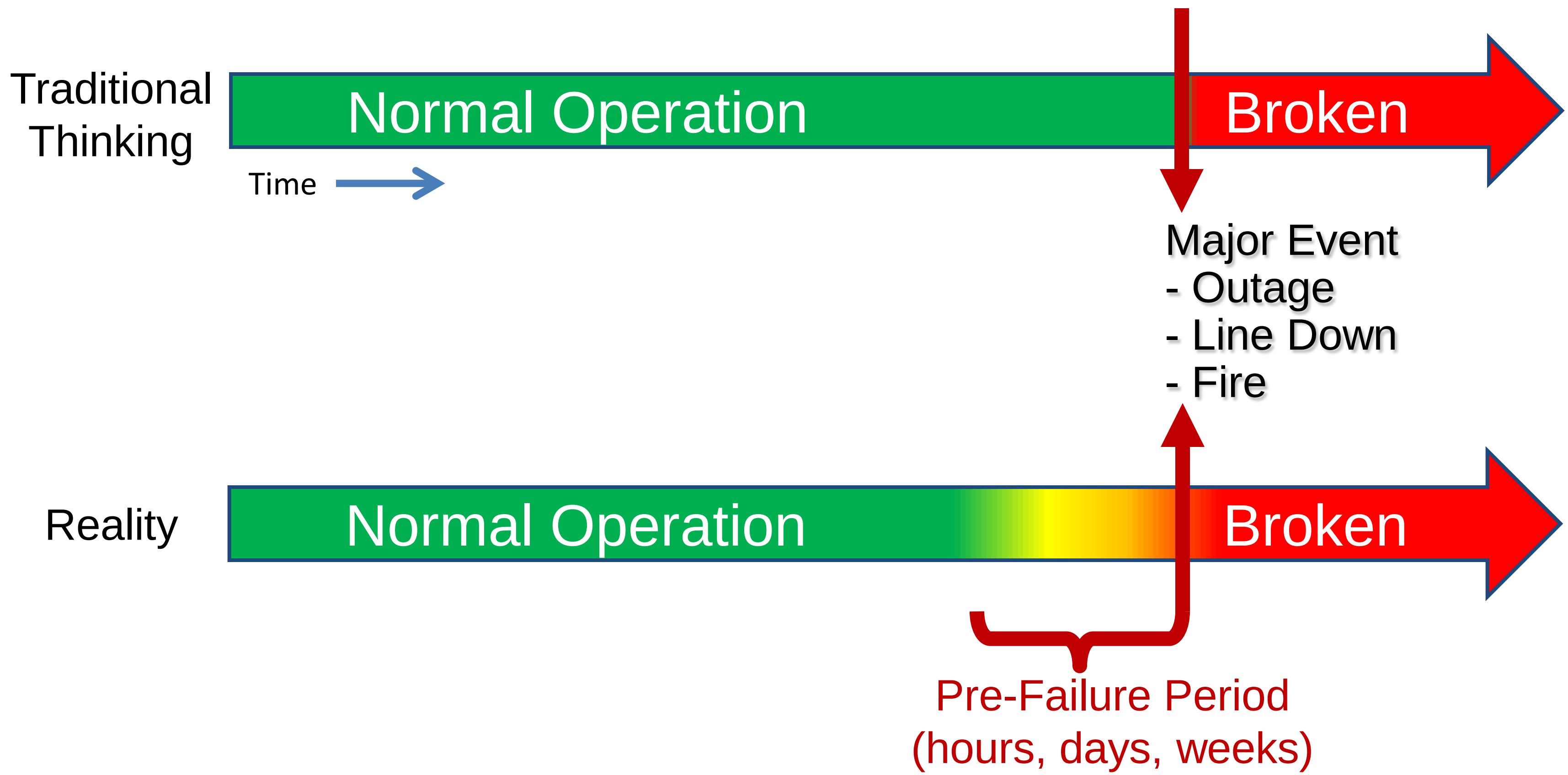
Grid of the Future Symposium

CIGRE US National Committee

21 October 2014

Houston, Texas, USA

Electrical Feeder Operational Paradigms



Detecting pre-failures makes it possible to make repairs before major events occur.

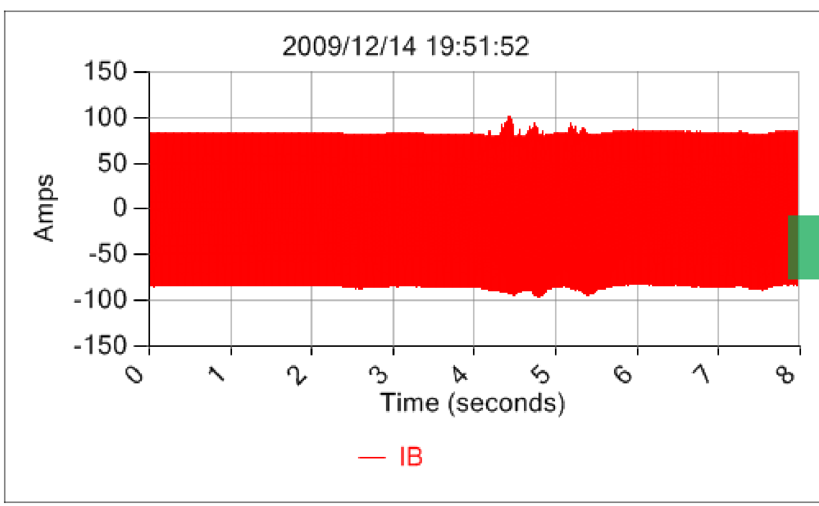
Fundamental Principles of Waveform Analytics

- Feeder-level electrical waveforms represent feeder activity.
- Sophisticated waveform analytics, applied to waveforms of sufficient fidelity, can detect failures, pre-failures, and other feeder events.
  - PQ meters and relays have the same inputs (i.e., CTs and PTs) but do not record data of sufficient fidelity to support DFA functions.
- Waveform analytics also report operations of line devices (reclosers, capacitors, etc.), enabling oversight of those devices, without requiring communications to them.

With support from EPRI and others, Texas A&M has developed an on-line system of waveform analytics. This system, known as DFA Technology, provides situational intelligence that enables improvements in reliability, operational efficiency, and safety.

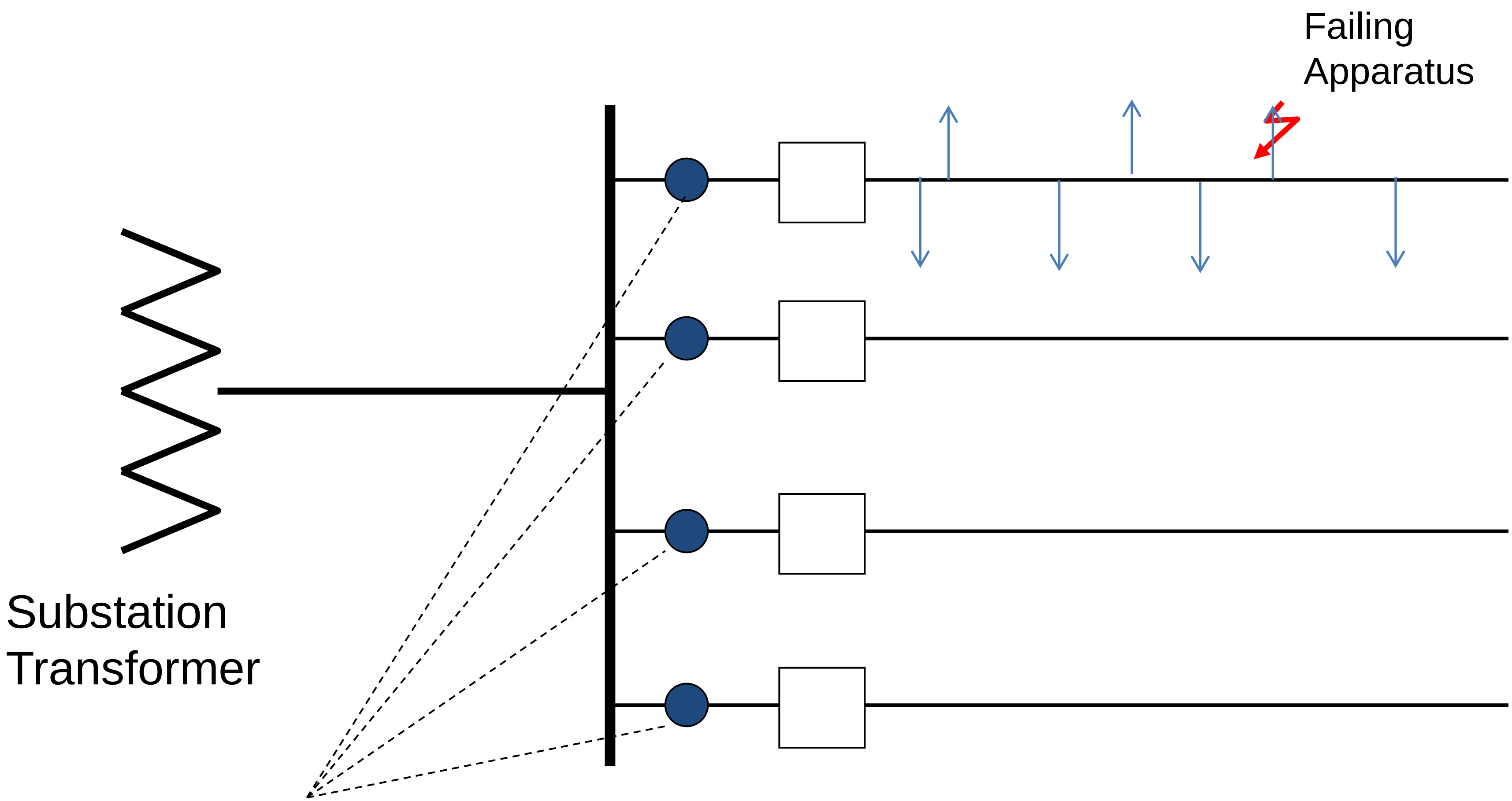
Measured Example

- Graph shows current during “normal” feeder operations.
- Analytics report this specifically as a failing clamp. Failing clamps can degrade service quality and, in extreme cases, burn down lines.
- Conventional technologies do not detect pre-failures such as this one.



On-Line Waveform Analytics

Monitoring Topology



High-fidelity DFA devices, connected to conventional CTs and PTs, one per feeder.

Documented Failures

- Voltage regulator failure
- LTC controller maloperation
- Repetitive overcurrent faults
- Lightning arrestor failures
- Switch and clamp failures
- Cable failures
  - Main substation cable
  - URD primary cables
  - URD secondary cables
  - Overhead secondary cables
- Tree/vegetation contacts
  - Contacts with primary
  - Contacts with secondary services
- Pole-top xfmr bushing failure
- Pole-top xfmr winding failure
- URD pad mount xfmr failure
- Bus capacitor bushing failure
- Capacitor problems
  - Controller maloperation
  - Failed capacitor cans
  - Blown fuses
  - Switch restrike
  - Switch sticking
  - Switch burn-ups
  - Switch bounce
  - Pack failure

Certain failure types have been seen many times and are well understood. Others have been seen fewer times. DFA system architecture anticipates and accommodates updates to analytics as new events are encountered, analyzed, and documented.

CenterPoint Energy Project

- Began DFA trial in 2012
- Instrumented four feeders
  - Two 12.5 kV feeders
  - Two 34.5 kV feeders
- Has detected multiple events
  - Repetitive tree-induced conductor clash that severely damaged conductors
  - Failing line switch
  - Capacitor restrikes
  - Pre-failure of capacitor vacuum switch (to be detailed in today's presentation)
  - Note: This is a partial list

Detailed Use Case

Capacitor Vacuum Switch Pre-Failure

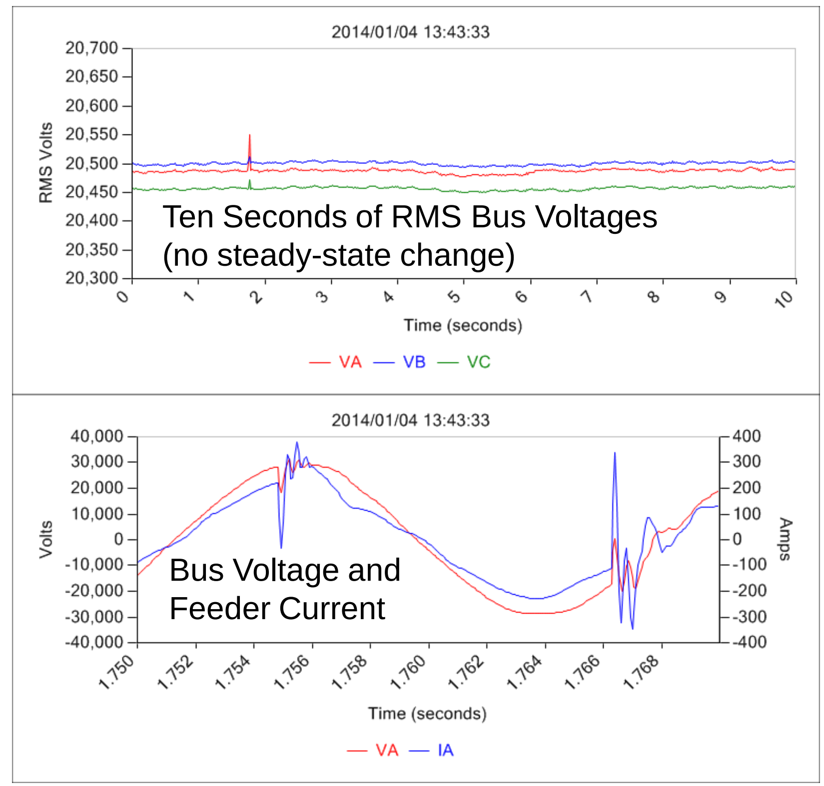
- CenterPoint uses one-way paging to switch feeder capacitors. After each page, the system monitors substation VARs to verify 1) that the bank has switched and 2) that it is balanced.
- On 11/29/2013, a DFA device began detecting unusual transients suggesting pre-failure of a capacitor bank.
- Trouble tickets indicated no problem. CenterPoint and Texas A&M continued to monitor.
- The transient occurred 500 times over the next 2-1/2 months.
- After 2-1/2 months, increasing event activity suggested the problem might be accelerating toward failure, prompting corrective action.

Detailed Use Case

Capacitor Vacuum Switch Pre-Failure (cont’d)

<u>Theory and Analysis</u>

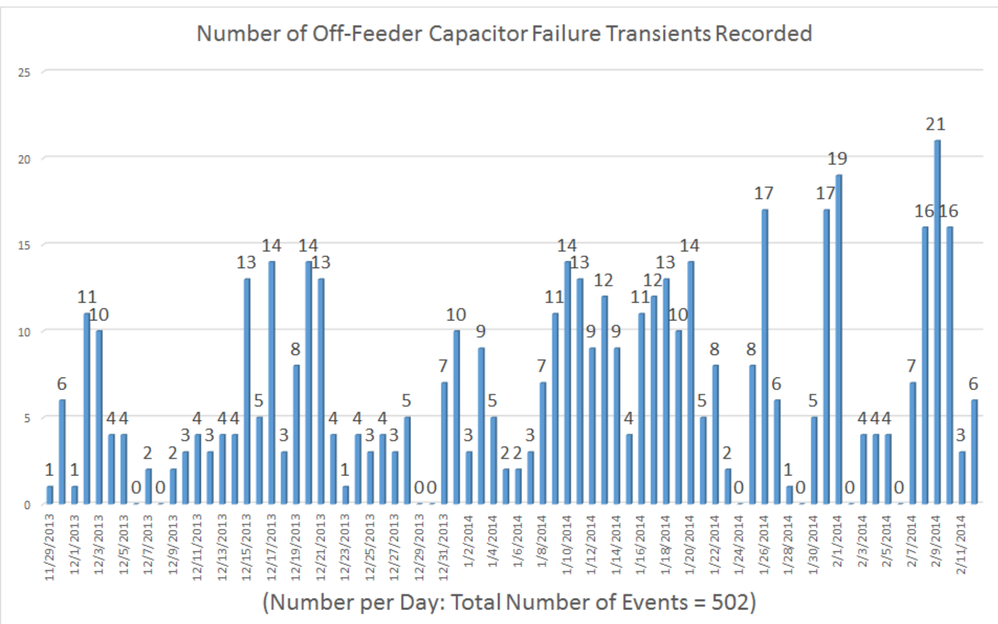
- Normal capacitor switching causes two phenomena.
  - A short-lived high-frequency transient
  - A step change in voltage (yes, even at the bus!)
- Each subject event caused a transient, but no step change.
  - This indicates the events were not during switching.
- Each event caused a high-frequency spike in current and voltage.
  - The current and voltage spikes had the same polarity (i.e., when voltage spiked up, current spiked up).
  - This indicated a “reverse” event. For “forward” events, voltage and current spikes have opposing polarities.
  - From the DFA’s perspective, a “reverse” event is one occurring on a different feeder or on the bus itself.



Detailed Use Case

Capacitor Vacuum Switch Pre-Failure (cont’d)

<u>Statistical Analysis #1</u>: Number of transient events recorded per day, during 75-day period.

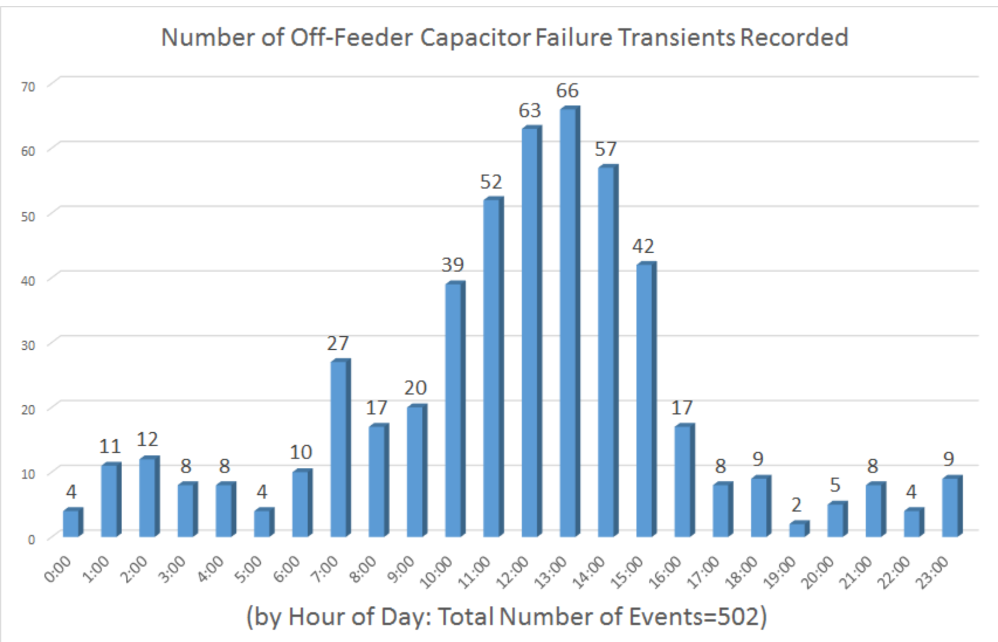


- Graph shows the number of events on each day (11/29/2013 – 2/12/2014)
- There is no definitive trend.
- “Peaks” <u>weakly</u> suggest a slight increase in activity over time.

Detailed Use Case

Capacitor Vacuum Switch Pre-Failure (cont'd)

Statistical Analysis #2: Number of transient events recorded as a function of time of day.

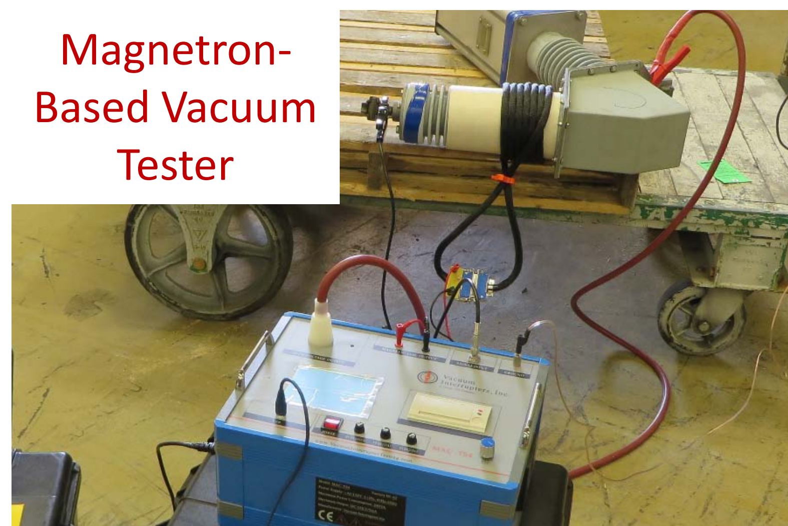


- Graph shows the frequency of events as a function of time of day, cumulatively for the 75-day period.
- Events occur at all times of day but most frequently during the middle of the day.
- 64% occur during 25% of day.
  (319 of 502 events between 10:00 and 16:00)
- 47% occur during 17% of day.
  (238 of 502 events between 11:00 and 15:00)

Detailed Use Case

Capacitor Vacuum Switch Pre-Failure (cont'd)

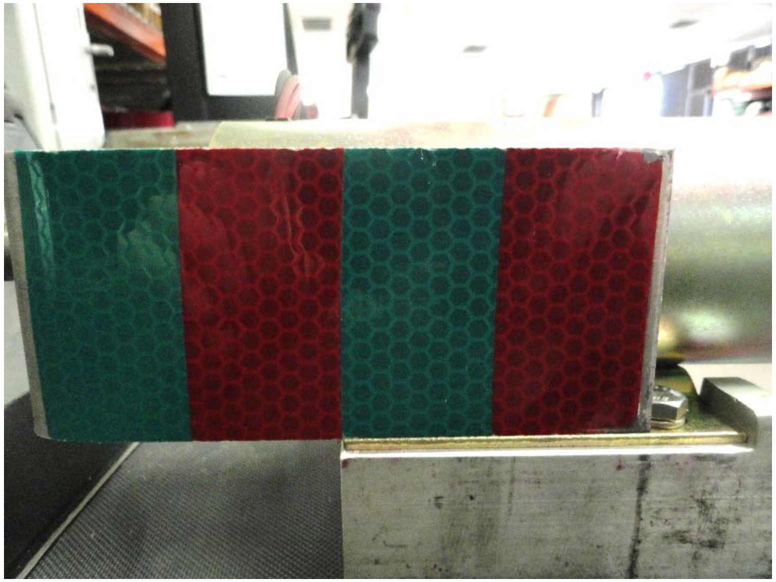
- On February 14, the utility decided to open the fuses of all five of the feeder's banks to confirm the "pre-failure capacitor bank" diagnosis.
- A crew found an anomaly at the first bank.
  - The bank's "closed" current should be 30 amps.
  - The paging system showed the bank as "open."
  - A hot-stick meter showed 0.7 amps through the "open" switch.
  - First bank's fuses were pulled.
  - Other four banks were left in service.
  - DFA system was watched for five days. Absence of additional transients validated diagnosis.
- The pre-failure switch failed a hi-pot test. A vacuum interrupter expert performed a root cause analysis.



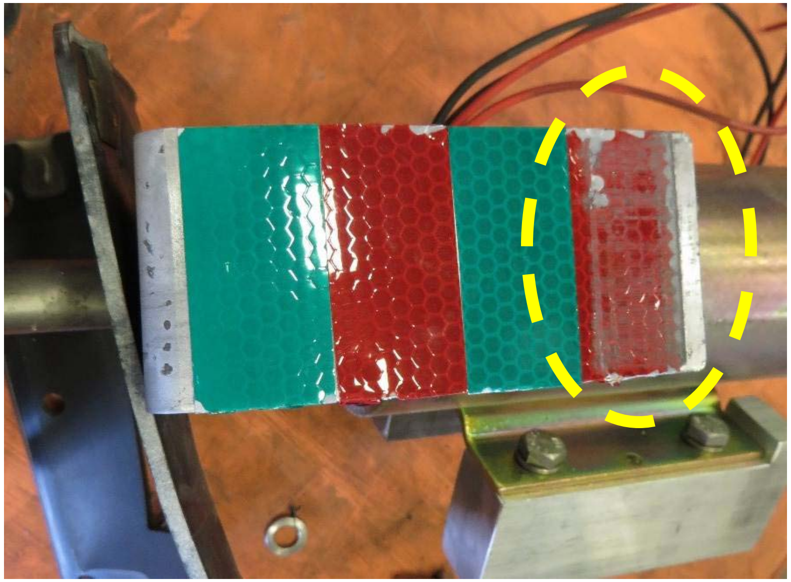
Magnetron-Based Vacuum Tester

Detailed Use Case

Capacitor Vacuum Switch Pre-Failure (cont'd)



Red/Green Indicator
on Normal Phase

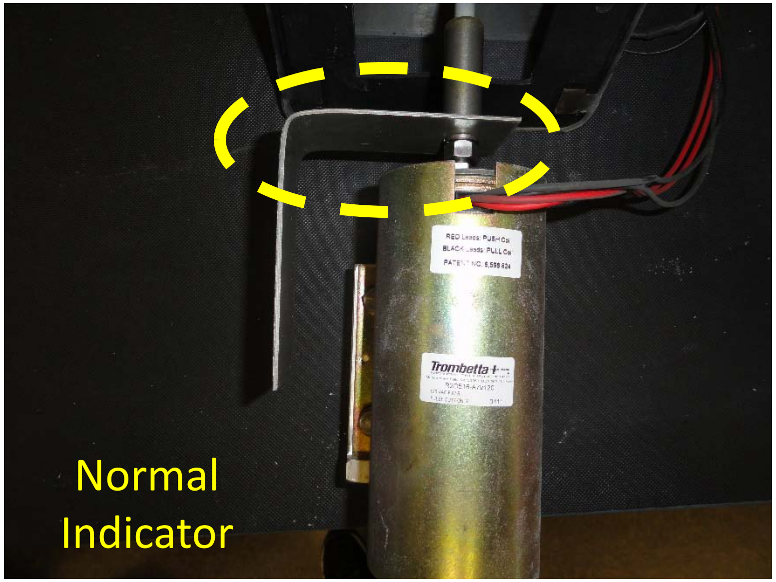


Red/Green Indicator
on Pre-Failure Phase

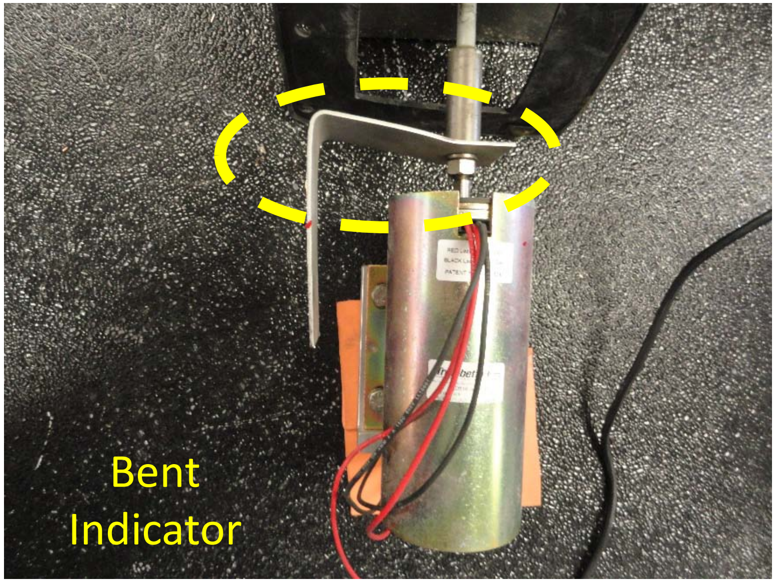
The switch has a sight window with a red/green position indicator. The pre-failure switch's indicator had clear signs of rubbing against the mechanism housing.

Detailed Use Case

Capacitor Vacuum Switch Pre-Failure (cont'd)



Indicator on
Normal Phase

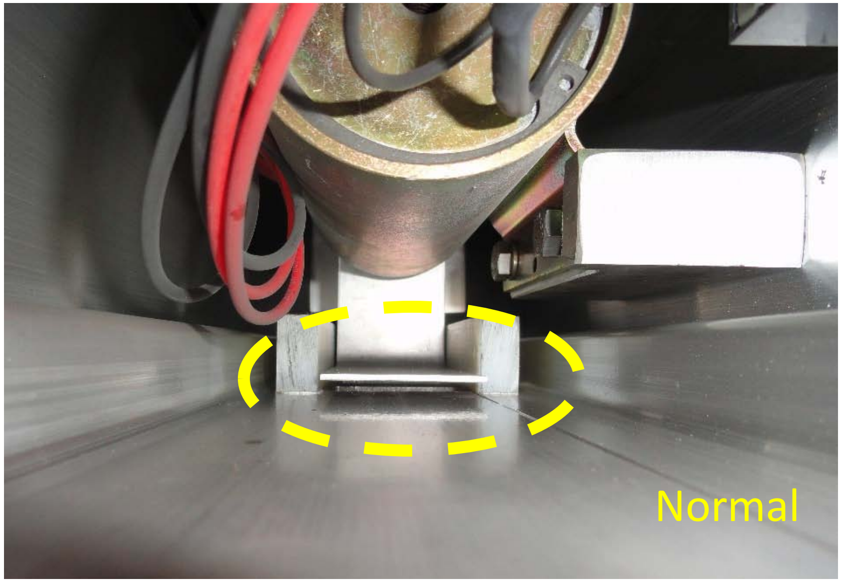


Indicator on
Pre-Failure Phase

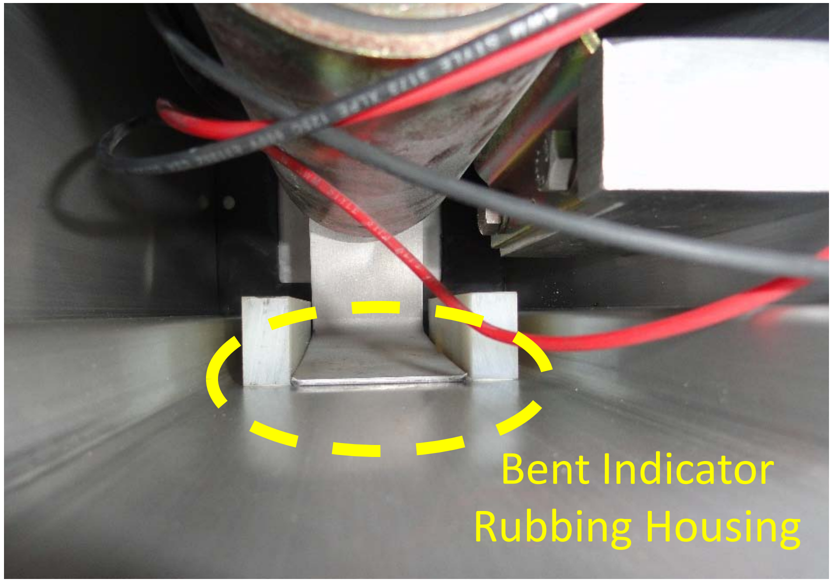
The indicator on the normal phase has an intentional 90-degree bend. The indicator on the pre-failure phase clearly is deformed.

Detailed Use Case

Capacitor Vacuum Switch Pre-Failure (cont'd)



Red/Green Position Indicator
Mechanism on Normal Phase



Red/Green Position Indicator
Mechanism on Pre-Failure Phase

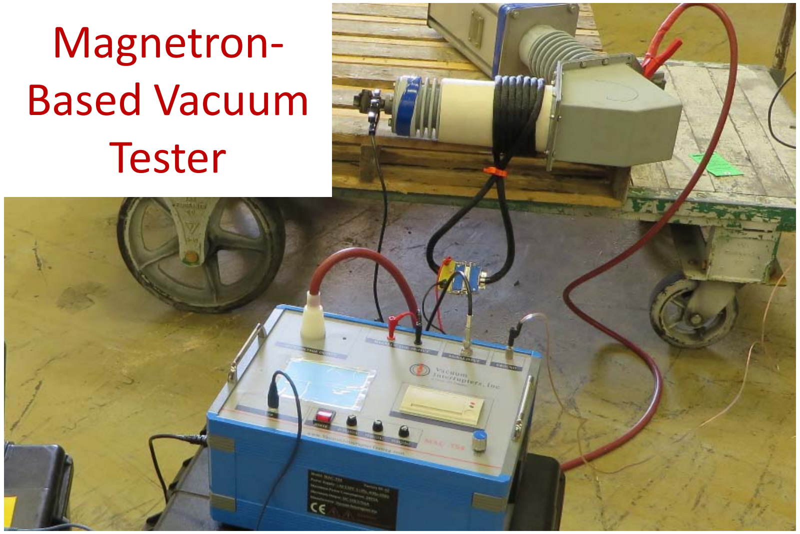
The root cause of the pre-failure was the indicator rubbing and binding, preventing the switch contacts from parting fully. Current (0.7A) flowing through the gap is believed to have caused progressive internal damage to the vacuum interrupter.

Detailed Use Case

Capacitor Vacuum Switch Pre-Failure (cont'd)

<u>Summary and Conclusions</u>

- Vacuum switch failures have multiple potential consequences.
  - Least severe: unbalanced capacitor operation
  - Most severe: rupture of switch or capacitor
- This pre-failure example persisted 2-1/2 months before intervention.
  - Normal operational practices did not and do not detect this kind of pre-failure.
  - Pre-failure detection provided time (in this case, 2-1/2 months) to correct the condition and preempt full failure.
- Waveform analysis provided only notice and opportunity to correct proactively.



Magnetron-Based Vacuum Tester

Conclusion

- Often capacitors can exist in a pre-failure state for an extended period of time (e.g. months) with no conventional notice that there is anything wrong
- Waveform analytics can detect a wide variety of capacitor problems (switch failures, controller failures, unbalanced operations, etc.).
- When integrated into utility practice, actionable information provided by waveform analytics allows utilities to prevent catastrophic failures before they occur.

Wildfire Mitigation Through Advanced Monitoring – State of Texas Demonstration Project

Jeffrey Wischkaemper (Presenter)
B. Don Russell
Carl L. Benner
Karthick Muthu Manivannan
Texas A&M University

College Station, Texas 77843-3128
jeffw@tamu.edu, 979-575-7213

Grid of the Future Symposium

CIGRE US National Committee

21 October 2014

Houston, Texas, USA

Wildfires – A Growing Problem


SET EDITION: U.S. | INTERNATIONAL | MÉXICO | ARABIC
TV: CNN | CNNi | CNN en Español | HLN

CNN

Home | TV & Video | CNN Trends | U.S. | World | Politics | Justice | Entertainment | Tech | Health | Livin

Power lines blamed for 2 of Australia's dozens of fires

By **Kevin Wang**, CNN
updated 8:31 AM EDT, Sat October 19, 2013

"Two of the dozens of bush fires burning out of control in the eastern Australian state of New South Wales were sparked by power lines that had been buffeted by strong winds, fire officials said Saturday, citing preliminary investigations"
 - CNN, 19 October 2013

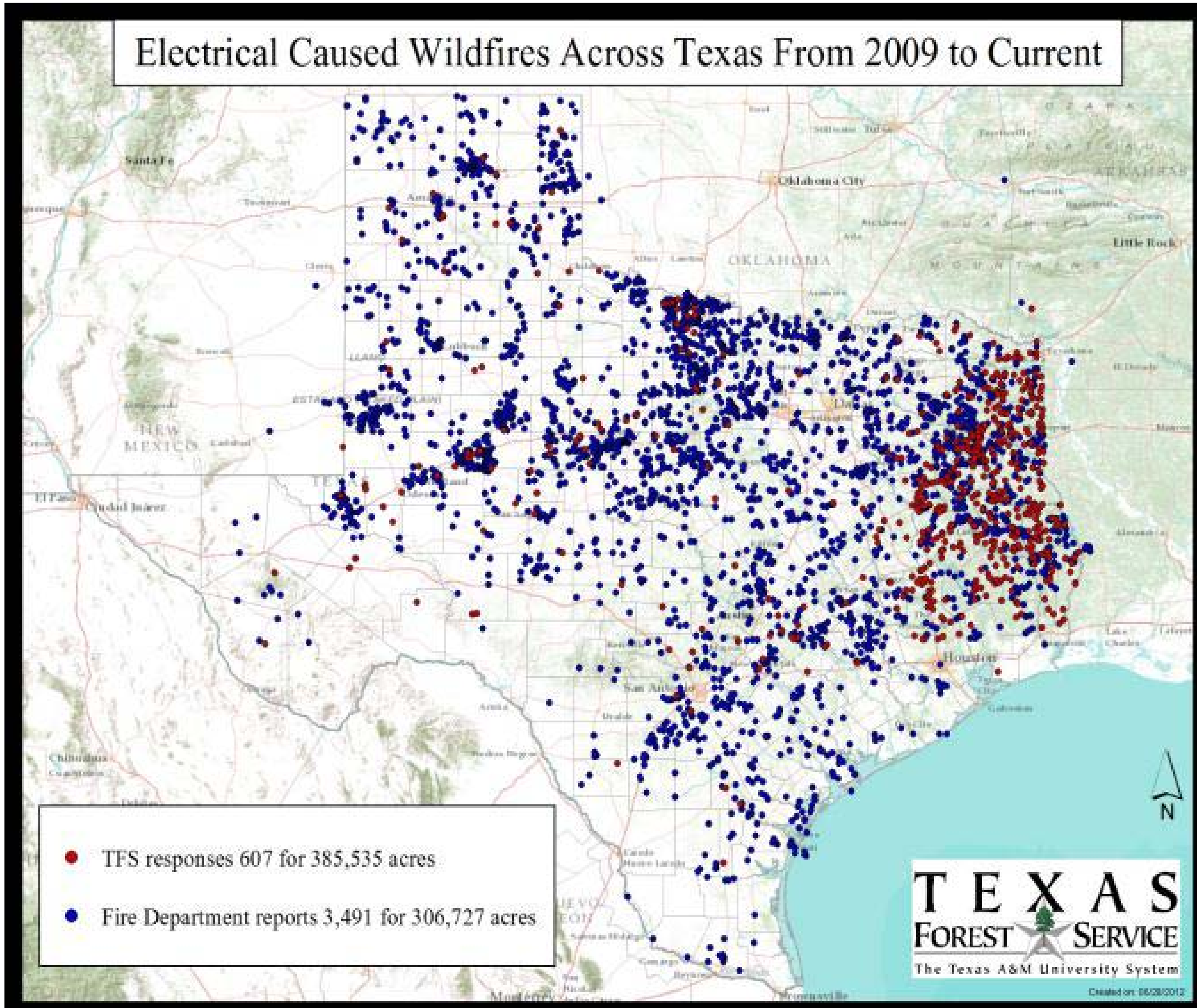
Hundreds of homes burned in Australia

Project Overview

- In 3-1/2 years, more than 4,000 power line-caused wildfires have occurred in Texas, destroying more than 1,000 square miles (About the size of Rhode Island). (Examples: Bastrop, Steiner Ranch)
- The Texas A&M Engineering Experiment Station (TEES) and the Texas A&M Forest Service (TFS) have developed technologies that can be used to mitigate wildfire risk.
- The State of Texas has approved a 2-year project to instrument 100 distribution circuits as a demonstration of the technology.

Texas Wildfires 2009 – mid 2012

Start Dat	Cause	County	acres	Hon
14-Apr-11	Pwr Lines	Andrews	80907	0
04-Sep-11	Pwr Lines	Bastrop	34068	1660
09-Apr-11	Pwr Lines	Garza	32000	1
11-Apr-11	Pwr Lines	Crockett	30814	0
09-Apr-09	Pwr Lines	Archer	21525	3
16-Feb-11	Pwr Lines	Lipscomb	15908	0
15-Apr-11	Pwr Lines	Wichita	11785	3
04-Apr-09	Pwr Lines	Wheeler	11000	0
01-Apr-09	Pwr Lines	Archer	8000	0
24-May-11	Pwr Lines	Deaf Smith	7600	0
11-Mar-11	Pwr Lines	Jack	7555	2
30-Aug-11	Pwr Lines	Palo Pinto	6555	39



How Do Power Lines Cause Fires?

Downed Conductors

Clashing Conductors

Vegetation

Failing Apparatus

Example #1: Preventable Failure that Can Cause Fire

- The pictured limb hung on a phase conductor, sagging it near an underbuilt earth wire.
- Over the next 24 hours, this caused multiple faults and finally burned the line down.
- The utility knew nothing of the problem until customers called after the line broke.
- Each fault represented the potential for ignition. The final fault dropped an energized line and a smoldering limb on the earth.

11/2/2004	6:57:47
	7:58:33
11/3/2004	0:09:06
	0:16:48
	0:40:38
	0:40:53
	1:10:51
	1:12:37
	1:15:30
	3:24:47
	4:19:39
	4:30:36
	5:51:01
	6:19:45

Identify, Find, and Fix

Avoid Future Faults, Outages, and Potential Ignition Events

The utility asserts that, if they had had DFA technology in operation, they believe they would have prevented multiple fault episodes and the burn-down.

Example #2: Preventable Condition that Can Cause Fire

- 11/12/2007 – Fault

Identify, Find, and Fix

- 12/02/2007 – Same Fault
- 11/13/2009 – Same Fault
- 11/18/2009 – Same Fault
- 12/25/2011 – Same Fault

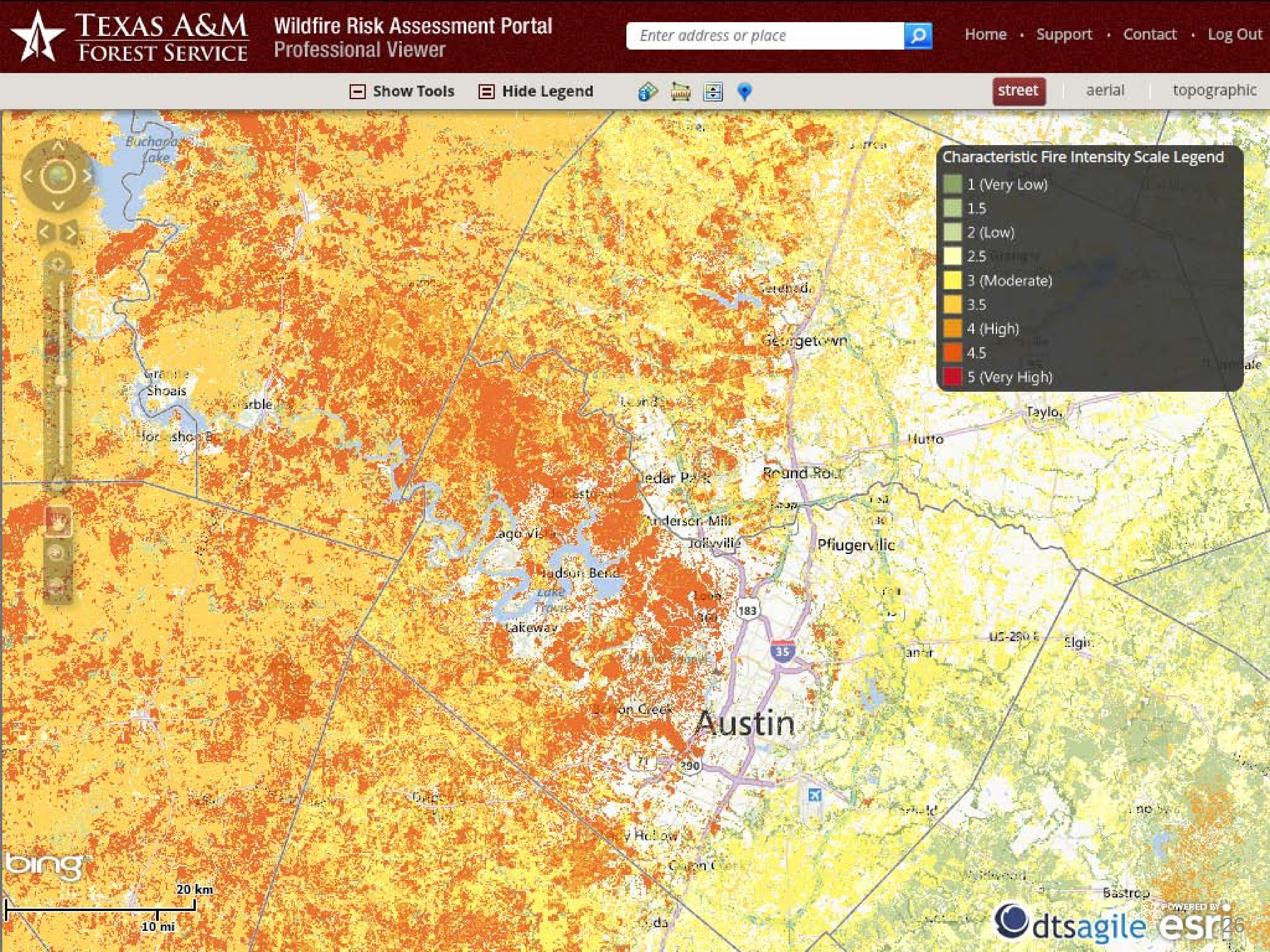
Avoid Future Faults, Outages, and Potential Ignition Events

Over a period of four years, these five faults all occurred from the same root cause, at the same location, but conventional utility processes did not identify the problem or its root cause. Each episode causes arcing and represents the potential for ignition. Texas A&M's DFA technology determined the root cause, enabling location and repair, to avoid future episodes.

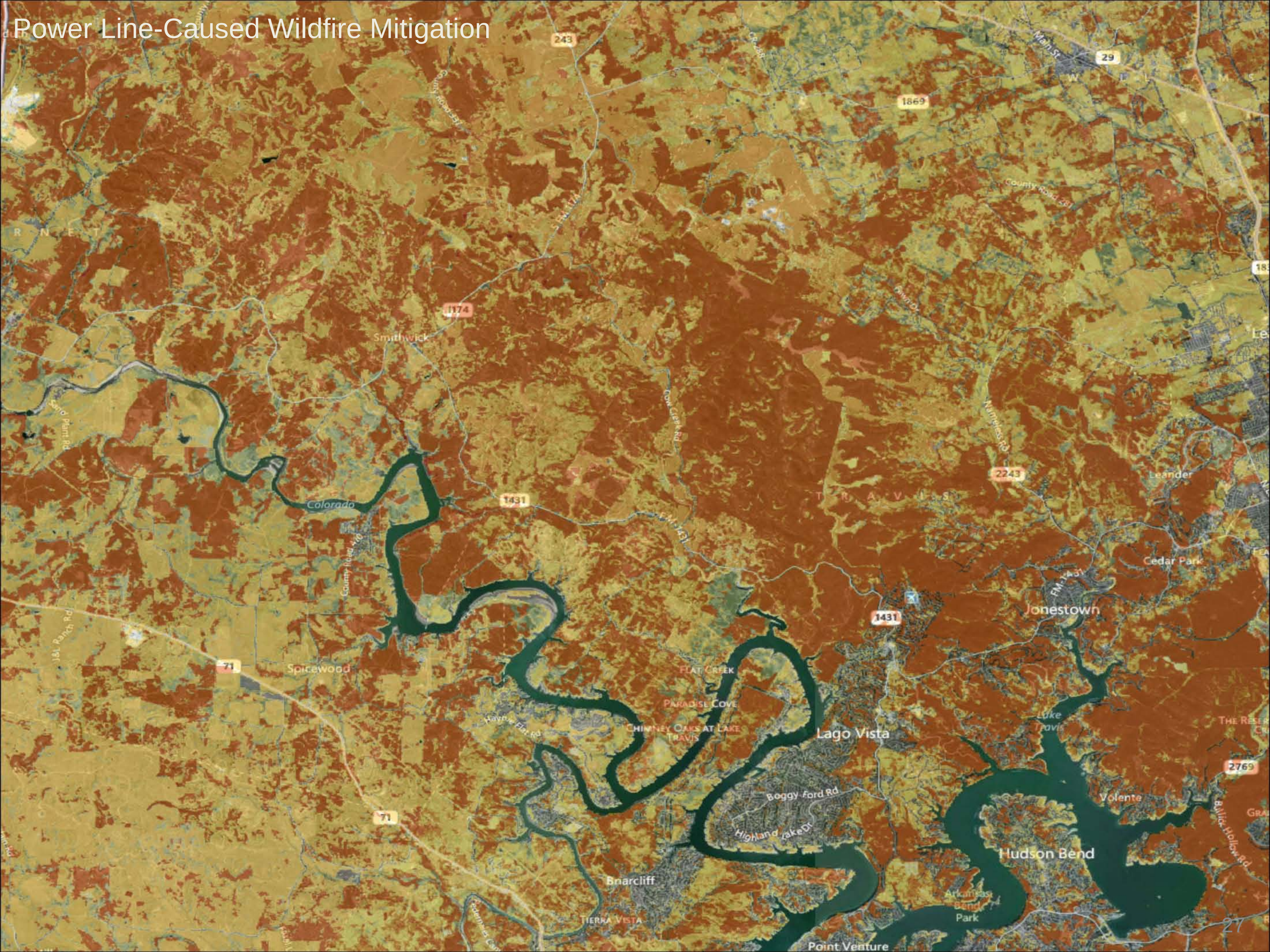
Reducing Wildfire Risk: Prevention and Early Notification

The project seeks to reduce wildfire risk through two strategies:

1. Prevention – TEES developed technology detects equipment pre-failures which may lead to future ignition events
2. Early notification – TFS maintains maps which quantify fire risk at locations throughout the state. When TEES detects the occurrence of a powerline event known to be a potential ignition source located in an area with elevated fire risk, automated alerts will be sent to first responders.


TEXAS A&M FOREST SERVICE
Wildfire Risk Assessment Portal
Professional Viewer
Enter address or place
Home · Support · Contact · Log Out
Show Tools
Hide Legend
street
aerial
topographic
Characteristic Fire Intensity Scale Legend
1 (Very Low)
1.5
2 (Low)
2.5
3 (Moderate)
3.5
4 (High)
4.5
5 (Very High)
Georgetown
Taylor
Hutto
Round Rock
Cedar Park
Anderson Mill
Jollyville
Pflugerville
Lago Vista
Hudson Bend
Lake Travis
Lakeway
Granite Shoals
Austin
Elgin
Bastrop
183
35
290
71
bing
20 km
10 mi
dtsagile
POWERED BY esri

Power Line-Caused Wildfire Mitigation



Power Line-Caused Wildfire Mitigation

Project Timeline

- Utilities will receive monitors for installation in Q4 2014.
- All monitors will be installed in Q1 2015, for monitoring throughout the high-risk fire period.
- Preliminary success stories expected for Grid of the Future 2015 in Chicago!