Wires Down Improvement Program at Pacific Gas and Electric

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Abstract

Downed conductors reduce service reliability, but more importantly pose a safety risk through potential electrical contact or fire ignition. In 2012, Pacific Gas and Electric Company initiated a corporate Key Performance Indicator on the number of Transmission and Distribution "Wires Down" with the goal of reducing the risk to public safety and improving service reliability. This effort has collected detailed information on a large number of distribution Wires Down. Wire Down events that meet defined criteria initiate a post event investigation by a distribution engineer. The collected data from site visits is analyzed to understand Wire Down causes and take corrective actions to reduce the Wire Down rates. Risk analysis and data mining have been used successfully to reduce the number of Wire Down events caused by equipment failures through focused spending and review of design and construction practices.

Detailed analysis of the data will be presented. Correlation will be shown between conductor types, corrosion areas and failure modes.

The post-event investigation also uses established criteria to determine if the downed conductor could possibly remain energized. Detailed analysis of the data will show a subset of events that could possibly remain energized due to a "High Impedance Fault" condition or through a backfeed through the primary winding of distribution transformers.

1. Pacific Gas and Electric

Pacific Gas and Electric (PG&E) is an investor owned vertically integrated electric and gas utility serving most of northern and central California. PG&E has 5.4 million electric accounts and serves a population of approximately 15 million. The asset base at PG&E includes 142,000 circuit miles of overhead and underground electric distribution lines; 18,000 circuit miles of electric transmission, 2.4 million distribution poles, 140,000 transmission structures and more than 7,000 MW of company owned generation.

2. PG&E Wires Down program

A. Goals/Risk Analysis

PG&E is working to integrate a risk based approach across the enterprise including using risk analysis to drive investment and prioritization decisions. Identifying and quantifying the risk drivers which can lead to negative outcomes is a fundamental step in optimizing risk reduction. Wire Down events have been identified as an important risk driver for PG&E due to the link to a potential hazard to life and property. Wire Down event trends are also a reflection of system integrity against various environmental factors.

B. Corporate Key Performance Indicator for Wires Down

Wire down tracking started at PG&E in 2010 and developed into a corporate public safety metric in 2012. The metric is a count of all events involving transmission or primary distribution conductors that contact the ground or a foreign object (structure, vehicle, tree, etc.). Instituting a Wires Down metric is an important measure of how our performance can impact safety and reliability.

C. Activities/budget priorities.

With over 110,000 distribution circuit miles of overhead primary lines, focusing mitigation on the highest priority spans and risk areas of the system is critical. High priority spans are identified through a site visit process, evaluation of splice counts, conductor type and size, location within environmental zones, and historical performance.

D. Results.

Since weather events can have a significant impact to the yearly Wire Down total, each day is evaluated by PG&E's meteorology department and classified as either a weather or non-weather day. A Wire Down rate is calculated based on the totals per day. Figures 1 and 2 show the non-weather and weather day rates for the equipment failure segment. Since 2012 each rate has shown a decrease which supports the mitigation efforts discussed in this paper.

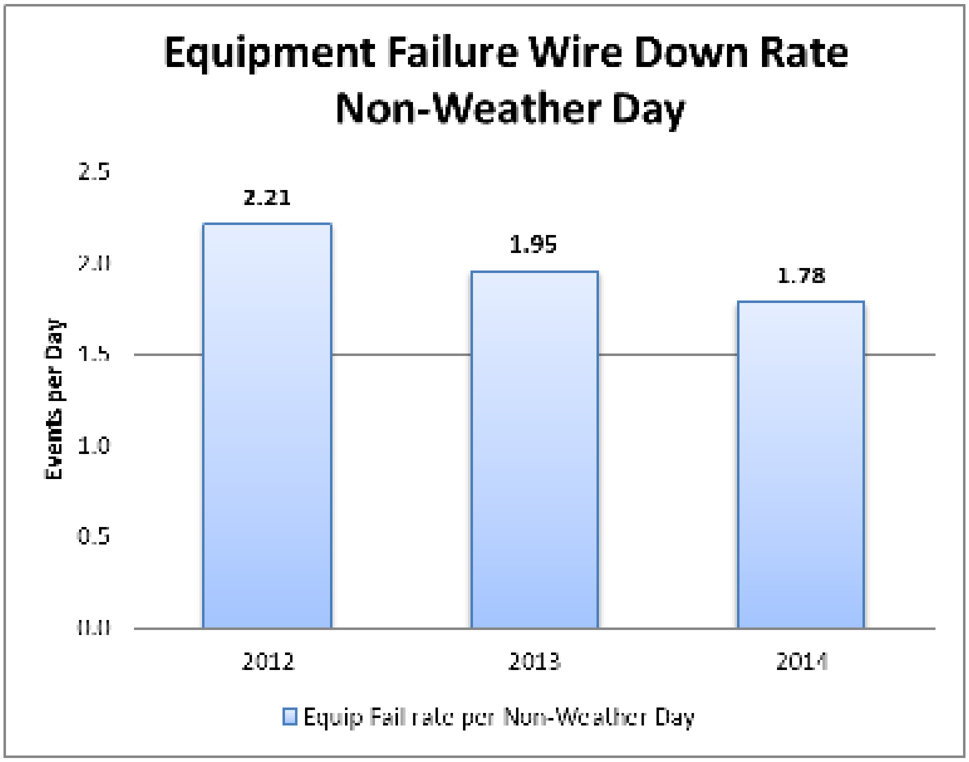

Figure 1

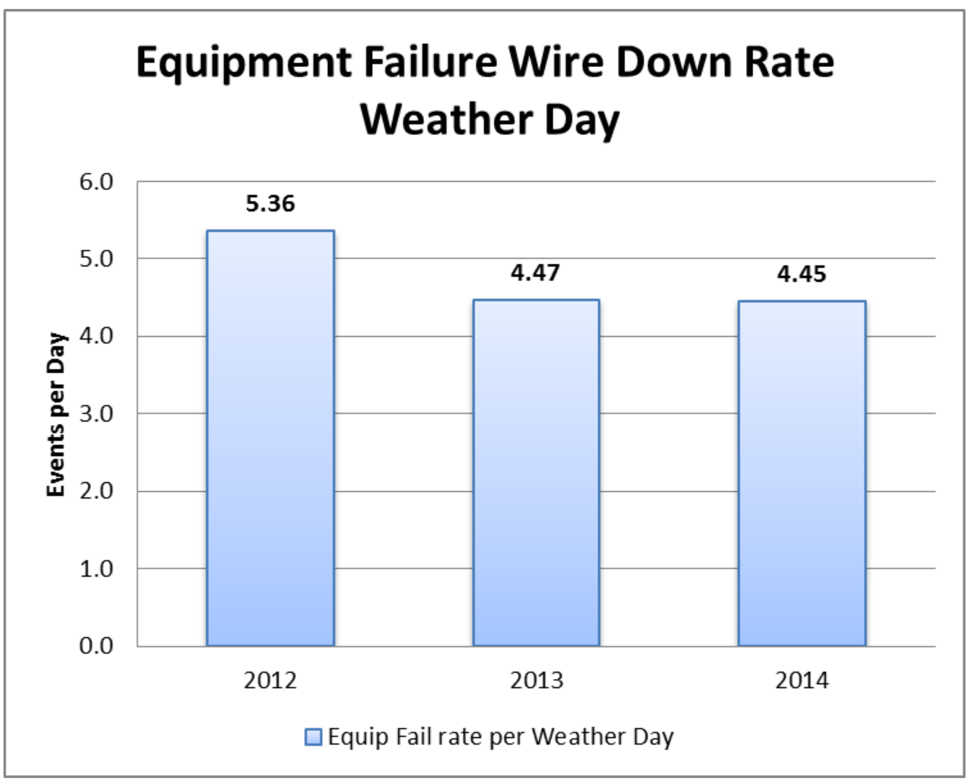

Figure 2

3. **PG &E distribution circuit data**

The 142,000 circuit miles of the PG&E distribution system is made up 3,243 feeders operated at 4 kV, 12 kV, 17 kV, and 21 kV. These are located in very diverse areas from seashores, coastal mountains, deserts, agriculture areas, high elevations of the Sierra Nevada and Cascade mountains, areas with the tallest trees in the world to the very densely developed San Francisco Bay Area. Due to the large size of this system and the number of Wires Down events that occur every year, the results are statistically significant. Details on this system are shown below to illustrate similarities and differences with other utilities.

<u>Distribution Miles by Voltage Level</u>

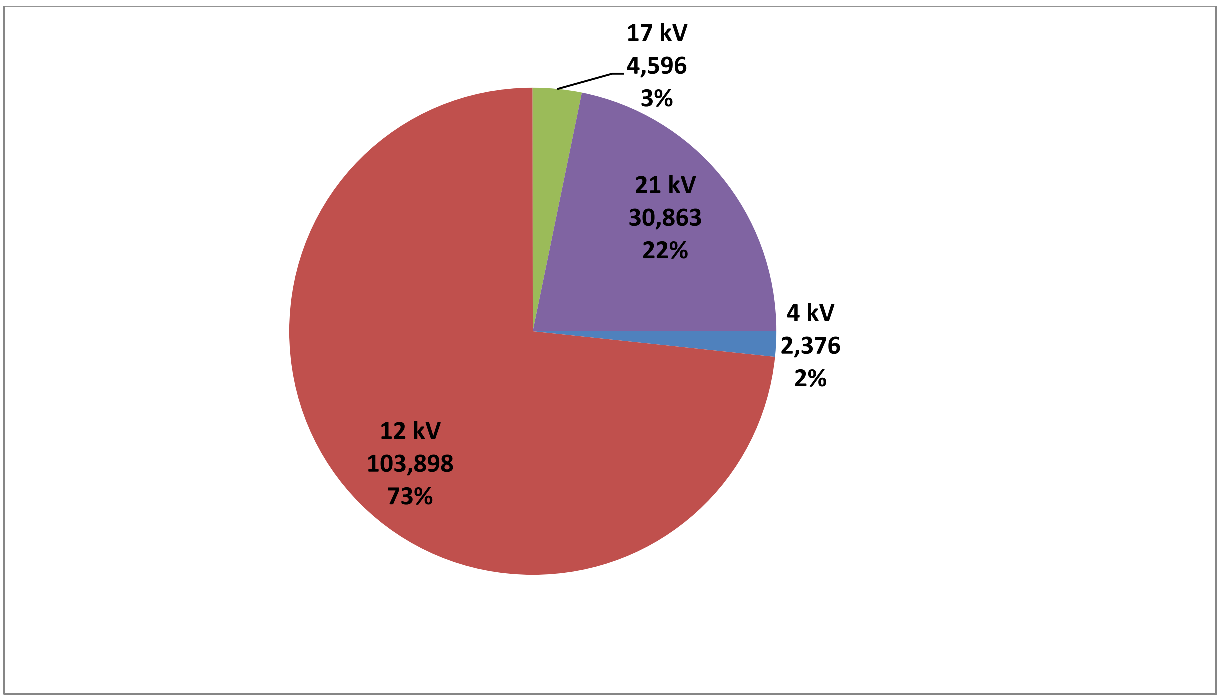

Figure 3

The distribution system is primarily composed of radial feeders. The 12 kV and 17 kV distribution systems are single point solidly grounded at the substation transformer neutral. (3-Wire) The 4 kV is predominantly multipoint grounded (4-Wire) and the 21 kV is about one third 4-Wire. In rare cases, reactors and neutral resistors are used to limit the maximum fault currents to 12 kA 3-phase and 10 kA Line to Ground. The distribution system contains approximately 16% underground cable except at 21 kV which is comprised of 31% underground. Almost every distribution feeder contains at least a small amount of underground.

Feeder statistics

Number of Feeders by voltage		Average Circuit Miles	Longest Single Circuit Miles
4 kV	414	6	34
12 kV	2292	45	362
17 kV	47	98	357
21 kV	483	64	494

Figure 4

Feeder Protective Devices

	Fuses	Over Head Reclosers	Over Head Sectionalizers	Under Ground Interrupters
Total Number	152,235	7,152	394	1,876
Average Per Feeder	46.9	2.2	0.1	0.6
Maximum on a Single Feeder	489	20	7	13

Figure 5

An image of one of our longest distribution feeders with almost 500 miles of circuit at 21 kV is shown in Figure 6. Note the hundreds of end of line points on the feeder.

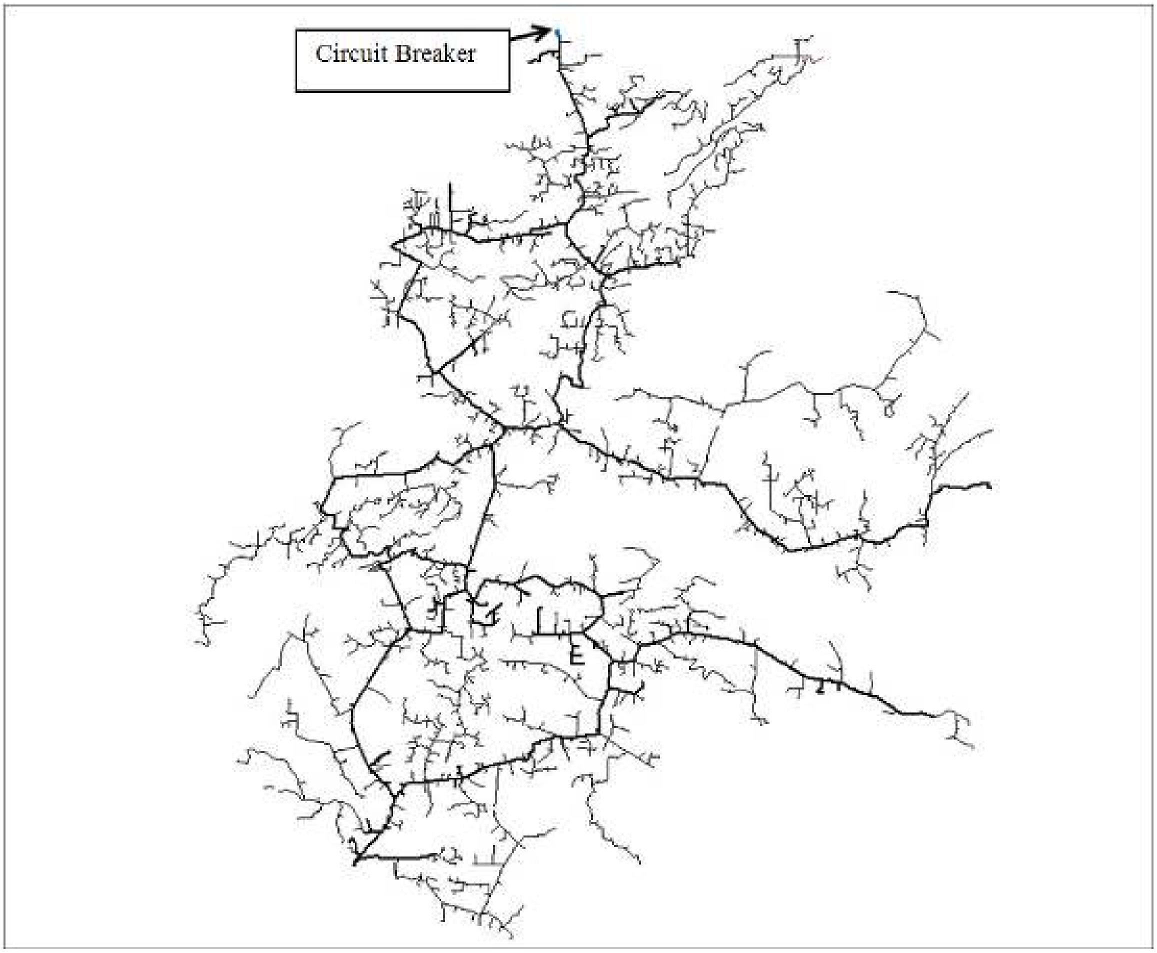

Figure 6

4. Criteria for Site Visit

The PG&E outage reporting tool has seven basic cause categories: 3rd Party, Animal, Company Initiated, Equipment Failure, Vegetation, Environmental/External, and Unknown. These basic causes are assigned by the control center operations group with input from the company first responder on the scene of the outage. A Wire Down outage can occur in any of these basic cause categories, with the exception that no wires down outages are coded with an unknown cause. Once there is an outage record resulting in a Wire Down specification, the outage is added to the Wires Down Database managed by the Asset Strategy team. If the outage cause is Equipment Failure with overhead conductor or overhead connector/splice specified as the failed equipment, the outage is assigned to the distribution engineering team for further review and engineer investigation assignment as necessary. Third party, vegetation, animal, and environmental caused outages are closed without any review from the distribution engineering team.

Equipment Failure outages (shown in blue in Figure 7 below) are approximately 1/3 of the Wire Down outages reported. The graph below excludes outages that occur on a qualifying Major Event Day (MED). The majority of equipment failure outages specify that the failed equipment was the overhead conductor or connector/splice.

Vegetation caused outages (shown in green in Figure 7 below) account for roughly 1/3 of the Wire Down outages reported. Vegetation Management also completes an extensive analysis of the vegetation caused Wire Down events including details regarding the tree species involved, height of tree, distance from the line, and other tree attributes. Vegetation Management then provides asset strategy with splice count information. The Asset Strategy Department is also maintaining a splice count database with splice counts collected from infrared patrols, vegetation patrols, reliability patrols, and engineer investigations. The splice inventory is being modelled in our GIS program and is used when making decisions to create capital projects for reliability or for targeted conductor replacements.

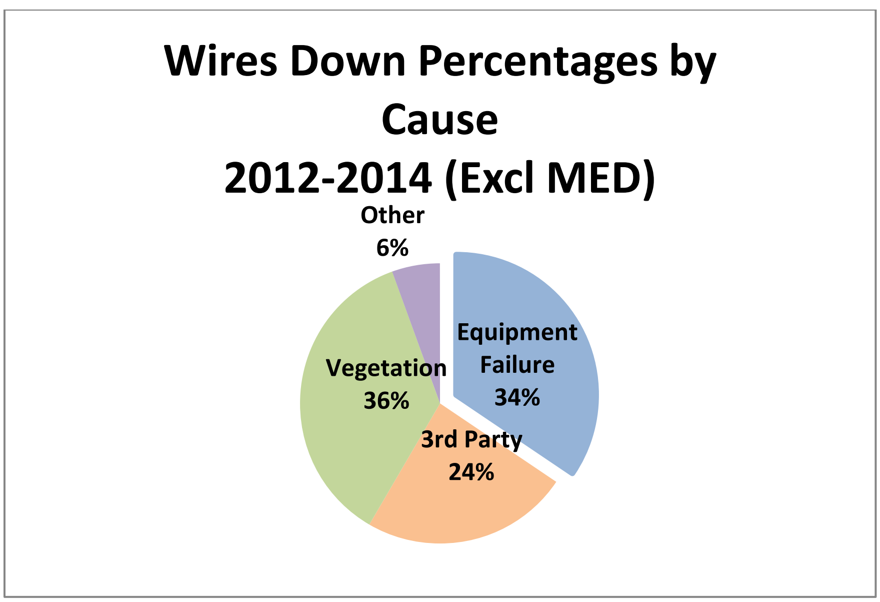

Figure 7

If a Wires Down event is marked for follow up, a distribution engineer goes to the failure location and interviews the first responder in order to complete the investigation form to collect details the regarding the circuit configuration and environmental factors. This form is used specifically for Equipment Failure Wire Down outages with overhead conductors or overhead connectors/splices as the failed equipment. In addition, the engineers determine if the Wire Down was possibly energized based on the configuration of the line, how transformers are connected (LL, LN or 3 Phase), how the line fell or lack of operation by protective devices.

<u>Sample Wires Down Investigation Form</u>

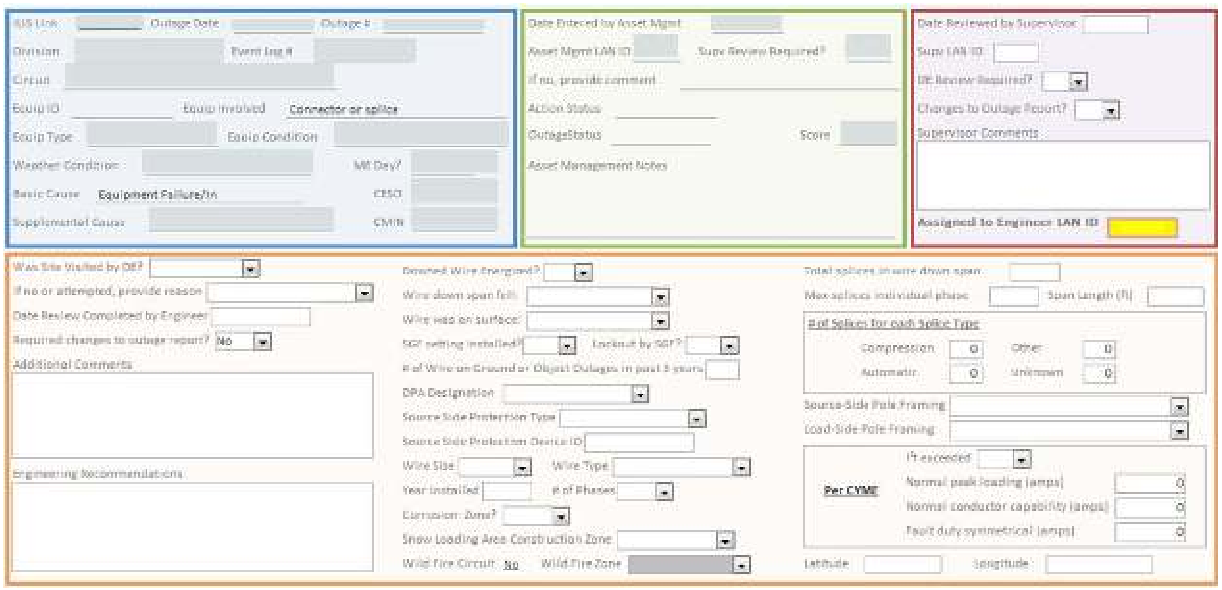

Figure 8

5. Data Collected and Analysis

The yearly distribution Wire Down totals since 2012 is shown in Figure 9. Even though tracked, performance metrics exclude events that occurred on a qualifying Major Event Day (MED) per IEEE 1366 method. Major Event Days are typically extreme weather events but in 2014 included an earthquake.

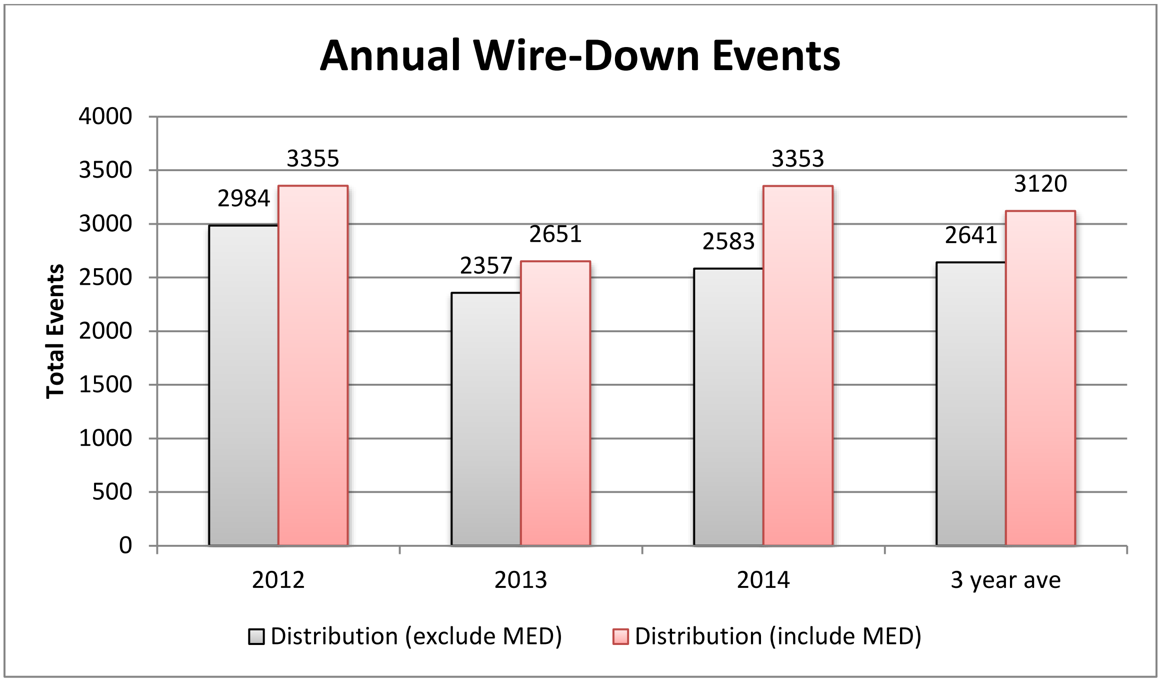

Figure 9

<u>Distribution Cause Breakdown</u>

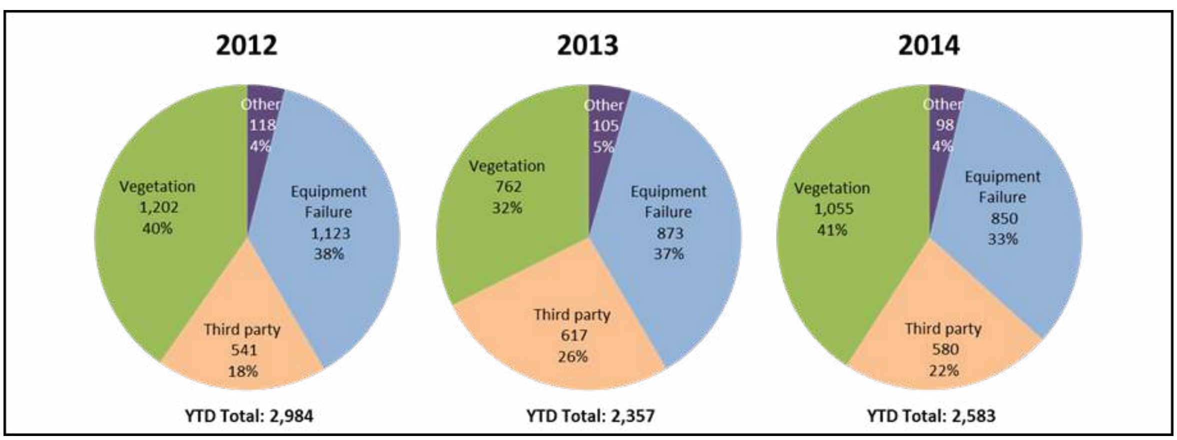

Figure 10

The distribution cause breakdown is shown in figure 10 and the rate per 100 distribution circuit miles in Figure 11. Wires Down caused by equipment failure, third party and vegetation contact make up approximately 94% of the yearly total. While the rate of Wire Down due to equipment failure has consistently decreased, the overall number of Wires Down varies significantly from vegetation caused events and third party caused events. Focusing on areas that can be controlled will create a more robust distribution system overall.

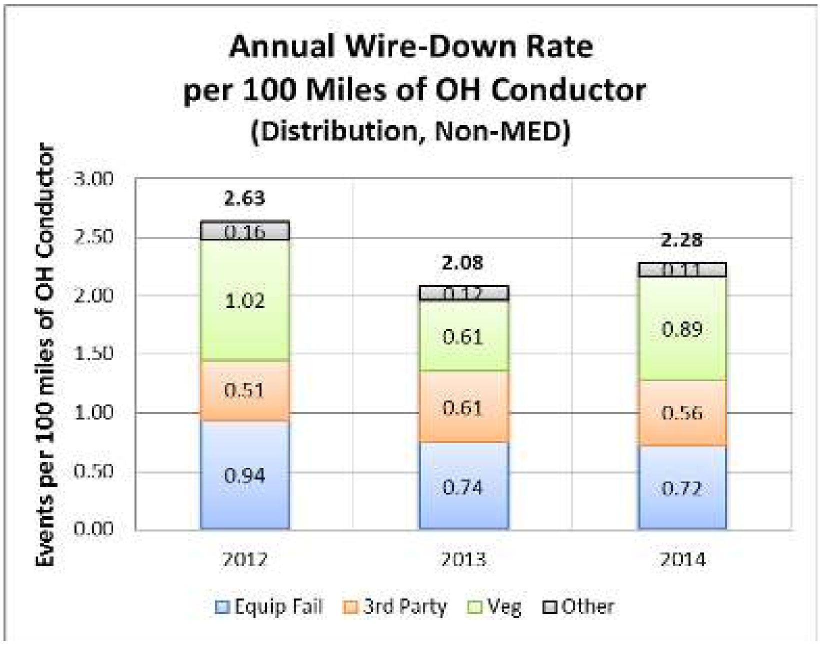

Figure 11

The total engineering site visits completed between mid-2012 and year-end 2014 are detailed in Figure 12. Total site visits peaked in 2013 and have dropped since due to fewer events and changes to the site visit criteria. The current site visit focus is equipment failure related Wire Down events due to failed conductor or splice. This is a considerable investment in engineering resources with hundreds of site visits every year.

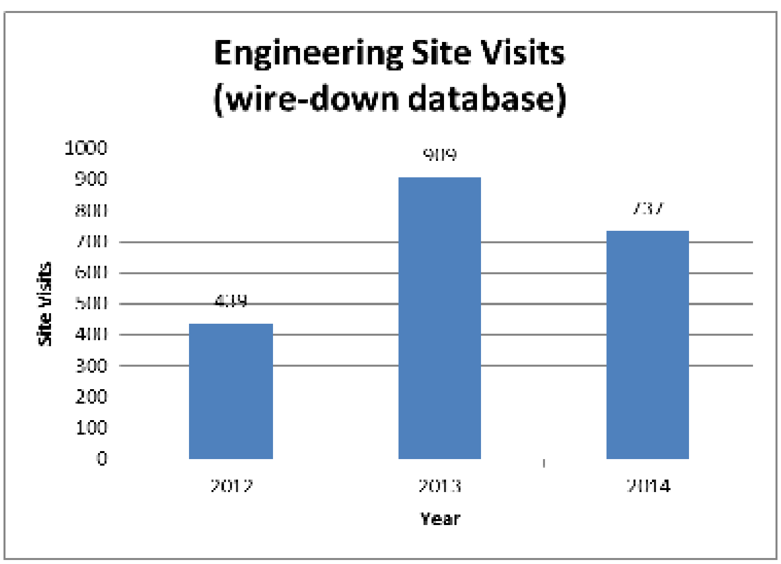

Figure 12

The data obtained during the site visit has made it possible to evaluate the Wires Down rate by: Conductor size, conductor type, number of splices, corrosion zone, construction type, equipment failed, source side or load side failure within a span, and the cause of failure.

Data Analysis

Rate by conductor type and size

The equipment failure annual Wire Down rate per 100 distribution circuit miles of several primary conductors is shown in Figure 13. The data has shown the #4 and #6 copper conductors with the highest Wire Down rate followed by #2 copper and #4 ACSR. These results supported a 2014 initiative to remove #4 and #6 copper from company standards involving new installations.

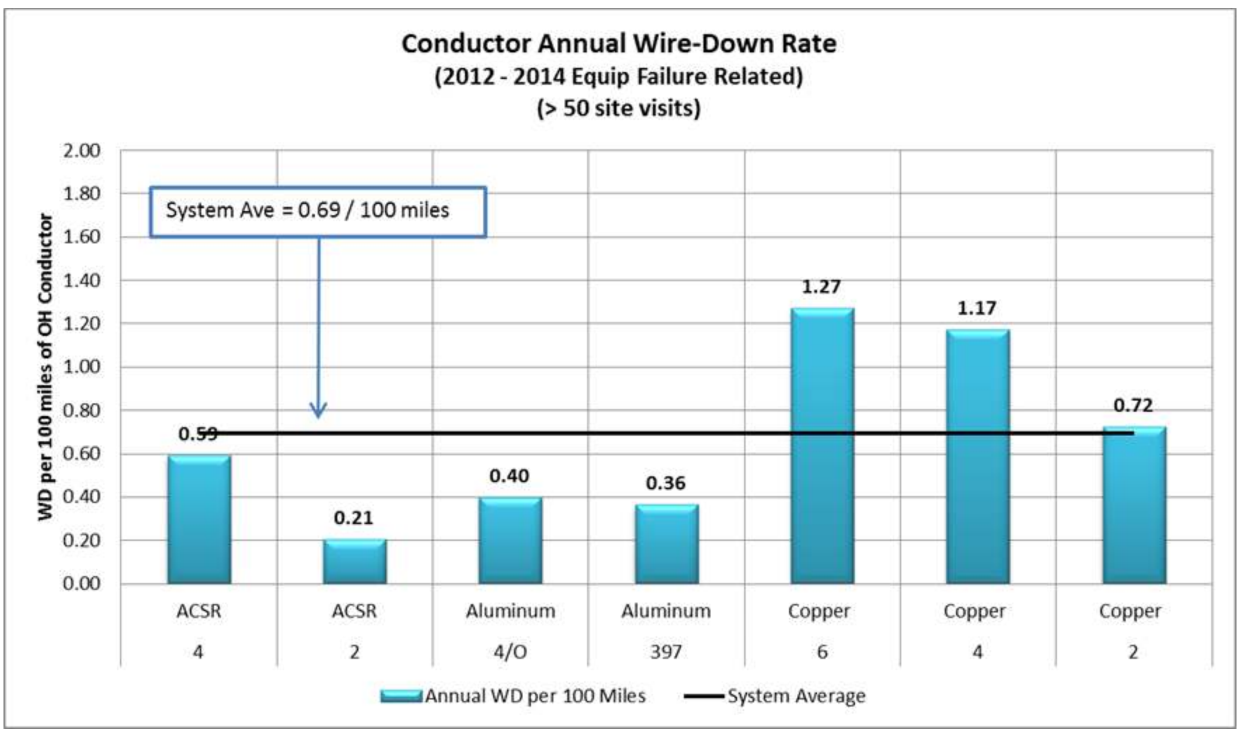

Figure 13

Rate near coastal area

Areas near the Pacific Coast are designated as a special “Corrosion Zone” and use different construction standards. Figure 14 shows the failure rates for three conductors in the “Corrosion Zone” versus the non “Corrosion zone”. The data shows the Wire Down rate is much higher than the system average for #4 ACSR. For this reason, the #4 ACSR conductor is targeted for replacement in the corrosion zone.

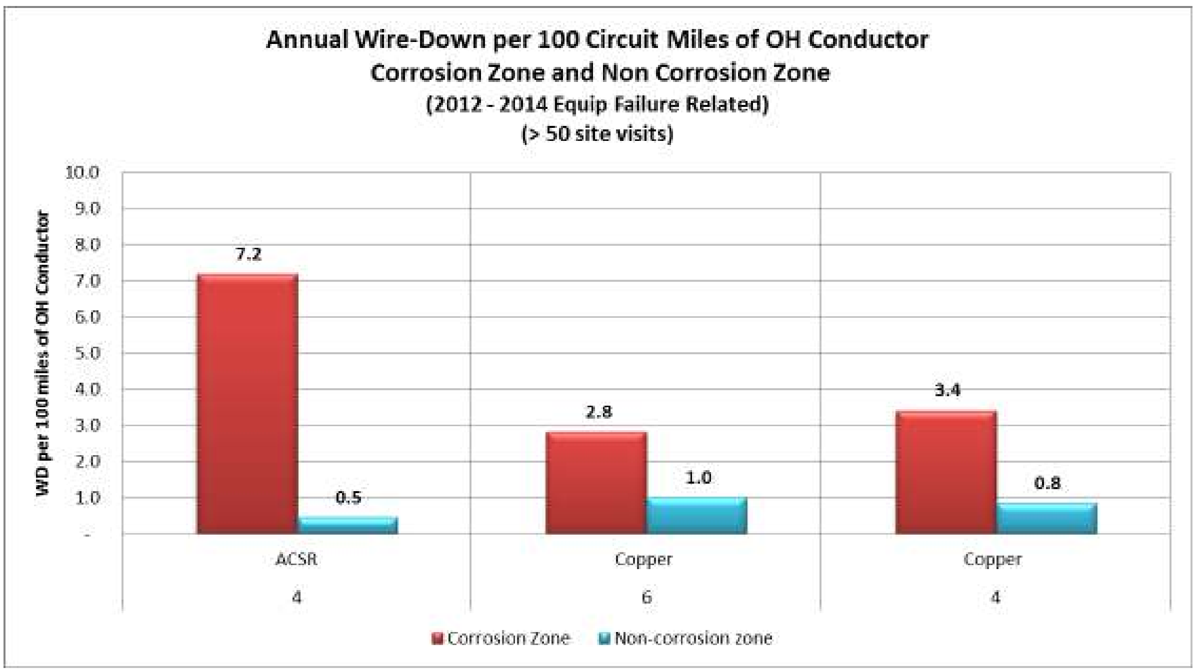

Figure 14

Total splices in conductor span

The number of splices in an individual phase on each failed span is tracked. The number of splices is detailed in Figure 15. Our strategy currently prioritizes the individual phase totals that exceed three splices.

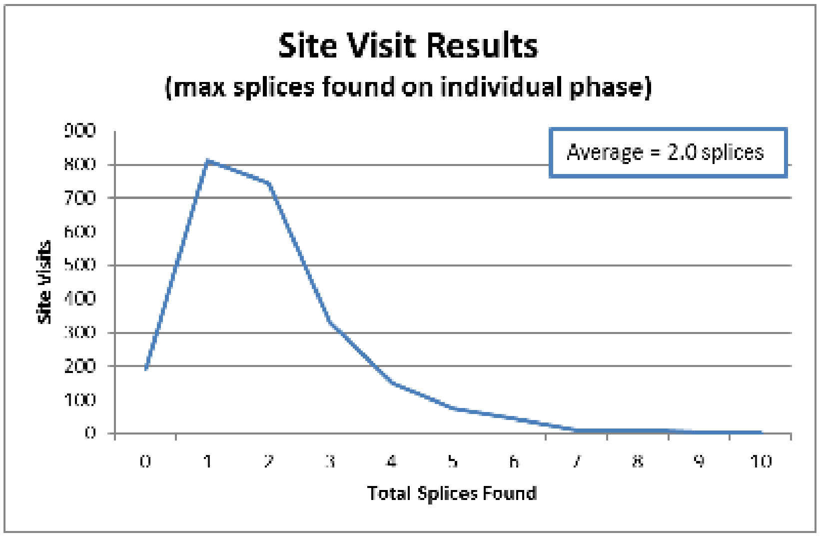

Figure 15

Focusing on Equipment Failure caused outages, the specific equipment that failed resulting in an outage and Wire Down is shown in Figure 16. The majority of equipment failure outages specify that the failed equipment was the overhead conductor or connector/splice. These are the events that currently receive a site visit.

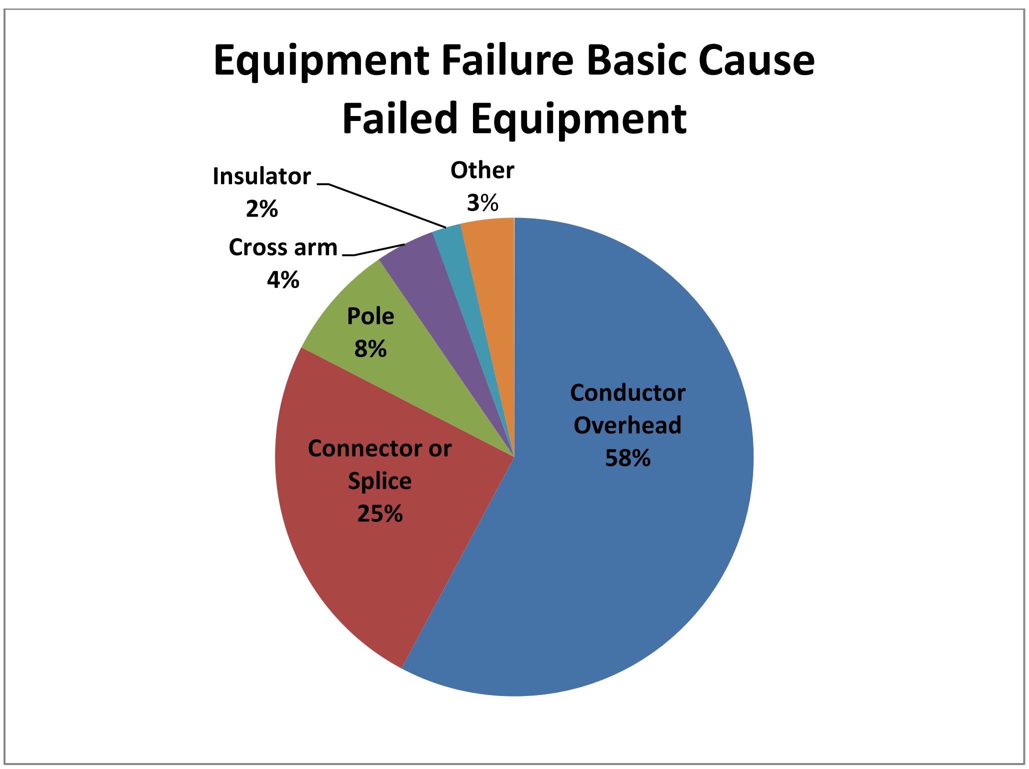

Figure 16

Infrared Inspection and Splice Inventory Program

In 2012, an infrared program was started with the goal to inspect the entire distribution system and obtain splice location data. Figure 17 shows the total circuit miles completed and forecast. Completion is expected in 2018. All infrared findings are collected through the maintenance process and splice data is added to the geo-spatial tool described in the next section. Average rate of findings is 2.1 per 100 circuit miles with the majority related to connectors.

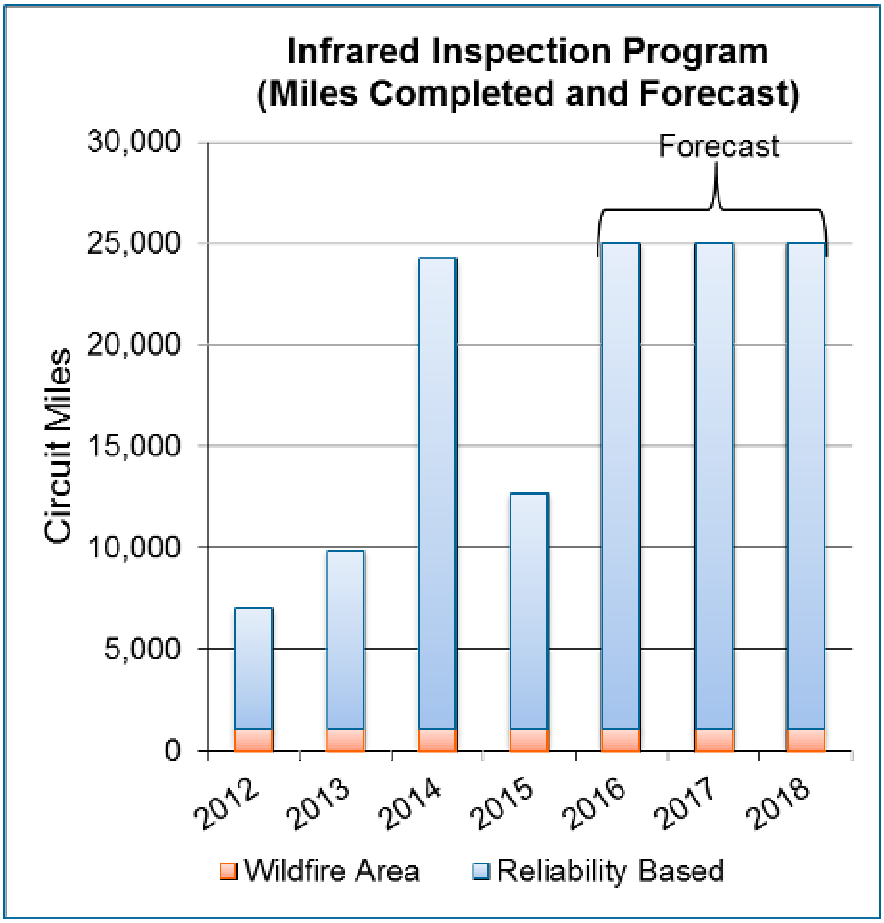

Figure 17

6. GIS and other tools developed.

A. GIS

PG&E is utilizing a geo-spatial tool to store all splice data and allow users to view splice locations as a layer with other distribution circuit data. Figure 18 below shows the splice location on the load-side of fuse 5131 and in a designated "wildland fire" area shaded in purple. The geo-spatial tool has been very helpful in locating splices in various environmental zones.

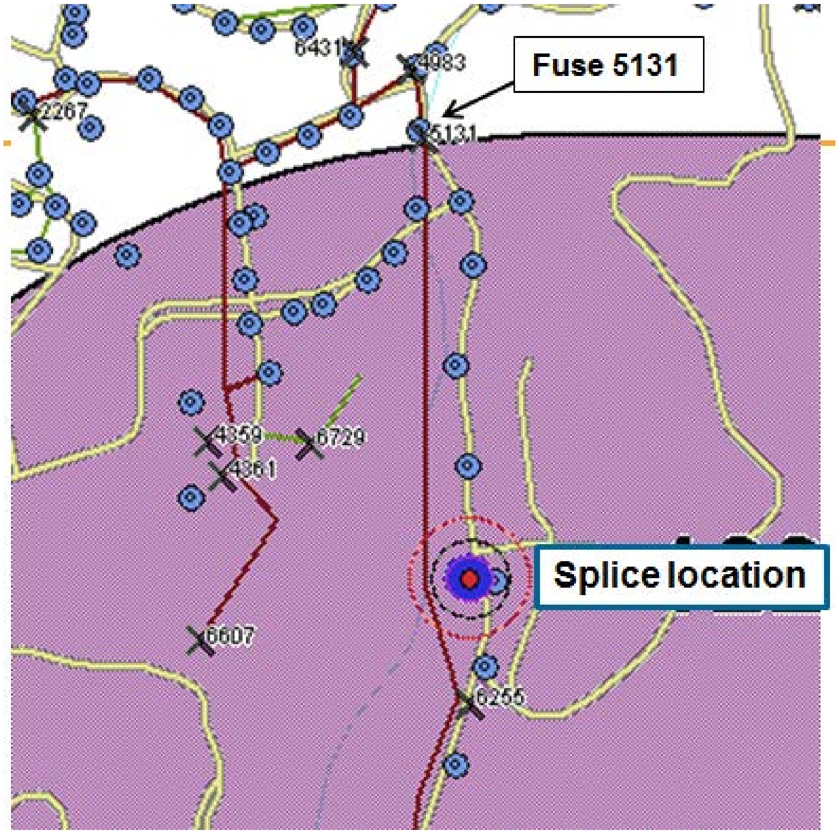

Figure 18

B. High Risk Areas /STAR

PG&E is working on improving analytical capabilities associated with risk based investment decisions. The risk informed budget allocation process (RIBA) is the enterprise wide method for driving high level project and program budget decisions using a risk based methodology. System Tool for Asset Risk (STAR) is a tool being developed to create risk based scores for all assets in consideration for proactive replacement. The STAR uses data from different sources to calculate and display individual asset risk scores and "system" risk scores. STAR will serve as a key input for a RIBA.

When fully developed, the STAR application is envisioned to be the source system for risk information such as: asset and system health indices, asset and system risk impact factor score, asset and system risk scores. Asset health indices reflect the condition of an asset. Risk impact factors include elements such as safety, reliability, financial, etc., and the effect a risk can have on those elements. A risk score is the product of: (1) probability of failure, and (2) impact of failure. An asset risk score is related to a specific asset such as a single substation transformer or a single wood distribution pole. A system risk score is related to an entire substation or an entire distribution circuit. System risk scores are useful for gauging the risk of a system containing different assets.

7. Improvement in Wire Down rates and reliability

As mentioned earlier in the paper, improvements in the equipment failure rates have been achieved since 2012 in both the non-weather day and weather day category. Figure 19 and 20 below show the improvements that have been achieved by the mitigating efforts including investigations, conductor replacement and infrared.

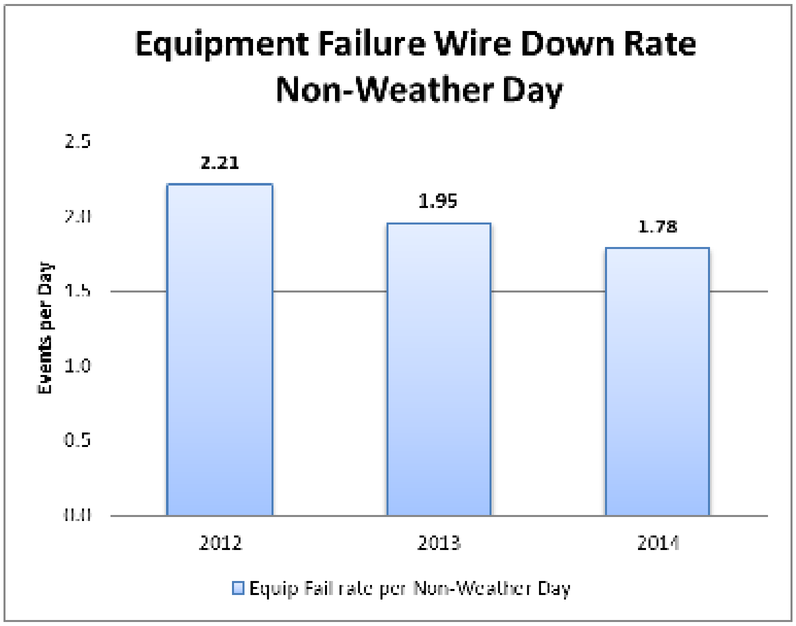

Figure 19

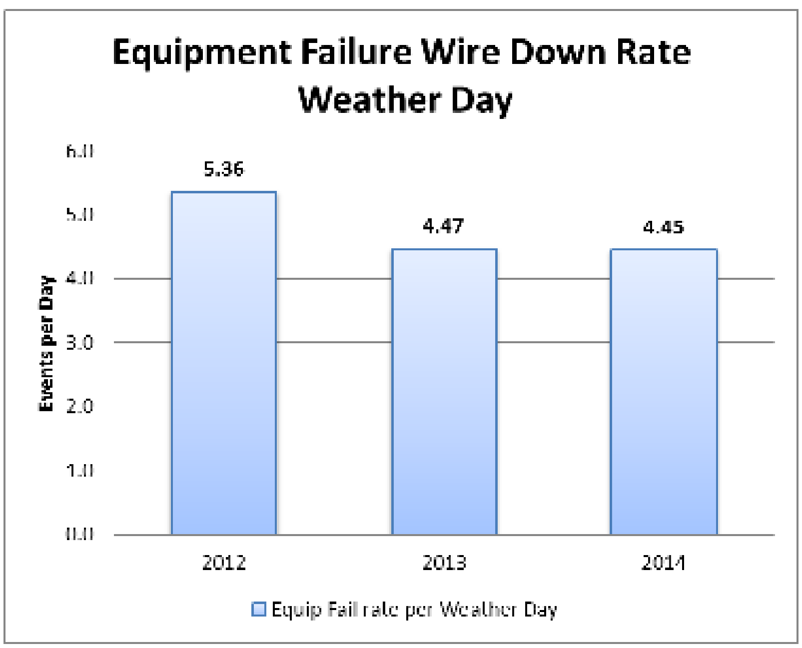

Figure 20

One of the methods used to drive these results is the targeted replacement of certain conductor types within different risk areas. Some of these conductors types are replaced due to loading/capacity issues but significant mileage is replaced on our risk/reliability program. Figure 21 shows the circuit miles of conductor replaced per year and current forecast. The yearly replacement totals have significantly increased since 2012.

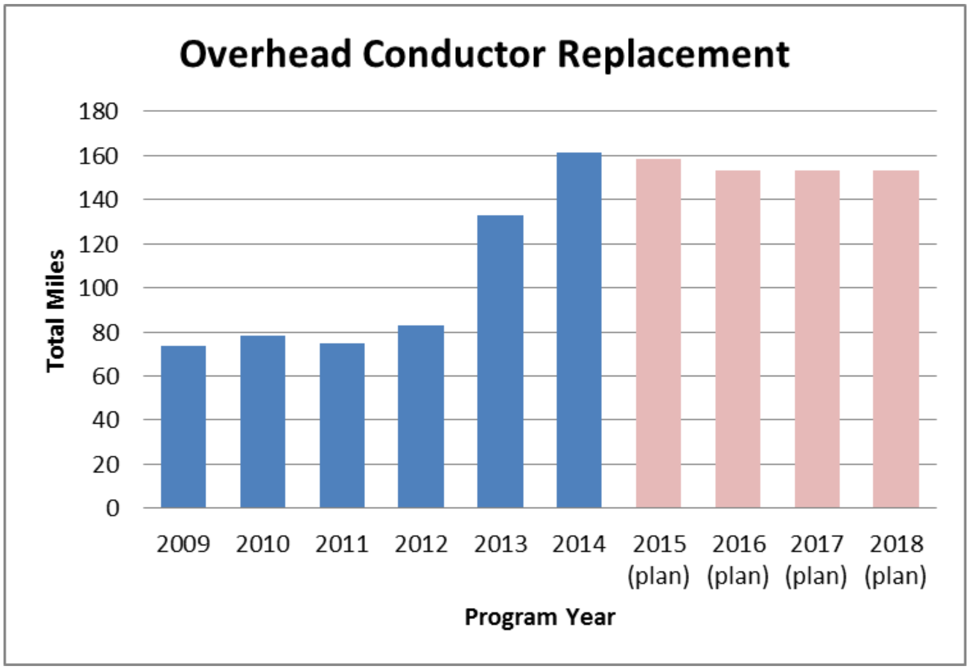

Figure 21

8. Wires Down and Possibly Energized

One area that is being tracked and analyzed is the number of Wires Down that could possibly remain energized. This is determined from field reporting and later analysis of the Wire Down location configuration. One cause of Wires Down remaining energized is High Impedance Faults (HIF). Many industry papers have been written on this topic but very little literature exists on the other causes of Wires Down remaining energized. These other causes will generally not be detected by the HIF algorithms presently available. The other causes may not have full voltage to ground but may still remain energized at a level that could be a potential hazard to life and property.

The data collected in the field is entered into a database as well as other attributes. These include: location of the break and how the wire contacted the ground, three phase/single phase, primary voltage level, source side protective device, peak loading of the span and the fault duty at the failure point.

Wires Down outages occur throughout the distribution system and protection zones. The source side protective device for all Wires Down outages investigated is shown in Figure 22.

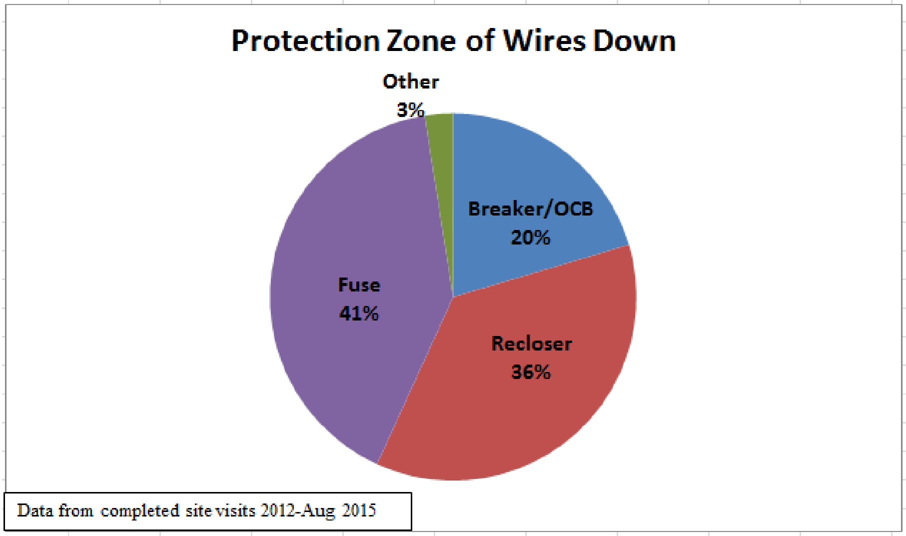

Figure 22

Based upon data collected from 2012 thru August 2015 on completed site reviews, approximately 30% of the site visits completed by engineers were determined to have possible energized Wire(s) Down. Most of the engineer site visits were performed on outages caused by Equipment Failure with overhead conductors or overhead connectors/splices detailed as the cause. Figure 23 shows the percentage of Wires Down that could have remained energized. Figure 24 details if the down wire was touching the ground from the source side, load side or both. This is an important consideration for some causes of Wires Down and possibly energized.

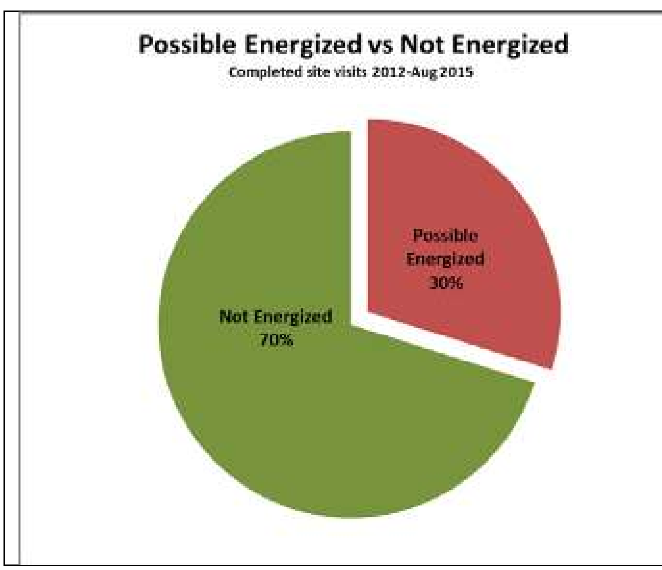

Figure 23

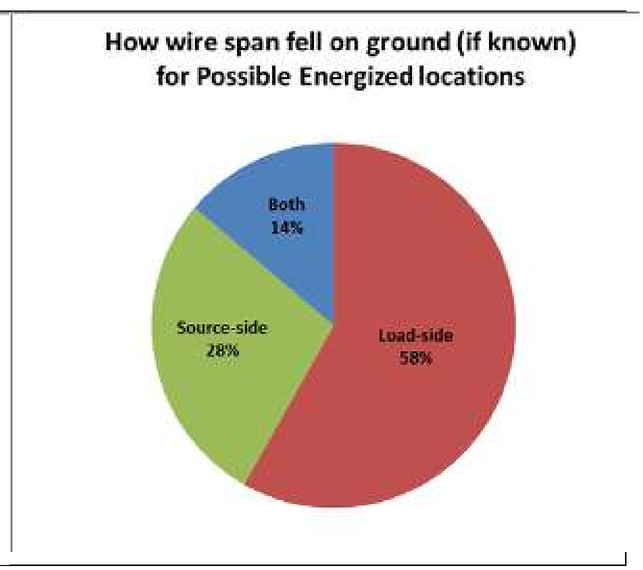

Figure 24

Since the information gathered by the distribution engineer is collected after restoration, there were a significant number of "unknowns" for how the wire span fell on the ground during the outage. Figure 24 depicts the data that was collected excluding the "unknowns".

Statistically, mid-span conductor breaks (with both source and load-side conductors down) are less common. More Wires Down are seen with a source-side or load-side break near the poles where more equipment, connections, and hardware are present. If the conductor falls to the ground with the wire on the ground on the source-side, the source-side protection should operate unless the device cannot see the fault due to a high impedance fault. On radial feeders, if the conductor falls to the ground with the wire on the ground on the load-side or both (source and load-side), there is a greater opportunity for the wire to be possibly energized on a backfeed condition.

The breakdown of Wires Down and possibly energized, where the wire fell on the source side is detailed in Figure 25 by the surfaces that the possibly energized conductor fell on.

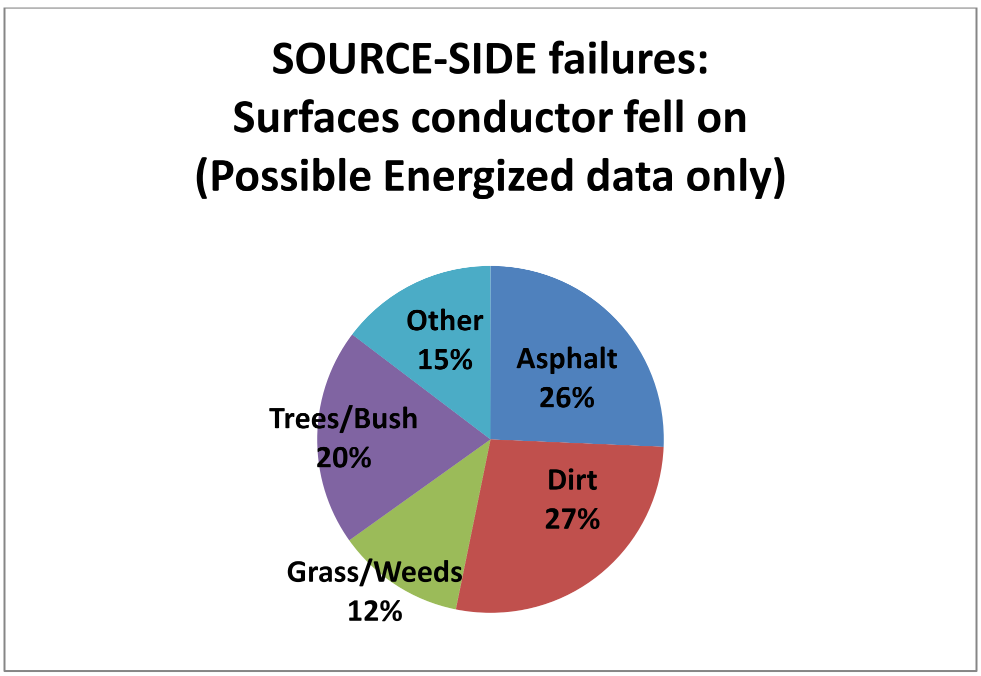

Figure 25

Asphalt, dirt, and sod all have high impedances when dry which may create a high impedance fault condition.

Many of the Wires Down specified to be energized on the load side coincided with "hot" backfeed conditions (through a transformer) either identified through the outage reporting system or from engineering analysis after the outage. Detecting high impedance faults and detecting "hot" backfeed through a transformer is extremely difficult or impossible with conventional protection schemes.

The Wires Down tracking effort shows a correlation between possibly energized Wires Down and voltage level. Figure 26 shows the rate of Wires Down and possibly energized by primary voltage level. This matches conventional wisdom and our experience at transmission voltages. The 4kV samples show a much greater occurrence of the Wires Down remaining energized than the higher voltages.

The lowest percentage of Wires Down and possibly energized occurs on the 17kV system which is made up of single point solidly grounded 3 wire feeders. The 4 kV system is almost all 4 wire multi point grounded and the 21 kV system is about one third 4 wire multi point grounded and have higher rates of Wires Down and possibly energized.

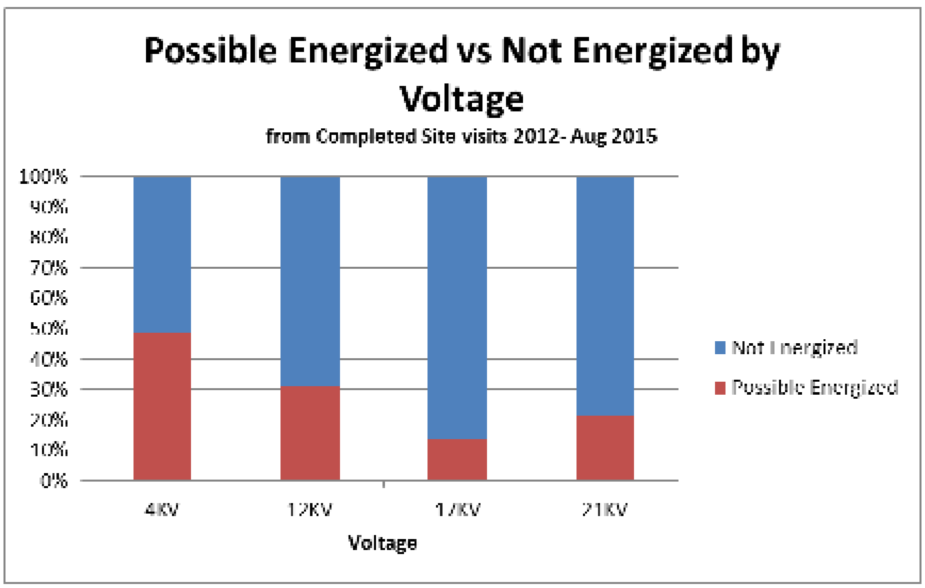

Figure 26

Looking specifically at the 21kV Wires Down subset with possibly energized Wires Down, the data collected showed 45% occurred on 3 wire distribution systems and 55% occurred on 4 wire distribution systems.

There may also be a correlation between energized Wires Down and conductor size. The larger conductors have a larger surface area and should make better contact with the ground. Data analysis has not shown a consistent correlation. It is important to note that with the use of insulated tree wire conductor, it is very difficult to detect a Wire Down condition because only the broken cross section area is able to conduct.

9. Wires Down and Possibly Energized Due to Backfeed

There are many different causes of Wires Down that may remain energized. Several different causes will be discussed but the focus will be on Wires Down that remain energized due to a backfeed condition through the primary winding of distribution transformers. This condition is often not fully understood or recognized.

A. Wires Down and energized due to high contact resistance. If conductor contacts the ground and is fed from the source but does not relay due to a high resistance surface this is a classic High Impedance Fault (HIF). Conductors that fall on dry vegetation, sand, or asphalt can result in little to no fault current flow. Tree wire or insulated wire exacerbates this problem. Many papers have been written on this topic and many relays include algorithms that can be used to detect some but not all of these instances.

B. Generation connected to the distribution circuit on the load side of the down conductor. There have been many papers published on this topic for both rotating machine based generation and inverter based generation. PG&E has more Photo Voltaic (PV) interconnections than any other utility in the United States. Currently more than 175,000 PV interconnections with more than 4,000 new connections per month. This does pose some risk of Wires Down that remain energized even if the source side protective device opens. This risk is mitigated by enforcing the use of certified inverters with active anti islanding and enforcing limits on PV penetration levels on individual circuits.

C. Inductive coupling. If a conductor contacts the ground and a source side fuse operates or if a conductor contacts the ground but the source side conductor remains isolated from the ground, the load side wire may remain energized at a level that could be a potential hazard to life and property. This is caused by load current remaining on the intact phases and inductively coupling to the broken phase. The level of voltage is proportional to the load current, phase to phase spacing and the length of the circuit past the open point. This condition is often seen on long transmission lines but can also occur on de energized feeders if they are on the same structure as an adjacent feeder or underbuilt on a transmission structure.

D. Broken Neutral Conductors can have enough voltage to be a potential hazard to life and property under certain configurations. If a neutral conductor is severed and contacts the ground there is not a source of primary fault current but the unbalanced loading or the lack of a metallic path back to the substation will result in a potential difference between local ground (neutral conductor on the ground) and remote earth. A best practice is to loop the neutral conductor on three phase construction so that two metallic paths are always available back to the source. In cases where this is not practical or on single phase taps the risk is higher. Longer distances between ground rods connected to the neutral increases this risk.

E. Wires Down and energized due to backfeed is very common from a probabilistic standpoint. The voltage on the down wire is often lower than nominal voltage but may be high enough to be a potential hazard to life and property. There are many different 3 Wire and 4 Wire configurations that can create this condition, several of which are detailed below. Every distribution system has this risk but many engineers believe it to be an extremely rare occurrence. This mistaken belief may be a result of Wires Down and energized that are not actively arcing or by engineers who are not often in the field while the conductors are on the ground before they are cleared and grounded.

We have seen one publically available report from a large consulting firm that re-iterated this belief: *"Benchmarking data is not readily available in the industry, but we have experience with some other utilities. We know of several major utility systems (23 kV) where downed energized conductors are estimated to be fractions of one percent."*

There are many factors that can affect Wires Down and energized due to backfeed including:

a) Source side protective device – 3 phase or fuses
b) Transformer connection – 1 phase or 3 phase
c) Number of transformers on the load side of the down wire
d) Active loading on the transformers on the load side of the down wire
e) Single phase tap or three phase line
f) 3 wire distribution or 4 wire distribution
g) Circuit design/Neutral design.
h) Location of failed conductor within a span - source side, mid span or load side
i) Capacitors on the load side of the down wire
j) Voltage Regulators on the load side of the down wire

Transformer Equivalent Circuit

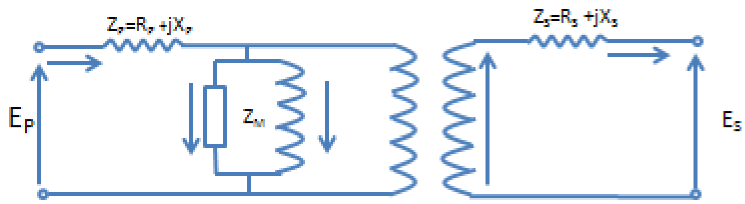

Figure 27

A simple transformer equivalent circuit is shown in Figure 27. If this transformer is connected between two phase conductor and one of those conductors is open, the open conductor will be energized through the primary winding of the transformer. This voltage/current source has two components. One component is a function of the transformer open circuit magnetizing impedance. This is typically many kΩ. The second component is a function of the actively connected load on the transformer secondary. This is out of utilities control, highly variable and changes during the low voltages caused by an open conductor or an active fault. Sound utility practice does not rely on this second component to detect Wires Down. The authors have seen some technical papers that claim HIF relay algorithms can detect down wires through a transformer backfeed as long as the transformer is loaded. This may occur in rare cases where the transformer size and connected load create ideal circumstances. Typically many transformers on the load side of the Wire Down location all contribute to the backfeed voltage/current. The current through each transformer is much less than the transformer fuse ratings.

Three phase transformers have many different connection types with different backfeed effects. Most feeders contain many three phase transformers and even all overhead feeders frequently feed some padmounted three phase transformers. Several different transformer winding configurations are detailed below.

Delta/Delta – If one or two phases remain energized into the primary winding of the transformer it will maintain some voltage on the open phase(s) due to the transformer magnetizing impedance path. This will not result in zero sequence current flow but can provide enough capacitive current to be a potential hazard to life and property.

Delta/Wye - If one or two phases remain energized into the primary winding of the transformer it will maintain some voltage on the open phase(s) due to the transformer magnetizing impedance path.

Wye/Wye Ground - If one or two phases remain energized into the primary winding of the transformer it will elevate the potential on the ungrounded neutral due to the transformer magnetizing impedance path. The open phase will have a voltage due to this neutral shift with respect to remote earth.

Wye Ground/Wye Ground – If the transformer is in a single steel case, it will create a virtual tertiary effect. This virtual delta tertiary is created by magnetic coupling with the case. This is a weak effect but it can be measured on large transformers. The Wye ground will act as a zero sequence source to the open and downed conductor and will produce some voltage.

Wye Ground/Delta - The Wye ground will act as a zero sequence source to the open and downed conductor and will produce some voltage.

Some capacitor bank connections or line voltage regulator connections can create the risk of backfeed as well.

Several simple scenarios that may result in a backfeed condition are detailed in Figures 28 to 31. The conductor may be isolated from any primary fault current source. Figure 28 shows a wire down with no direct primary fault current source but the down wire may remain energized due to backfeed. The level of voltage on the down wire is a function of the number of transformers on the load side of the Wires Down, their size, connections and active loading.

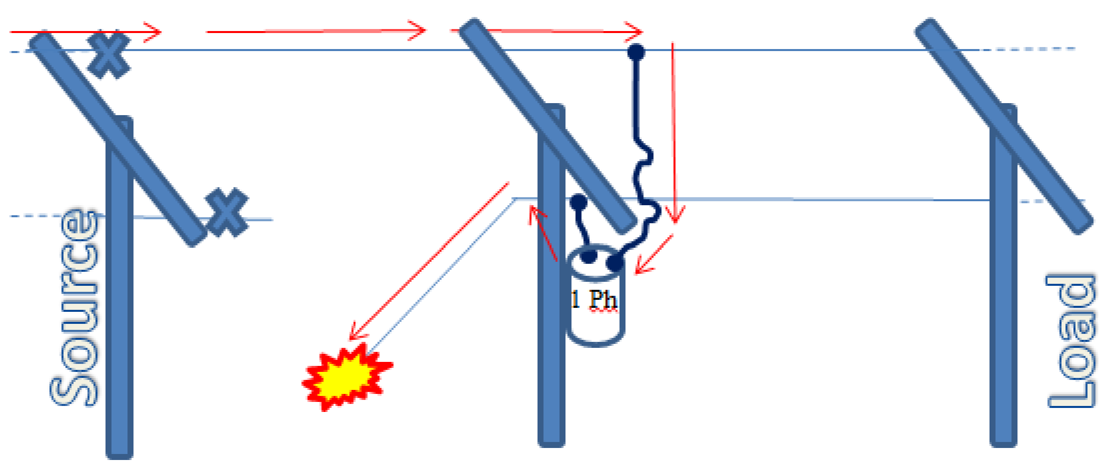

Figure 28

If not all fuses blow, any phase to phase connection between the fuses and Wires Down may be a source of backfeed as shown in Figure 29 and 30.

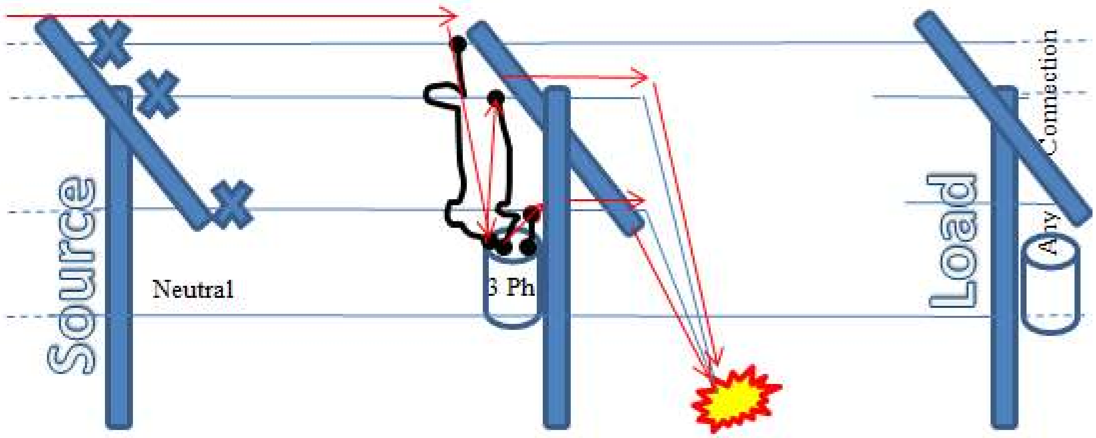

Figure 29

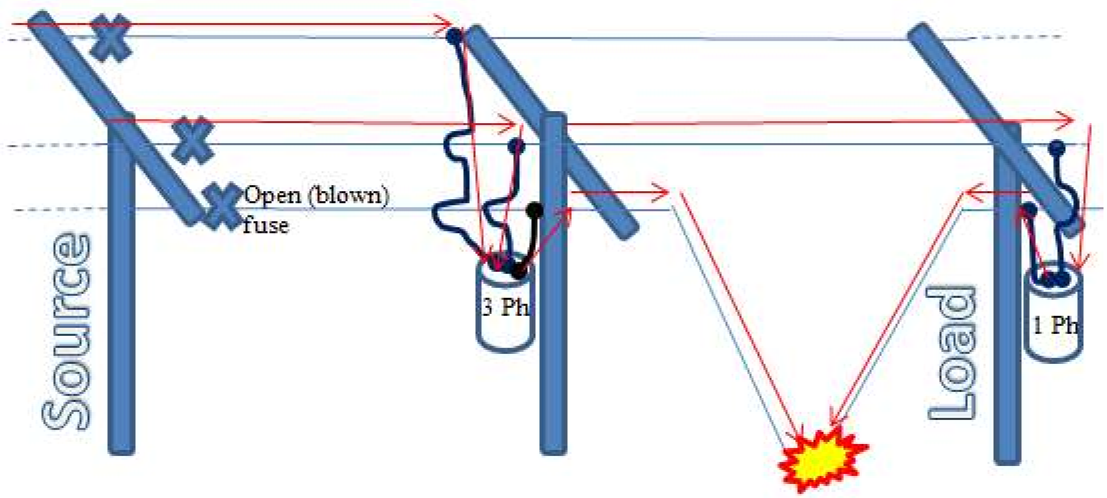

Figure 30

Three phase protective devices reduce the backfeed risk but do not eliminate it. If the source side device detects the fault and operates it eliminates the risk of backfeed. If the conductor breaks at the source side of a span the source side protective device will not operate but the conductor may remain energized due to backfeed.

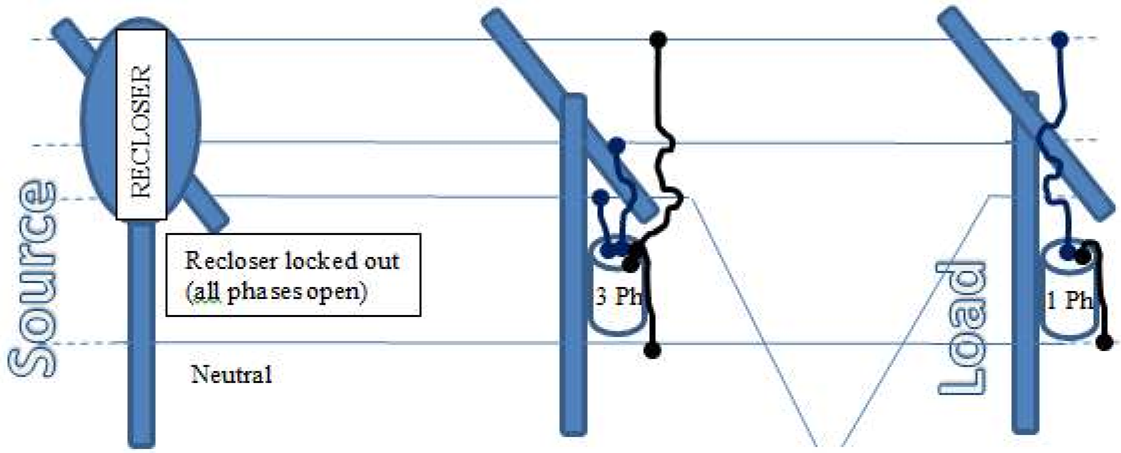

Figure 31

A failed conductor may happen anywhere on a span but it is much more likely to occur at the point where a conductor is at a connection point. (bump splice, clamp, insulator tie wire, etc.) Consider a typical distribution span of 300 feet with the conductor 30 feet above ground at the poles. If a conductor breaks within the first 29 feet of the source side pole there will be no direct path to ground for the fault current. If the conductor breaks within the last 20 feet of the span (load side) there is little risk to humans due to backfeed as the conductor is above the typical touch height. If the conductor separates in the middle section of a span it will be down from both load and source side. If the source side is a three phase interrupting device and it successfully detects and trips for the fault, the risk is removed. If the source side device is made up of fuses (single phase device) only a single phase is opened. The load side conductor may remain energized through the primary windings of distribution transformers connected on the load side of the down conductor.

Several configurations are detailed in Figure 32 to illustrate that there is significant risk of Wires Down remaining energized from backfeed. This is in addition to any that may remain energized due to HIF faults or other causes.

Wires Down and Potentially Energized by Backfeed			
Case		Variables	**Potentially Energized From Backfeed**
Single Conductor Intact and Down			
Source Side Device 3 Phase			
Three Phase Tap			**No**
Two Phase Tap			**No**
One Phase Tap			**No**
Source Side Device 1 Phase	(Fuses)		
Three Phase Tap			**Yes**
Two Phase Tap			**Yes**
One Phase Tap			**No**
Conductor Separated and Down	**Separation Point**		
Source Side Device 3 Phase			
Three Phase Tap			
	Source Side		**Yes**
	Mid Span		**No**
	Load Side		**No**
Two Phase Tap			
	Source Side		**Yes**
	Mid Span		**No**
	Load Side	Any Phase to Phase connected single phase transformers or most three phase transformer connections will create a backfeed risk.	**No**
One Phase Tap			
	Source Side		**No**
	Mid Span		**No**
	Load Side		**No**
Source Side Device 1 Phase	(Fuses)		
Three Phase Tap			
	Source Side		**Yes**
	Mid Span		**Yes**
	Load Side		**Yes**
Two Phase Tap			
	Source Side		**Yes**
	Mid Span		**Yes**
	Load Side		**Yes**
One Phase Tap			
	Source Side		**No**
	Mid Span		**No**
	Load Side		**No**

Figure 32

10. Currently available methods of detecting high impedance faults.

A. Conventional methods – Harmonic/signature based schemes. These schemes are provided by most relay manufacturers and can detect some HIF faults but will generally not detect a backfeed condition. They have not been widely implemented by the industry due to possible high rates of trip/alarm where there is no safety risk. (leaking insulators or conductor resting on wooden crossarm.)

B. Synchrophasor/communication based schemes. These schemes show promise but require communication to every end point on a circuit to provide complete coverage. On a large distribution feeder, hundreds of monitoring points would be required.

Summary

The best way to improve safety and reliability is to prevent faults and Wires Down. While many of the causes are beyond the control of utilities (Car Poles, Fires, Trees failing outside the right of way, etc.), we have shown that by rigorously collecting and analyzing data, improvements can be made to the rate of Wires Down. Pacific Gas and Electric has implemented a robust program and through targeted work has made improvements. The paper demonstrates that certain wire sizes, types and corrosion zones have significantly increased risk of failure. Last year we replaced over 800,000 feet of conductor that is helping to accomplish this goal.

Protection Engineering is a blend of art and science. Engineers always strive to find the right balance of safety and reliability for the public. If devices trip with no risk to the public it results in wider outages. This affects hospitals, traffic lights, safety lighting, life support systems, etc., and has an adverse public safety impact. If schemes are not properly applied they may not detect all down wires and pose a public safety risk. No schemes can credibly detect all Wires Down due to backfeed conditions and remain practical.

PG&E is tracking rate of Wires Down and potentially energized to look for opportunities to reduce risks. The use of fuses is key to improving the overall safety of distribution systems. They reduce outages to the mainline and operate at lower currents than ground or phase relays. They do however result in an increased risk of Wires Down and energized due to backfeed since they operate single phase and may leave remaining phase conductors energized. Downed conductors should always be treated as energized. PG&E and many utilities have public safety campaigns to warn the public of the dangers of Wires Down. This paper is intended to further the industry knowledge and discussion about these risks and possible solutions.

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Biographies

Scott Hayes received his BS in Electrical and Electronic Engineering from California State University, Sacramento in 1985. He started his career with Pacific Gas and Electric Company in 1984 as an intern. Since then he has held multiple positions in System Protection including supervisor and is currently a Principal Protection Engineer focusing on standards, procedures and quality. He has also worked as a Distribution Engineer, Operations Engineer, Supervising Electrical Technician, and Supervising Engineer in Power Generation. Scott has previously co-authored papers for the Western Protective Relay Conference, Georgia Tech Protective Relaying Conference, TechCon Asia Pacific, CEATI Protection and Control Conference, i-PCGRID and Transmission and Distribution World Magazine. Topics include Thermal Overload Relays for Intertie Lines, Data Mining Relay Event Files to Improve Protection Quality and Effects of CCVT Ferroresonance on Protective Relays, Relay Asset Strategy and Transmission Fault Locating. Scott is a registered Professional Engineer in the state of California and has served as Chairman of the Sacramento Section of the IEEE Power Engineering Society. He is currently on a NERC Standard Drafting Team.

Damon Thayer received his BS in Electrical Engineering from California Polytechnic State University, San Luis Obispo in 1985. He started his career with Pacific Gas and Electric soon after graduation and has held multiple positions in Distribution Capacity Planning, Distribution Service Planning, Distribution Reliability, Supervising Distribution Engineer and currently an Expert Distribution Engineer in the Asset Strategy organization. Damon is currently managing the distribution wires-down program at PG&E which includes: event investigations, data gathering, trend analysis, metric reporting and capital project recommendation and execution. Damon is a registered Professional Engineer in the state of California.

Shawn Holder is currently a Principal Risk Specialist for Electric Operations Asset Management. He is responsible for leading risk assessments and control adequacy assessments across Electric Operations. Shawn's responsibilities include working with Electric Operations clients to develop, implement, and monitor appropriate risk mitigation activities and controls. Shawn's prior role at PG&E was Senior Protection Engineer where he was responsible for supporting protection related project work as well as clearances and real-time operations. Prior to joining PG&E in 2008, Shawn worked as a Research Engineer at Schweitzer Engineering Laboratories and Electrical Engineer at Avista Utilities. He has a Bachelor's and Master's Degree in Electrical Engineering from University of Idaho holds a certificate in Decision and Risk Management from Stanford and is a registered Professional Engineer in the state of California.

Emili Scaief received her BS in Electrical Engineering from California Polytechnic State University, San Luis Obispo in 2004. She is currently a Senior Asset Strategy Engineer managing the distribution wires-down database at PG&E. Emili also held a prior position at PG&E as an Electrical Distribution Engineer focusing on capacity planning and reliability. Prior to joining PG&E in 2005, she worked as a Design Engineer for Chevron. Emili is a registered Professional Engineer in the state of California.