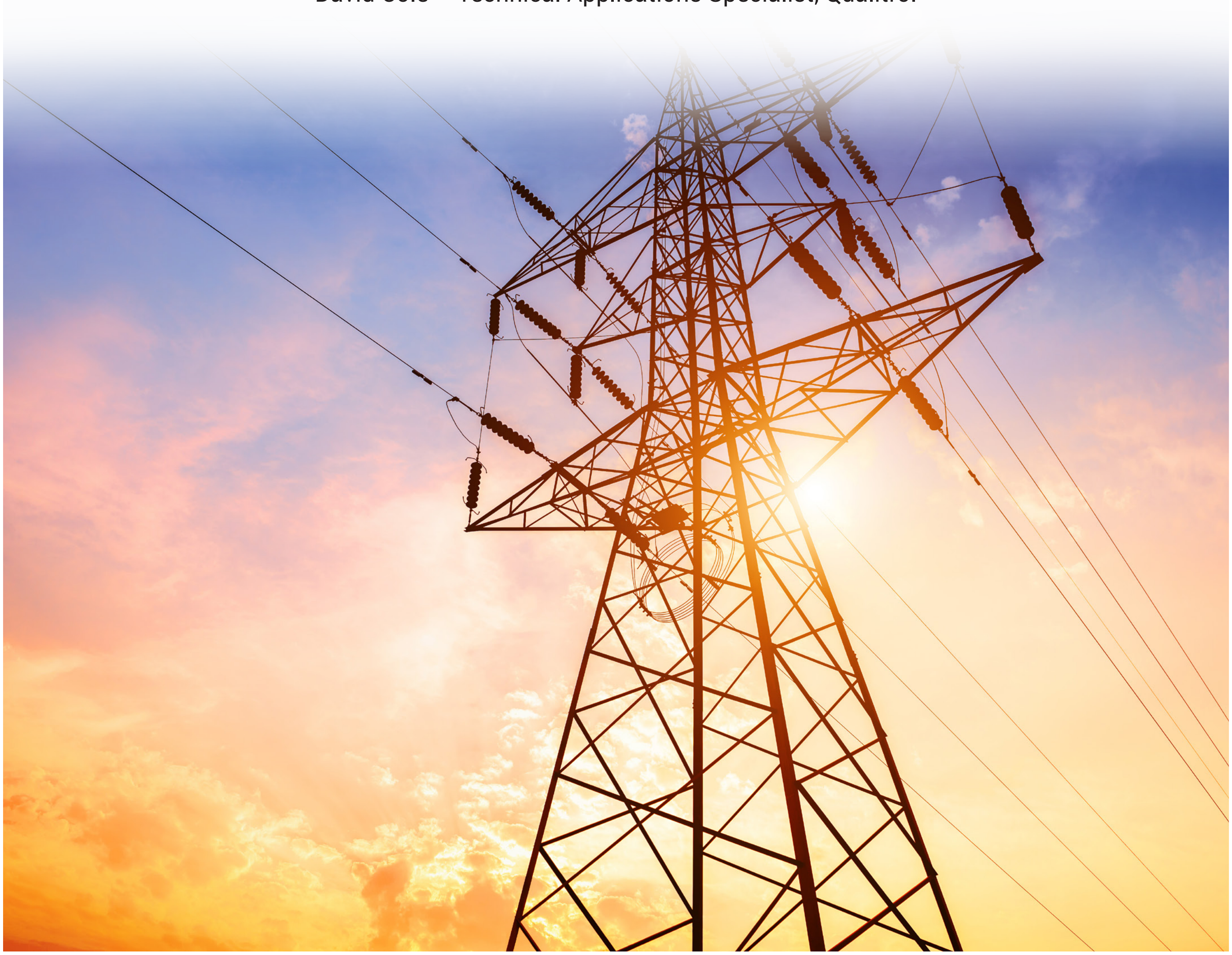
AUGUST 2020 • POWER GENERATION

A COMPARATIVE STUDY ON COST SAVINGS OFFERED BY TRAVELING WAVE SYSTEM FAULT LOCATORS OVER TRADITIONAL DISTANCE RELAYS FOR LONG DISTANCE TRANSMISSION LINES

Jonathan M. Trejo – System Protection & Control Engineer, El Paso Electric Company
David Cole – Technical Applications Specialist, Qualitrol



OVERVIEW

El Paso Electric (EPE) has experienced an average annual load increase of 2.88% over the past 10 years. The peak loads in 2014, 2015 and 2016 were 1766MW, 1794MW and 1892MW respectively. To deliver this load there are a total of 14 x 345kV transmission lines totaling 945 miles, 73 x 115kV transmission lines totaling 462 miles and 32 x 69kV transmission lines totaling 204 miles.

The 345KV network is particularly important as it is used to import approximately 645MW, about 30% of the peak load. High availability is essential to maintain power to the service area. The majority of these 345kV lines are in very remote, rough terrain. Two of the lines are in excess of 200 miles long. Consistent, accurate fault location has been an essential operational tool to effectively manage these lines and return significant cost savings by quickly reaching fault sites and minimizing downtime.

This paper describes the deployment of a double ended traveling wave method of fault location, its benefits over existing impedance schemes and its contribution to remedial works described in four case studies.

EL PASO ELECTRIC

El Paso Electric is a regional electric utility providing generation, transmission and distribution service to approximately 400,000 retail and wholesale customers in a 10,000 square mile area of the Rio Grande valley in west Texas and southern New Mexico. Its service territory extends from Hatch, New Mexico to Van Horn, Texas and includes two connections to Juarez, Mexico and the Comisión Federal de Electricidad (CFE), Mexico's national utility. See Figure 1. EPE's principal industrial and large customers include steel production, copper and oil refining, and United States military installations including the United States Army at Fort Bliss in Texas and the White Sands Missile Range and Holloman Air Force Base in New Mexico.

EPE has a net dependable generating capability of 1,990 MW. Its facilities include a 15.8 percent interest (633MW) in the Palo Verde Nuclear Generating Station in Wintersburg, Arizona, the Rio Grande Power Station in Sunland Park, New Mexico, the Newman Power Station, Copper Power Station and Montana Power Station in El Paso.

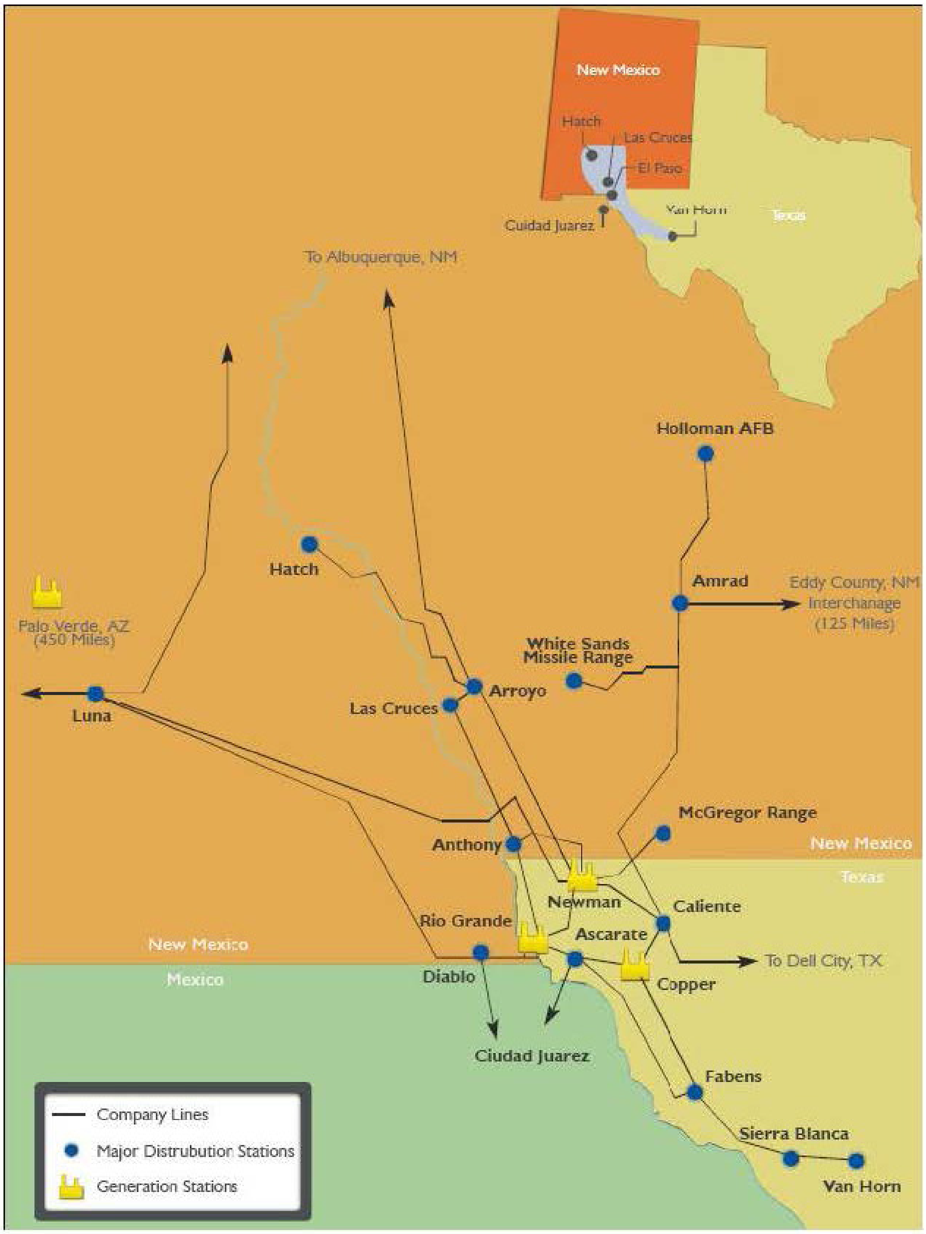


Figure 1 El Paso Electric Service Area

THE 345KV NETWORK

As already stated in the Overview the 345KV network has particular significance as it is responsible for the import of approximately 30% of the peak load. The network is shown in Figure 2. Case studies are included for the three labeled lines.

Impedance Fault Location and Case Studies on the 345KV Network

In the 1990s numerical protection relays were used on the 345KV lines, a distance to fault feature was not included. Distance to fault was obtained from single ended impedance calculations performed off line from fault records. Apart from the time taken to produce a result, especially after hours, the accuracy of approximately 10% to 15% meant it was difficult to find permanent faults and almost impossible to find the root cause of momentary faults. Search areas on the longest lines were 20 to 30 miles typically in remote and rough terrain.

Case Study 1 is based on the Luna to Springerville line, one of the most important lines in the network for importing power from Arizona. During the 1990s it experienced repeated momentary faults for unknown reasons. This prompted the first traveling wave installation in 1998 and the results, accurate to the nearest structure, meant the root cause was determined and remedial action taken to significantly improve reliability.

Case study 2 from 2013 is based on the Amrad to Eddy line where the accuracy of the traveling wave system resulted in the location of damage caused by an ice storm.

Case study 3 is based on the Arroya to West Mesa line where traveling wave results in 2016 pinpointed fire damaged structures leading to a design upgrade of the earthing system.

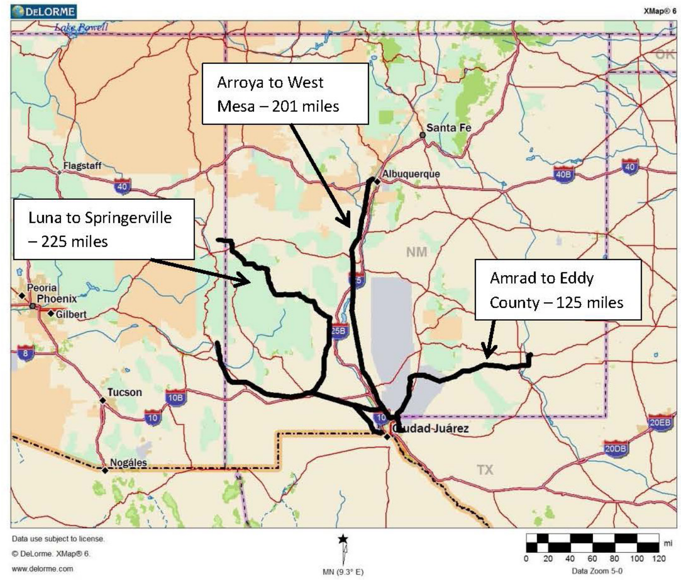


Figure 2 El Paso Electric EHV Network

Although modern relays deployed on the network now include an impedance distance to fault feature giving a direct read out the accuracy from the single ended measurement has not improved much. Additionally, communication to the sites at present is via modem and security concerns prevent remotely accessing the relays to download the distance to fault results. It normally requires a site visit to gather the information. This significantly increases the time taken to get a result. Traveling wave devices not linked to control functions can be accessed via modem and these systems, where deployed, are now the primary source of distance to fault data.

CASE STUDY 1

The 345kV transmission line from Luna to Springerville Substations has a mixture of wooden and steel structures along the 225 mile route as shown below in Figure 3. The differences in the zero sequence value along the route contributed to the errors in the single ended impedance calculation.

This line had a significant amount of outages in the 1990s, an average of 15 per year from 1990 to 1995, but locating the faulted structure proved very difficult. The line traverses remote, rough terrain that in many places is only accessible via foot or all-terrain vehicles. Operators would typically reclose the line after a first trip and if it held a single lineman would be dispatched the next day to search for a root cause. However, the poor accuracy, 20 to 30 miles, of the impedance based fault location often meant nothing was found. In the case of a permanent fault a 4 person patrol crew was assembled with all-terrain vehicles.

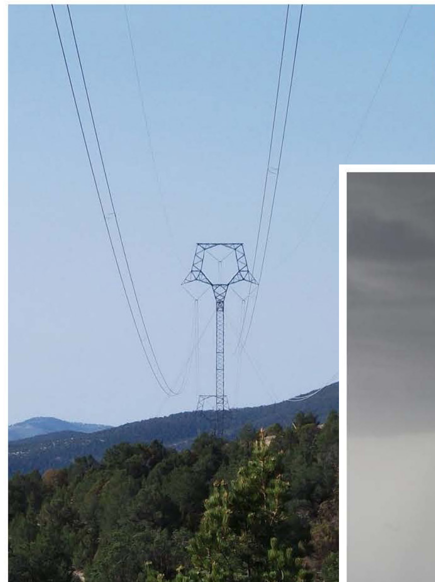


Figure 3 Two Different 345KV Structures

The minimum time to find the fault was 2 days, it was often longer, at a cost of $2,000 per day. Helicopters were also used on occasion at a cost of $1,000 per day.

The Springerville line is particularly important in summer to support the peak load. In order to maintain system security during an outage at this time it was often necessary to purchase power on the spot market which would typically cost in excess of $100,000 per day. Reducing the duration of any outage and tracking the root cause to prevent future outages was therefore a key concern.

A time synchronized, double ended traveling wave fault locating system was installed in 1998 to provide better distance to fault accuracy to allow the line crew to conduct more focused examinations. It was discovered after several line trips and fault locations, which were accurate to the nearest structure, that the middle phase of the line was flashing over to ground on the wooden structures. This was due to the high transient over voltages on this line and inadequate ground clearance of the middle phase to the main cross arm as shown on next page in Figure 4.

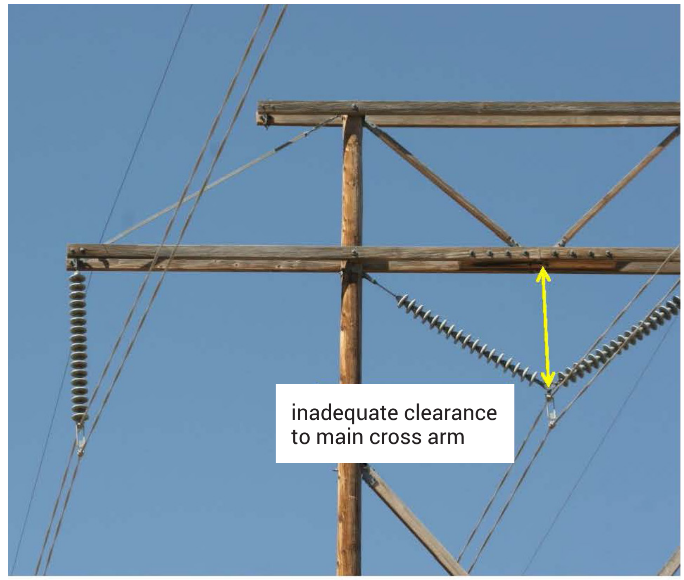


Figure 4 – Middle phase too Close to Main Cross Arm

A design change to lower the bracing cross arms by 24 inches and to remove the ground from the splice block was implemented on every structure as shown in Figure 5. Since then the reliability of the line has improved dramatically.

The traveling wave system has continued to perform well. The Line Crews have faith in the results such that now, even after a sustained fault, only one person is deployed. The fault site is quickly located and details of the damage given to follow on crews to allow efficient and timely repairs.

Figure 5 – Middle phase lowered to prevent flashovers to Cross Arms

CASE STUDY 2

The 345kV transmission line from Amrad to Eddy County Substations is 125 miles long. A traveling wave distance to fault result after a line trip in 2013 placed the fault 58 miles from Amrad. On arrival the crews found significant damage due to a severe ice storm, 103 structures had collapsed or were damaged over a length of 16.7 miles. See Figure 6. This fault was not hard to find but the speed in obtaining the result and the faith the crews had in the accuracy meant teams were on scene in the minimum time.

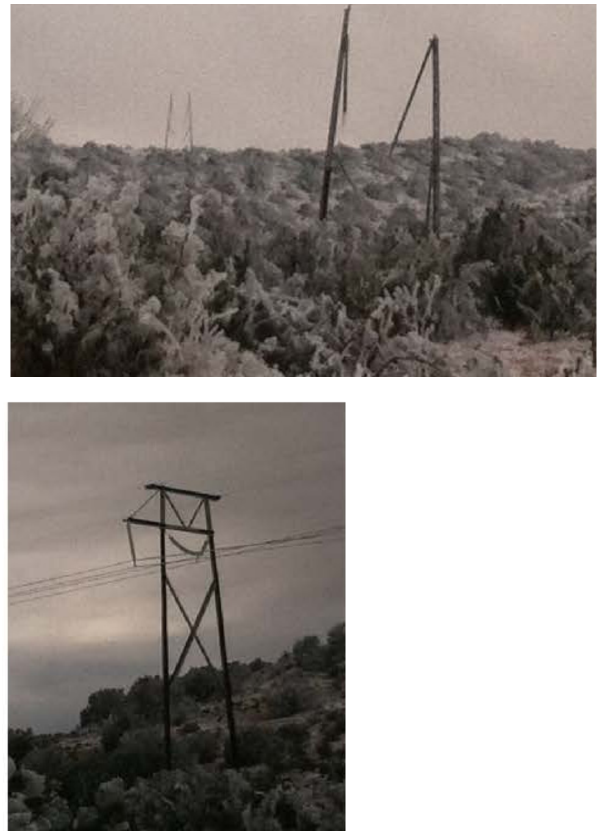


Figure 6 – Broken Structures due to Ice Storm

CASE STUDY 3

The 345kV transmission line from Arroyo to West Mesa Substation was built in 1968 and is 201 miles long. A traveling wave distance to fault result after a line trip in April 2016 placed the fault 53 miles from Arroyo. On arrival the crews found significant damage to a structure damaged by fire as shown in Figure 7.

Fig 7 Structure Collapse Due to Fire Damage

After similar incidents and further examination it was discovered that the fire was caused by the heating of the pole mounted earth wire from induced current due to increased loading on the line. After nearly 50 years in service the weathered poles were drier and more susceptible to burn. The staples used to clamp the earth wire had also worked loose resulting in further arcing. A design alteration to hold the earth wire away from the pole using stand-off supports was implemented on 1500 structures as shown in Figure 8.

During the remedial work program the traveling wave system successfully located other fire damaged structures keeping the outage time down to a minimum. See Figure 9. An impedance result from one of these events placed the fault site 30.8 miles from Arroyo substation when the actual distance, as defined by the traveling wave system, was 50.1 miles. Without the traveling wave result it would have taken several days to find the site using a 4 person patrol crew.

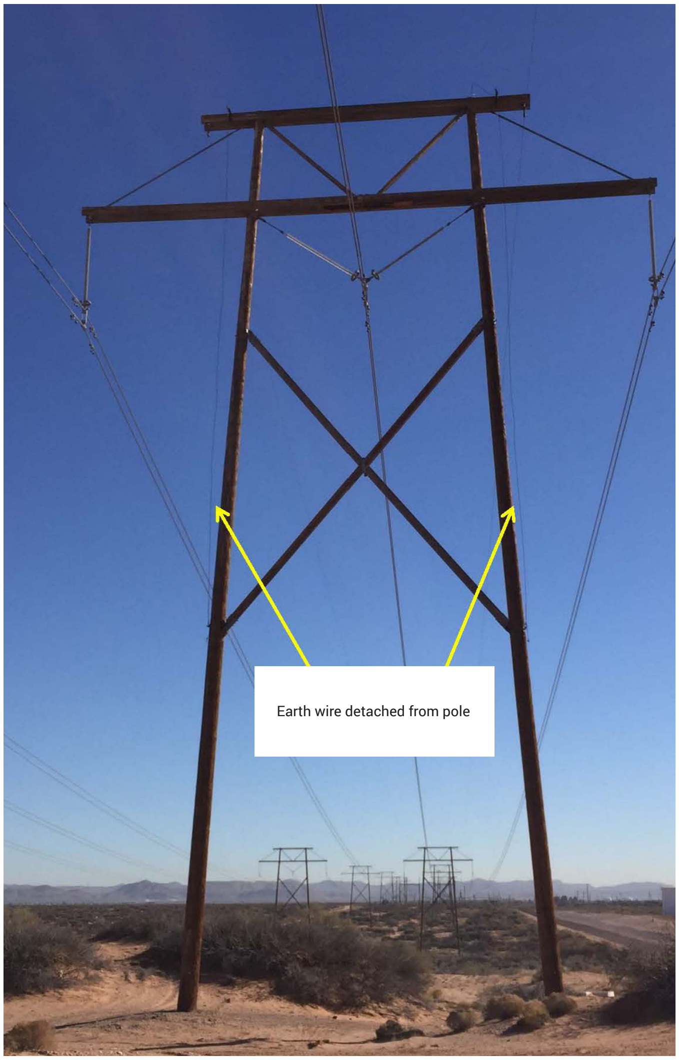


Figure 8 Design Upgrade on Earth Wire

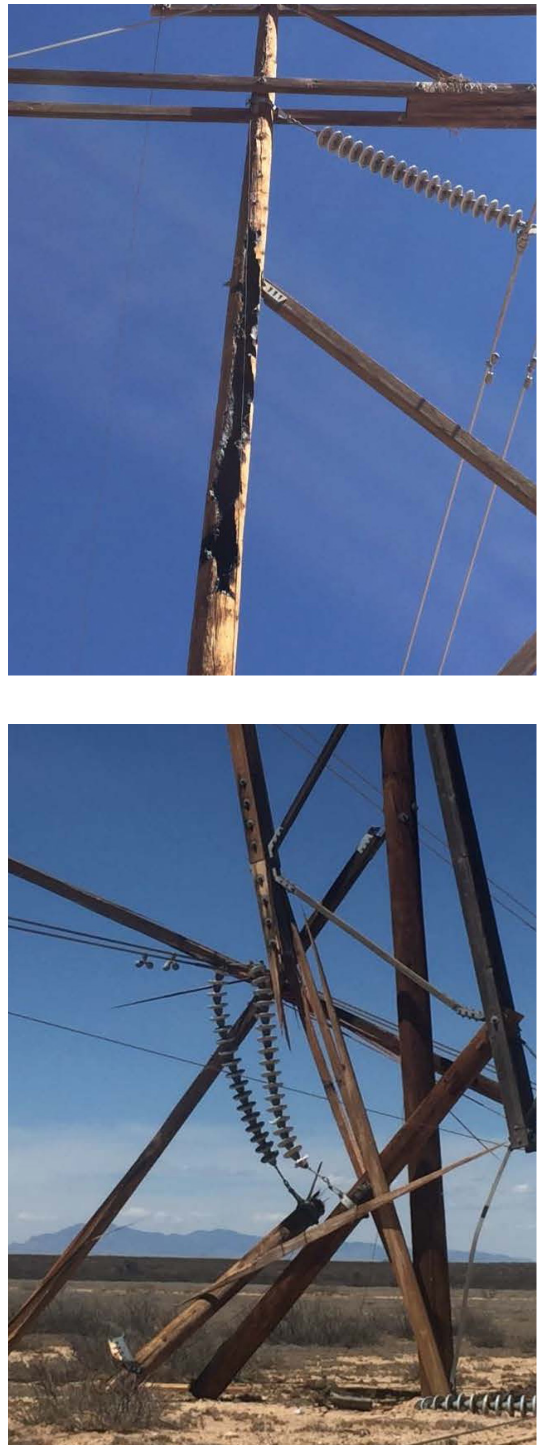


Figure 9 Other Fire Damaged Structures

The loss of this line does reduce the import capability from New Mexico and can result in extra power having to be bought from the spot market at a cost of approximately $50K per day.

CASE STUDY 4
69KV LINE

The traveling wave method of fault location has been deployed on lower voltage lines following the success on the 345KV network. This example is from a 69kV transmission line from Alamo Substation to Farmer Substation. It is a radial line supplying two substations. The total line length is 95 miles but the section monitored by the traveling wave system is 84 miles long.

This line section has been subject to high winds in recent years. Up to 10 momentary trips per year were recorded plus some permanent faults when damage to the structure occurred. Some examples of severe structure damage are shown in Figure 10.

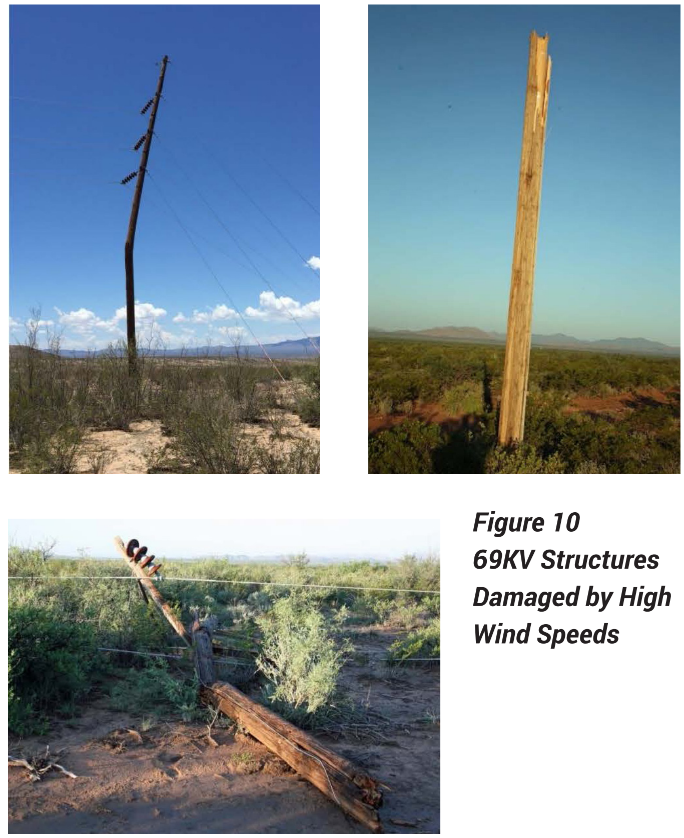


Figure 10
69KV Structures Damaged by High Wind Speeds

The effects of voltage dips as a result of a momentary fault and longer outages due to sustained faults are severe. Local loads include irrigation pumps that trip out on a voltage dip and have to be manually reset. The cost of lost revenue due to the line being out of service is approximately $30,000 per day. However, more importantly is the decrease in the reliability of service to the customers. The traveling wave system correctly identified the faulty structures allowing immediate repairs to be conducted thereby minimizing outage times by several days. This has resulted in a decrease in EPE's SAIDI (System Average Interruption Duration Index) meaning customers are out of service for a shorter period of time and the Regulatory impact reduced.

After several similar operations it was decided to replace the wooden structures with steel at a rate of about 100 structures per year.

DEPLOYMENT OF TRAVELING WAVE SYSTEMS

Following the success of double ended traveling wave fault location on the 345KV circuits, EPE has begun to deploy the technique on 115KV and 69KV lines. To date EPE has 42 traveling wave devices monitoring a total of 64 circuits. All the 345KV circuits are covered.

Alternative forms of fault location are less readily available on these lower voltage lines as many still have electro mechanical relays with no distance to fault capability. Where impedance measurements are available the accuracy has been poor. Results from the traveling wave devices to date have been good.

Note that NERC requirements now demand that all line trips on circuits 115KV and above must be investigated. This means getting a line crew to the fault site in the minimum time to reduce costs and increase the chance of establishing a true root cause especially if avian activity has occurred. The traveling wave system has consistently provided accurate data in a short time to facilitate such investigations.

SUMMARY

The EPE transmission network covers a wide area traversing difficult, hostile terrain much of which can only be patrolled by foot, all-terrain vehicle or helicopter. Single ended impedance results are available from the relays but the mismatch of steel and wooden structures and the inconsistency of the zero sequence value along the length has meant distance to fault accuracies are typically 10 to 15% of line length. On some lines this gives a 20 to 30 mile search area. To compound the issues communication to the substations at present is via modem. Security concerns prohibit the use of modems to access relays so results have to be gathered manually by site visits.

EPE started to use traveling wave methods of fault location in 1998 after experiencing repeated outages on a 345KV line responsible for importing power from Arizona. The cost savings to EPE on just being able to locate the fault site quickly were in excess of $4,000 per trip. A reduced outage time meant additional larger savings up to $200,000 were gained at peak times by minimizing the power that had to be purchased on the spot market to cover the loss.

The accuracy of the traveling wave system has significantly improved the possibility to identify the root cause of the line trip. This has enhanced the accuracy of NERC reporting and in some important cases led to the implementation of design changes aimed at improving the reliability and availability of a circuit.

To date 64 circuits are covered by double ended traveling wave fault locating devices including all the 345KV network and some of the 115KV and 69KV lines.

Savings per line trip are estimated at $4,000 as a result of being able to go directly to the fault site. Reduced repair times also limit the effect of lost revenue, $30,000 per day for one 69KV line, and help improve SAIDI.

AUTHOR NOTES

Jonathan Trejo is currently a Senior System Protection & Control Engineer at El Paso Electric Company, he has been in this position for four years. In this position he is responsible for the protection of HV and EHV transformers, transmission lines, and substation equipment. In addition he is also involved with system event analysis and transmission line fault location. He holds a Master's of Science in Electrical Engineering and a Master's in Business Administration with a Specialization in Finance from New Mexico State University.

David Cole is currently a Senior Technical Application Specialist with Qualitrol focusing on the Grid Monitoring products. After graduating he worked with a UK Distribution Company, researched techniques for locating partial discharge sites in cables and has worked as an application engineer on underground cable fault location. For the past 30 years he has worked with fault recorders, circuit breaker test sets, power quality devices and traveling wave fault locators in both commercial and technical roles.

Acknowledgements

The authors would like to thank the Transmission Engineering and Construction Departments at El Paso Electric for their help with putting this paper together.

QUALITROL®
Defining Reliability

FOR MORE INFORMATION ON
PRODUCTS AND SOLUTIONS

Contact us info@qualitrolcorp.com