21, rue d'Artois, F-75008 PARIS
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Outage Prediction Using Fault Sensing Devices

T. MAHAR, S. AGUILAR, C.M. MUÑOZ
Commonwealth Edison Company
USA

SUMMARY

Power interruptions cause significant economic damage and minimizing the frequency and duration of interruptions is critical to optimizing customer experience. Sustained interruptions are of particular concern because customer impact is related to interruption duration. A majority of faults that occur on an electrical distribution system are transient and do not immediately result in a sustained customer interruption [4, 5, 6], but they may be indicative of a condition that could cause one in the future. Correctly identifying deteriorating equipment and performing corrective maintenance before a sustained interruption occurs contributes to improving system reliability. Because of the relatively large number of these transient outages and because they do not typically require human intervention to restore, transient outages are difficult to analyze. Data that describe what caused a particular transient outage or the location of the problem tend to be sparse; most of the time the only account of what happened comes from records generated by field sensing devices. ComEd has developed an algorithm that detects recurring transient outages that share similar fault characteristics utilizing data from field located fault sensing devices and provides a location where latent damage is most likely. Field inspectors are dispatched to these locations to determine the root-cause of the repeated faults. In a pilot study, the algorithm was found to have detected multiple locations of serious asset damage which would have eventually resulted in a sustained interruption for ComEd's customers.

KEYWORDS

Line sensor, fault location, AMI, distribution automation (DA), outage prediction

Thomas.Mahar@ComEd.com

1. INTRODUCTION

Power interruptions are caused by a variety of factors including severe weather, electrical equipment failure, and human and wildlife interference. Studies estimate that sustained power interruptions cause $44 billion in economic damage on average annually in the U.S. [1,2,3]. A majority of faults that occur on an electrical distribution system are transient [4, 5, 6]. Transient outages that result in momentary customer interruptions inflict additional economic damage, although their impact is not as well studied as that of sustained interruptions. A subset of transient outages is indicative of conditions that will eventually lead to sustained outages. Identifying those transient outages and taking remedial action to remove the conditions that cause them could result in significant customer benefits and improve the effectiveness of utility inspections. Because of the relatively large number of these transient outages and because they do not typically require human intervention to restore, transient outages are difficult to analyze. Data that describe what caused a particular transient outage or the location of the problem tend to be sparse; most of the time the only account of what happened comes from records generated by field sensing devices.

ComEd employs various field located devices which collect data about faults including thousands of distribution automation devices and overhead line sensors. When a transient fault occurs, these devices collect information including fault magnitude, phases affected and switch status. All such data are useful during fault investigation. In the past, investigations have been conducted manually for some known repeat faults, which is time-consuming. To more fully leverage the opportunity presented by the data, ComEd has created an algorithm that identifies potential areas of concern.

This paper will describe how ComEd utilizes field device data to determine which transient faults are at risk of occurring again, which faults will require investigation by field inspectors, and where these field resources should look for potential issues. The goal of ComEd’s algorithm is to find the root cause of and any latent asset damage caused by transient faults before the underlying issues create a sustained customer interruption.

2. ALGORITHM DESIGN

The algorithm utilizes data from multiple data sources to gather information about fault events.

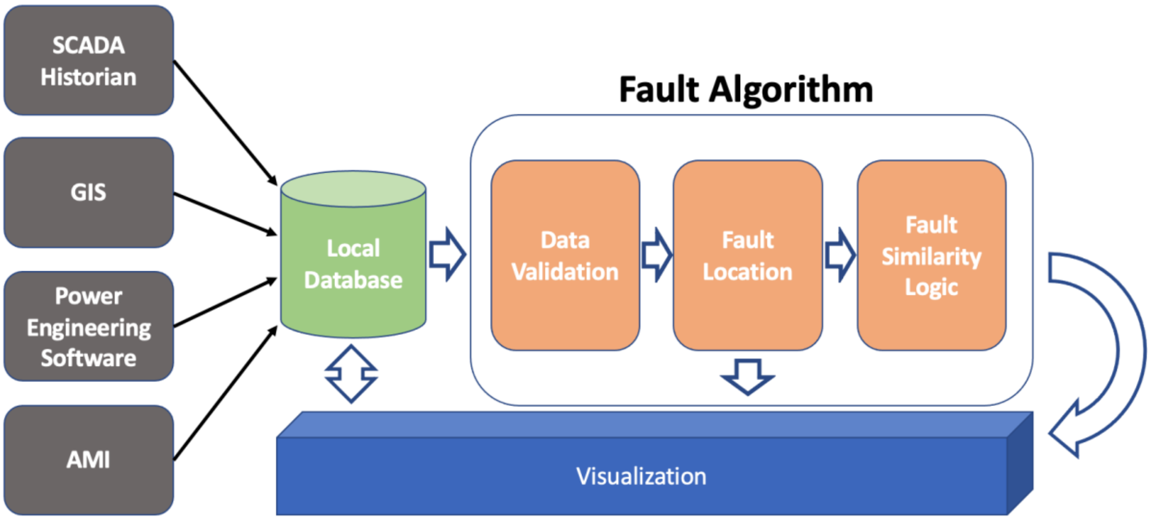

Figure 1 – Data Flow

Multiple data sources leveraged by the algorithm for analysis and visualization. First is SCADA Historian, from which fault magnitudes and distribution automation (DA) and breaker device status are extracted. Fault magnitudes are a key input to fault location studies and device statuses are used to identify when DA and feeder breaker devices operate during a fault. Power engineering software is utilized to perform a fault-current study. Maximum available fault current is calculated at all locations along studied feeders. The results of the study are stored in a tabular format in a database for later use. Smart meter power up / power down data is obtained from AMI Meter Data Management (MDM), processed and utilized to verify the presence of an upstream device operation or a voltage depression due to a fault. Conductor coordinates and device locations are extracted from Geographic Information System (GIS) and utilized for visualization of algorithm output.
Once acquired, the data flows through the algorithm as shown in Figure 1. The following sections provide more detail on the function of each module within the algorithm.

3. DATA VALIDATION

Various conditions exist which could cause a field device to falsely report fault current or a device operation. In ComEd's SCADA historian, ComEd has observed erroneous reports of recloser and breaker operations; this is believed to be a data artifact due to communications issues. Additionally, certain areas of ComEd's system are prone to fault sensors falsely reporting fault current. These instances are believed to be due to local interference or communication problems.

The first step taken by the algorithm is to verify that a transient event did occur. The algorithm leverages AMI data for this purpose. AMI power up and power down events are typically generated in response to an upstream device opening or to a voltage depression which accompanies a fault. Meter power up and power down events are paired and passed through a DBSCAN clustering algorithm [7, 8]. Inputs to DBSCAN are the time of power down, duration of the outage and meter latitude and longitude. The output of this algorithm is a set of clustered outages with noise removed. The presence of an AMI outage cluster on a feeder is used as positive verification of a fault event as reported by a field device.

4. FAULT LOCATION

Once a field device reports fault current and it is subsequently verified by AMI then it is passed through the fault location module. Power engineering software is used to determine maximum available fault current at each location of applicable feeders. Various fault types (L-G, L-L-G, L-L-L, etc.) are analyzed such that each conductor segment could have multiple possible available fault currents. Fault impedances are assumed to be zero. The results of this study are put into tabular format and saved for later use.

When a fault current is detected, the fault type is inferred by how many phases participated in the fault (for example, when only two out of three phases report fault current it is assumed to be a L-L-G or L-L fault). The measured fault current (plus/minus a threshold) is then compared against the table of available fault currents of the appropriate type on the appropriate feeder. The result is a short list of locations where the fault may have occurred. This list of conductors is the output of the fault location study.

5. FAULT SIMILARITY

The fault similarity module evaluates all of the data from the previous modules and determines if a particular fault is similar to any of the faults that have occurred in the past two years. Certain conditions that have the potential to cause multiple transient outages over time before causing a sustained outage include improperly tensioned conductors which slap together during windy conditions, intermittent vegetation contact, conductors which become detached from insulators, among others. The purpose of the fault similarity module is to identify faults which are reptitive in nature and may be indicative of an underlying problem.

The key inputs to the fault similarity module are fault magnitude, fault location, fault type, meters affected, and phases affected. The algorithm used by the similarity module is comprised of simple logical statements and filters. Once similar faults are found, a fault frequency criterion is applied to filter out faults that have only one or two other similar instances. This step reduces the probability that previous similar faults are a coincidence.

6. VISUALIZATION

A visualization is created using spatial data from GIS and the output of all of the previous modules. The visualization allows a human to perform a final review of the previous incidents to determine if the incidentstruly appear to be related. The reviewer will also examine the quality of the information and determine if there is enough available information to pass on to a field inspector. Once an event passes the human review, it is sent to field inspectors for damage assessment. Future automation of this step is possible once enough inspection data is collected and the key indicators of a successful inspection are determined.

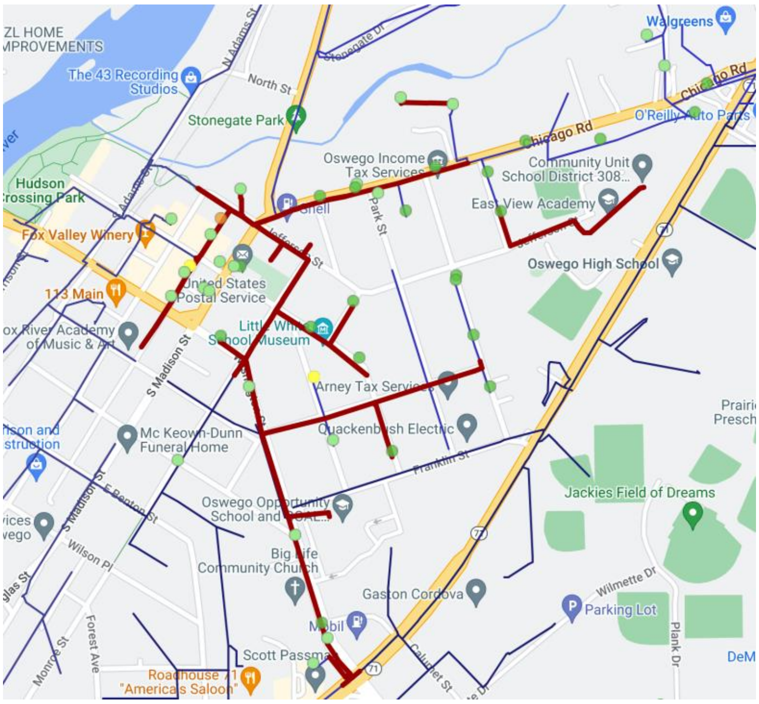

Figure 3 – Visualization showing AMI outages (circles) and calculated fault location (red)

7. RESULTS AND NEXT STEPS

While the algorithm is still in the pilot stage, initial results are promising. Within the first six months of operation, the presence of damage was confirmed at 7 of 13 locations identified by the algorithm, which corresponds to a 54 percent true positive rate. This damage could eventually have resulted in 2,810 customer interruptions.

ComEd also suspects that the initial estimate of the algorithm's true-positive rate may be low given that two of the locations where inspectors found no damage have continued to experience transient faults since initial inspection. The detailed investigative work required to find the root cause of these transient faults is different than the field inspector's usual duties, which are to patrol large areas of ComEd's system and identify damaged equipment. Additional training for field personnel may be required after the pilot stage once ComEd better understands the types of underlying issues that cause these recurring transient faults.

Some examples of damage verified by inspectors after identification by the algorithm are shown in Figure 4 and 5.

Figure 4 – Damage from Phase-Phase Contact

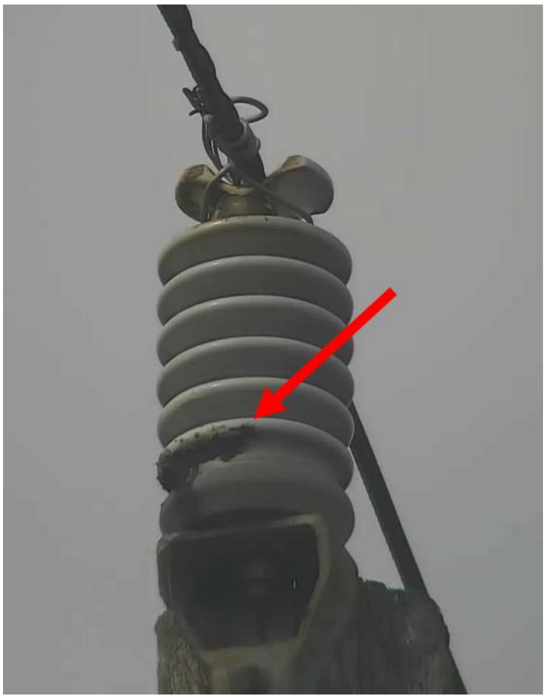

Figure 5 – Damaged Insulator

8. CONCLUSION

Initial results confirm the algorithm's potential to benefit customers by avoiding interruptions through early identification and corrective maintenance. In addition, the targeted nature of these investigations significantly increases the efficiency of maintenance inspections. ComEd has received positive feedback from field inspection personnel due to the ability of the fault location module to narrow the problem down to specific area of a feeder, which is a substantial improvement over the old method of dispatching inspectors to entire areas downstream of frequently operating fault interrupting devices. With additional testing of the algorithm and further automation of the incident review process and field personal dispatch process, ComEd anticipates that the algorithm will continue to improve reliability for its customers and increase the efficiency of field inspections.

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