Using Advanced Metering Infrastructure Data to Detect and Improve Customer Voltage Quality Issues

Niamat Ullah Ibne Hossain, Alexandr M. Sokolov, Scott Karbon, Brian Merrill
Engineering Management and Construction Management
College of Engineering and Computer Science Arkansas State University
State University, AR 72467, USA
nibnehossain@astate.edu, asokolov@astate.edu, scott.karbon@smail.astate.edu, brian.merrill1@smail.astate.edu

Abstract

Advanced Metering Infrastructure (AMI) is being adopted worldwide by electric utilities because of the benefits offered by the automated meter data it provides. The utility industry has been exploring methods to best leverage the abundance of AMI data now available to maximize customer power quality and develop delivery efficiencies to reduce customer electricity rates. Utilities are required by regulations to provide power at voltage levels within a set bandwidth of the nominal delivery voltage to the customer. Variances in the voltage delivered by utilities can cause a multitude of issues for the individual customer and for the entire distribution grid system. AMI meters are capable of providing voltage data at frequent time intervals, a 1-hour interval sample and 15-minute interval sample are quite common. A DMAIC process can be developed to allow an electric utility to appropriately review and act upon the AMI voltage data available. In this paper the voltage specifications will be defined (D) and measurement (M) of data explained. Analysis (A) of the abundant data is an area of significance. Suggestions are made from the analysis to improve (I) the utility management of voltage issues and control (C) the distribution grid to better maintain within specifications.

Keywords
Electric Utilities, Advanced Metering Infrastructure (AMI), Voltage, Power Quality, Distribution, Monitoring

1. Introduction
The electric utility industry has been aware for decades that significant benefits could be recognized from automating the reading of customer electric meters. The expected benefits included reduction of labor in reading meters, increase in accuracy of read data, and an increase in amount of data for electrical consumption and power quality analysis. Industry meter manufacturers developed Advanced Metering Infrastructure (AMI) technologies to provide automated meter information to utility head-end servers (Ashok, et al., 2019). Another term that is commonly used to refer to AMI technologies is smart metering. Electric meters with AMI technology have the capability to measure parameters and variables with frequent reporting intervals. 1-hour intervals and 15-minute intervals are common for AMI (Ashok, et al., 2019). Smart meters record real-time data and allow for real-time pricing and distributed control of customer equipment (Joskow, 2012). Manual methods of meter reading provide only one data point per month and some utilities only read manually once per quarter or semi-annually.

The utility industry has been exploring methods to best leverage this new abundance of data made available by AMI (Kemal, et al., 2020). The larger datasets are intended to be used to maximize customer power quality and satisfaction, while also improving delivery efficiencies to reduce customer electricity rates. Utilities are required by regulations to provide power at voltage levels within a set bandwidth of the nominal delivery voltage as measured at the point of delivery to the customer, typically +/- 5% (Fehr, 2005). The typical point of delivery is the electric utility meter. Variances in voltage delivered by utilities can cause a wide variety of issues for the individual customer. Voltage excursions can also cause macro level disturbances and excess costs.

In a DMAIC process, defining the key parameter or problem to solve is the first step. The definition of a voltage deviation has many factors explained within this paper. Measurement of the variable is the function provided by the new AMI technology. The measurement of variables and parameters at frequencies of 1 hour or less creates a data overload and structured methods must be developed to strategically use the data. Analysis uses data management techniques, software algorithms, hardware flags and monitors, and finally statistical methods to confirm suspected problematic areas. When conducting DMAIC processes several tools and techniques are available to improve the product (ThanhDat, et al., 2016). Preliminary efforts to improve the out-of-control areas are trialed and methods to control the entire system through monitoring and feedback from modified areas are final steps in the DMAIC process. In the Results and Discussion section actual data is presented showing marked improvement in reducing voltage violations by following the DMAIC process over the course of one year.

1.1 Objectives

The research performed utilizes the principles of engineering management. Engineering managers use the DMAIC processes to improve products and processes in the workplace. The DMAIC process developed usable for electric utility scale management of voltage at the customer point of delivery. Engineering management programs train managers to use analysis tools to solve technical problems. The analysis in this paper includes discussion of potential causes of voltage disturbances. Statistical methods are devised that allow for determination of a level of confidence in the accuracy of data. Engineering management involves interpreting statistical models and concepts and applying them to technical problems (Sokolov, n.d). Research of relevant literature is necessary in engineering management to apply the most current technologies and methods. A review of relevant literature in management and electric utility initiatives ensures this study includes a focus on issues relevant to this industry.

2. Literature Review

Electric utility delivers electric power to customers to meet the amount of energy consumed in real-time with virtually zero storage of energy available. The fundamental laws governing electricity flow establish that the power delivered instantaneously is a product of the voltage and amperage on the supply lines. The negative effects of voltage delivered outside of a specified nominal voltage are both identifiable physical issues and economic problems at both large and small scales. Problems with voltage sags are more severe and common than voltage swells (Kufeoglu and Lehtonen, 2016). Customers experience blinking lights, flicker, non-performing equipment, breaker trips, motor failure, equipment damage, and potentially dangerous amperage increases. Electric utilities commonly operate under tariffs established with the state or national regulators to define the voltages required to be delivered to different classes of customers. One state administrative code requires standard services for customers that consume less than 500 kilowatts maintain a service voltage +/- 5% of the standard nominal voltage (PSC 113.0702). Harmonics issues in voltage or current can cause voltage disturbance. Regulations are in place internationally for practices, requirements and power quality indicator reporting by IEEE and IEC (Shklyarskiy, et al., 2021).

3. Methods

The nature of electricity as an instantaneous, on-demand product leads to an understanding that disturbances of short duration cannot be avoided and are acceptable. The time component of a deviation is therefore necessary in the definition of voltage conformance. Administrative codes and other governance instruments will include general language about duration, or a technical reference to define duration for certain customer classes. Language from a state administrative code includes a statement that short duration disturbances from unavoidable elements, such as weather, electrical grid repairs, and upgrades shall not be considered a violation of the requirements (PSC 113.0703). For the purposes of establishing a definition of voltage disturbances, the technical standard ANSI C84.1 is used. This standard is referenced by regulatory bodies in administrative codes, often in the context of larger polyphase customers such as a manufacturing facility where internal equipment loads lend to substantial effects on the greater electrical grid. In Europe, similar voltage specifications for levels and fluctuations are in standard EN 50160 (Kolek, et al., 2021). ANSI C.84.1-2020 includes a definition of voltage level that states the root mean square (RMS) voltage is averaged over a ten-minute period. AMI meters may default to collection of data over a one-minute averaging period. When the time periods are different, additional verifications will determine if out of control data points are out of control for the entire ten-minute averaging period. It is therefore not a coincidence that the perceptibility of light flicker disturbance severity is evaluated over a ten-minute period (Espel, 2010). Voltage is the primary variable of concern measured by electric meters in this paper. For this study, it is assumed AMI meters measure RMS voltage in one-minute intervals. The meters are also capable of measuring parameters related to voltage including highest daily voltage and lowest daily voltage. These time filtered records are valuable in the goal of determining if a customer meter has encountered any number of out-of- specification periods. The head-end software can establish alarm notifications that detect if voltage is out of the specified range for any period for one day.

For this analysis, a monitoring system that reports daily lowest voltage and separate daily highest voltage violations for 1-minute intervals is used. The nominal voltage monitored for most meters is 240 volts. The inspection range that will satisfy the criteria of a low voltage violation is a recorded value between 10.0 volts and 228.0 volts. The reason that ten volts is selected is to filter out any 0-volt records. Zero voltage may be reported in the system when a meter loses power because it is switched out by the utility, or because it is disconnected intentionally by the utility. 228 volts is the lower limit of the acceptable specification range, this calculation is shown in Equation (1).

$$\text{LSL}= Nomina\bar{l}\ Voltage - .05 \times Nominal\ Voltage \tag{1}$$

Likewise, high voltage monitors are setup to record any occurrence of voltage greater than 252.0 volts per the Upper Specification Limit calculation shown in Equation (2)

$$\text{USL}= Nomina\bar{l}\ Voltage + .05 \times Nominal\ Voltage \tag{2}$$

With the parameters established to define an acceptable voltage range, understanding of the measurement is clear and methods to evaluate data sets from AMI meters are developed.

4. Data Collection

The definition of voltage deviations has set a numerical range of acceptability and establishes the time averaging standards. The numerical range and time-average are requirements for each individual data point. Voltage however has seasonal, weekly, and daily variations. These variations are based on common electrical grid phenomena of consumer consumption patterns. Further understanding of customer load patterns happens through study of the hourly AMI data available (Selvam, et al., 2017). Daily and weekly fluctuations follow predictable patterns. The electric utility industry realizes the patterns and individual utilities will define on-peak and off-peak times and charge customers different rates during each time. Many industries are working to reduce peak demand including office building operation where lighting loads is often the largest electrical load. (Chinnis and Henze, 2012) The on-peak hours occur during normal working hours and some locales define on peak until 11:00 pm on weekdays (EIA,2020). Off-peak times are weekends and the remaining hours through the night when consumption is much lower. Conservation voltage reduction (CVR) is a utility scale initiative where voltage is reduced at the substation feeder in order to reduce annual peaks for the entire distribution grid to avoid costs for annual peak days (Lan, et al., 2017). Such systems require AMI readings to monitor customer voltage stays within the compliance range. Variance in daily and weekly consumption will correlate to voltage at points on the distribution grid. An analysis of voltage deviations must consider the voltage ranges for other time periods than the period of violation. Air conditioning load is a major contributor to power consumption. Even in northern regions and industrial grids, air conditioning demand is observable as a major component of the system annual peak. Studies have estimated that air conditioning demand may account for up to 90% of residential consumption during peak periods (Treidler and Modera, 1994). The seasonal variation of each customer's voltage is a key consideration prior to any corrective action. A correction to increase voltage in summer may result in over range voltage in winter if not properly applied. It is a suggested best practice to accumulate one year worth of voltage data for a customer meter to properly evaluate the seasonal effects on the distribution system. Before any equipment changes are made on the distribution grid it is necessary to understand what impacts may occur in seasons with significantly different load profiles. Electric Utilities design distribution grids with switches that allow backup supply by other circuits. When a circuit is switched to a backup circuit the voltage profile for an individual meter will change. A customer that may have been near the voltage source on the primary supply may become the end of line delivery point on a backup circuit and subsequently experience reduced voltage. The engineer analyzing voltage deviations must consider the most future backup scenarios expected and evaluate if the service will maintain in-specification voltage on a backup circuit after the voltage correction. Electric Utility companies vary in size and the number of customers served can be in the millions for large investor-owned utilities (IOU) or less than one thousand for small village or town municipal utilities. Many AMI systems were installed at different customer scale utilities during the ARRA Stimulus and are providing value to customers (Heile, 2013). An example test case for a system with 16,300 single phase meters will be presented. This number of meters is a large sample size that allows methods employed herein to be used in meter sample sizes for IOU's and smaller utilities. Dependent on the quality, age, and overall distribution system construction, the number of voltage violations can range from very few to a significant percent of customers. For this example, test case an analysis period of one month is selected. Recorded values that exceed the upper specification limit and values less than the lower specification limit will be filtered in Microsoft Excel. The data records will then be sorted and filtered to determine a count of unique meters that were outside of the specifications. Recall that the meters report in only 1-minute intervals and the chosen definition for voltage leveling is a ten-minute averaged reading. The sorting resulted in 197 unique meters above the upper specified range limit and 319 below specification. When viewing the raw data reports for minimum or maximum daily voltage over a one-month period it is common to see the same meter recording an out of specification value on most or all of the days of the observation period. This is a key factor that leads to a base assumption that all 1-minute violations are also 10-minute violations. AMI systems are also capable of producing daily violation reports. The daily numbers have been observed to fluctuate by a factor of five or more in a single day when the weather changes drastically. The better practice is to use monthly data to avoid high variability in the total number of meters with a violation present.

5. Results and Discussion

An objective of this analysis is to use measurement instruments and statistical analysis to correlate one-minute voltage deviations to possible ten-minute violations and prove the strength of the assumption that all one-minute violations are ten-minute violations. The DMAIC process will result in continuous improvement of overall customer voltage. Results from one year of program implementation are presented showing expected improvement.

5.1 Correlation of AMI and Regulatory Voltage

Utility metering departments are equipped with sophisticated portable measurement equipment. Utilities are required to investigate customer complaints for power quality and therefore invest in equipment and training to perform investigations. The portable equipment can be used at customer locations identified in the meter reports with voltage either above or below specification.

One way to relate the 1-minute data to 10-minute data collected at random sites is to use attribute control methods. The 1-minute data is a population where all points are expected to have an accompanying 10-minute nonconformance. A preliminary sample of size *n* from the 1-minute set is evaluated for 10-minute compliance over a 24-hour period. Statisticians recommend that the number of samples *m*, be 20 to 25 (Montgomery, 2013 p.299). However, this could take several months or years to manually sample subsets of 1-minute violations for 24 hours due to staff availability, equipment availability, and the low population of meters with 1-minute deviations to choose from. The process for establishing the relation of 1-minute to 10-minute deviations follows the process of control for fraction nonconforming. The method for an attribute control chart requires that a sample fraction nonconforming, p, is known. Estimating a fraction nonconforming from manual test data is the primary step in establishing the relationship between 1-minute and 10-minute data. The utility recorder is set to a 1-minute recording interval, if available, and installed temporarily at a 1-minute violation site that has been identified by the AMI meter data. The data downloaded from the meter recorder is manipulated using Microsoft Excel, into 10-minute intervals and averaged. A filter is set in the spreadsheet to check for any 10-minute period that exceeds the USL or is below the LSL. The data is then used in statistical formulae. Equation (3) is used for determining the process fraction nonconforming for an individual sample set of meters. Di is nonconforming units in sample *i, i =1, 2, . . ., m.* (Montgomery, 2013) The sample size is denoted as *n.* It is important to note that for this process, a nonconformance is an instance where there is not a single 10-minute average outside of the specification limit in the 24 hours of recorded data. The correlation is to prove that wherever a 1-minute violation occurs, a 10-minute violation can be safely assumed.

$$\hat{p}_i = \frac{D_i}{n} \tag{3}$$

Equation (4) calculates the average of the individual samples to create the statistic $\bar{p}$ which is the estimate of unknown fraction nonconforming p.

$$\bar{p} = \frac{\sum_{i=1}^{m} \hat{p}_i}{m} \tag{4}$$

Example data is summarized in Table 1.

Table 1. Example Relation of AMI Violation to Actual Violation from Test Case Data

1-minute nonconformities	**10-minute sample size, n**	**10-minute nonconformities, sample #1**	**10-minute nonconformities, sample #2**
Low Voltage Population	***n***	D_1	D_2
319	10	1	0
$\hat{p}_1$	$\hat{p}_2$	***m***	$\bar{p}$
1/10 = 0.1	0/10 = 0	2	(.1+0)/2 =0.05

Further statistical exercises can be conducted on the data now that a value for p has been determined through observed data. The binomial distribution properties for mean, variance, and standard deviation are determined. This allows for the creation of an attribute control chart with control chart features of Upper Control Limit (UCL), Lower Control Limit (LCL) and Centerline = p. The LCL will not be calculated and will instead be set to zero as no nonconformance is desirable for this attribute relationship (Montgomery, 2013). Standard texts on quality control are referred to for formulae used, with no standard fraction nonconforming, p, given to compute the results in Table 2. The calculation used in Exhibit 2 to determine UCL uses a standard deviation of $3\sigma_{\bar{p}}$ for 99.73% within control limits (Montgomery, 2013 p.28).

Table 2. Statistics and Control Chart Lines for Example Test Case Data

Population mean fraction 1-minute nonconform ≠ at least one 10 minute nonconform, $\mu_{\bar{p}}$	**Variance of results,** $\sigma^2_{\bar{p}}$	**Std. Deviation,** $\sigma_{\bar{p}}$
0.05	0.00475	0.06892
Control Chart Centerline, $\bar{p}$	**UCL**	**LCL**
0.05	0.25676	0

In narrative terms, the UCL result of 0.25676 indicates that the process is expected to return on average the mean of 5% of meters indicating a 1-minute voltage deviation that is not a 10-minute deviation so long as each sample set tested with the recorder over a 24-hour period shows greater than 74.3% (derived from 1-.25676) agreement with 1-minute deviations. The number of meters evaluated, *n*, in developing the process fraction nonconforming is lower than ideal, as is the number of samples *m*. To achieve a narrower range the sample size *n* should be increased as well as the number of samples. If the sample size *n* from the data in Exhibit 1 and 2 is increased to twenty, and results Di are the same the UCL is reduced to 12.97%. This confirms that as the sample size is increased the UCL will move closer to the center line (Duclos and Voirin, 2010). It is recommended to track all field data results and continuously update the p-chart parameters until such a time that variance in the calculated p, standard deviation, and UCL values change in relatively small percentages. There are three approaches to constructing p-charts for suggested review to properly apply approximations based on satisfying certain screening conditions for p and *n* (Duclos and Voirin, 2010).

5.2 DMAIC Analysis for Meter Voltage Improvements

Analysis of the violation data will follow the DMAIC process for examining the measurement data that is collected after the data has been validated through the processes described in the measure section above (Prashar, 2016). Typical causes of voltage drop, and disturbance are from several sources of which the most common is line loss. Utilities carefully design electrical distribution systems with the best knowledge available for customer load demands and potential future growth. Line losses will be the highest at the radial end of a distribution circuit. The circuit delivers primary voltage from the utility substation to transformers that step down the voltage to the nominal voltages necessary for customers. The most common customer voltage for any utility is that which serves single-phase loads for residential and light consumption customers. For the utility test case analyzed in this paper, approximately 16,300 meters are served by single phase nominal voltage of 240 volts. For comparison, approximately 1,000 meters are served by polyphase meters at higher voltages, typically 480 V. Line losses and transformer issues are frequent causes for voltage violations.

There are many potential causes of voltage variation. Common causes in residential and industrial areas are included in the fishbone diagram of Exhibit 3. A new and important contribution to the problem is from the fast-growing segments of renewable power sources such as photovoltaic (PV) solar power panels and wind power generators (Molla and Kuo, 2020). Industrial facilities are installing renewable generation and concern for grid degradation of power quality has led to research to make the grid more resilient (Shklyarskiy, et al., 2021). The electric utility industry has been preparing for the wide-scale adoption of Electric Vehicles (EV). Published literature is based on government studies to understand motivations of customers to convert to EVs (Rezvani, et al., 2015). Methods are actively being sought to overcome customer barriers to EV adoption. The increased number of EVs will have shorter charging times at higher voltages loading local distribution systems and affecting customers in the vicinity of a concentration of EVs (Jaskow, 2012). The concern for losses from a traditional wired transmission system being used to charge large numbers of EVs has led to proposals for a wireless power transmission system (Joseph, et al., 2018). The same source recognizes that an unreasonable integration of EV's to the grid will affect the power quality of the entire grid. This is the situation that is approaching electric utilities as EV adoption gains traction. Distributed Generation (DG) is the power generation supplied to the grid from small generators and non-traditional sources. Planners have envisioned DG and EV coupled systems. Large-scale deployments will lead to uncertainties in the grid system and research methods are underway to predict grid responses. (Huiling, et al., 2020). All the uncertainty of the future increases the importance of an electric utility to have reliable voltage quality data.

Quality Control techniques are effective in examining causes of voltage variations. A Pareto Analysis of causes for the voltage disturbances will help a utility to focus on problem solving most effectively (Prashar, 2016). A fishbone diagram of potential causes listed above is created as the cause-and-effect diagram helps determine the root cause of the problem through a structured approach that encourages group participation (Ilie and Ciocoiu, 2010). A fishbone diagram for voltage deviations is presented in Figure 1.

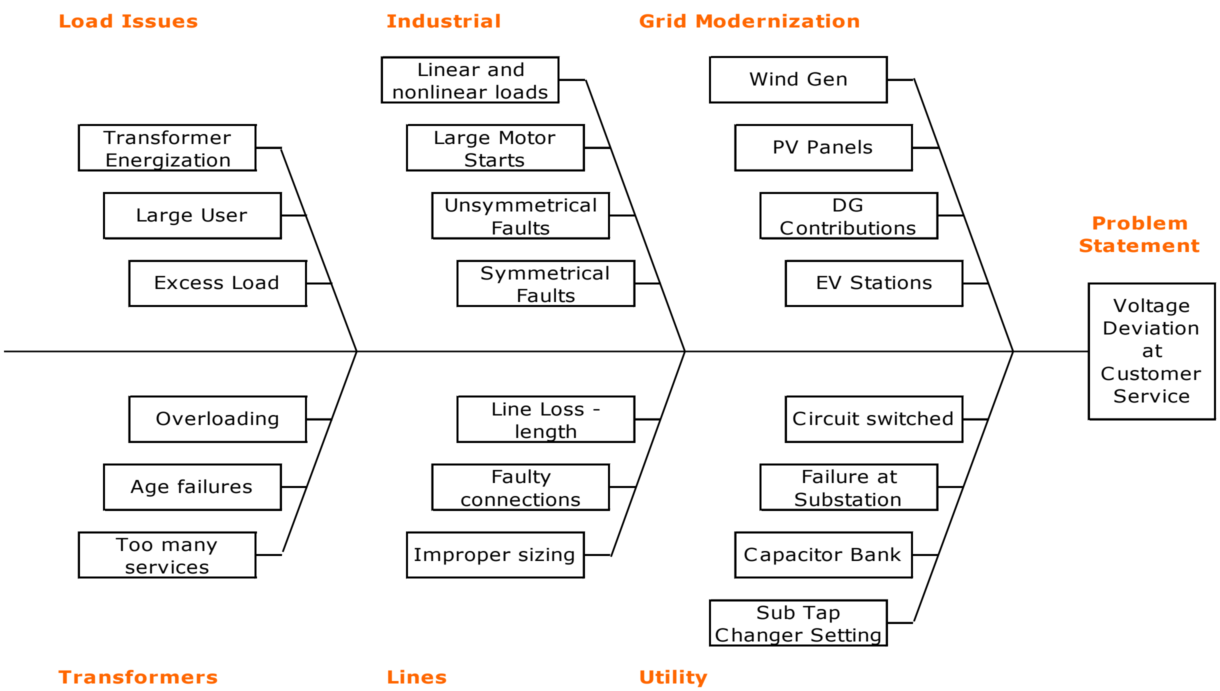

Figure 1. Fishbone Diagram for Voltage Deviations

5.3 Proposed Improvements

After analysis is complete on the voltage data the information will be used to improve the distribution system to reduce and eventually eliminate out of specification service. The fields of transformer status monitoring and failure prediction are increasingly important to utilities. Fault detection techniques have emerged employing the use of statistics and data driven diagnosis (Guo, et al., 2020). Improvements that have utilities often make after discovery of problematic voltage areas are the replacement of transformers, the removal of one or two services from a transformer, and the changing of tap voltages on transformers, among others. If distribution design to the area is a suspected cause, the system design should be reviewed and a load flow model and design optimization considered (Fehr, 2005). To maintain the acceptable range of +/- 5% voltage the main feeder from a substation is designed for up to a 10% drop. This is because the source is set to a higher level 1.05 per-unit and the end of the line is allowed to drop to 0.95 per-unit to maintain the 95% nominal voltage requirement (Fehr, 2005). The difference between settings at the source and end of line is 10%.

The improvement phase of a DMAIC process will involve predicting results from the improvements and testing for the results (Hossain et al., 2017). In the test data, it was observed that the transformer changes implemented resulted in improved voltage stability. Locations where loose connections were found also showed immediate improvement in voltage. The violation data will provide clues on where to investigate potential enhancements to remedy the various problems. If many meters in a cluster is experiencing low voltage, this is an area that may require a circuit design evaluation. If the cluster is centralized around one or two transformers, then the transformers are the logical place to begin the investigation. Figure 2 shows a mapping of voltage violations using commercial AMI Software.

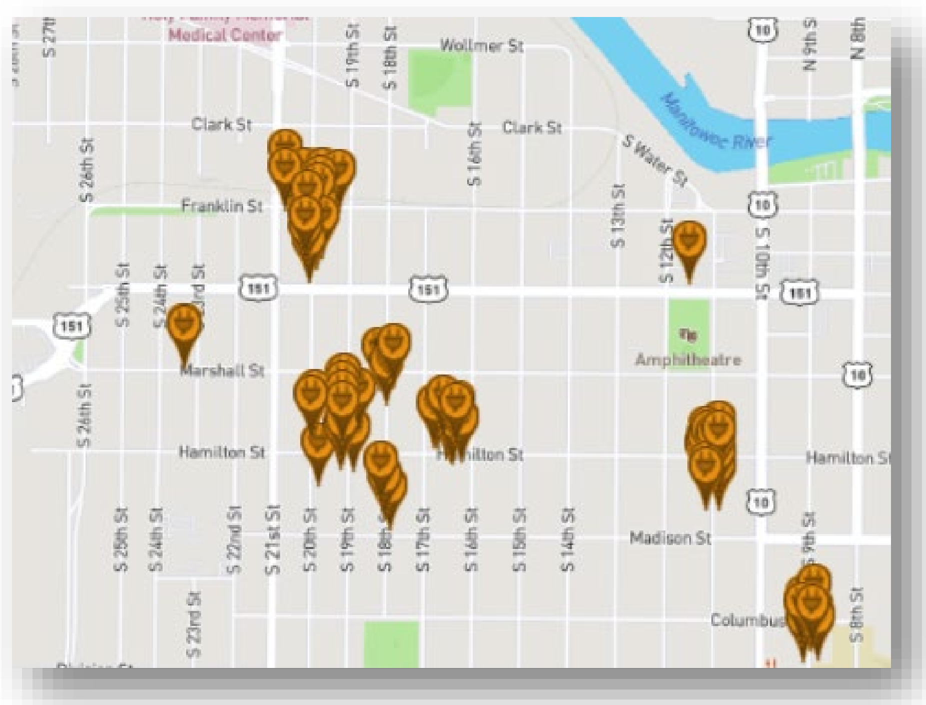

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Figure 2. Clusters of Voltage Violations using Commercial AMI Software

Management barriers to improvement may be encountered when enacting a program. Depending on the past maintenance and reinvestment in the distribution system the number of violations detected could be exceptionally large. The immediacy of the impact on a customer with voltage violations at 6% outside of range will not typically be significant enough to require action. Utility personnel will have to reexamine the priorities and responsibilities of providing power to all customers at the required service voltage. Organization change of priorities may be required to refocus workforce to correcting issues that are identified. Line workers will be occupied working on new construction projects and responding to accidents in the system. The organization may not have been prepared for a large undertaking to restore the grid to compliant conditions. Team dynamics may be of concern if a separate engineering department locates the conditions, but the maintenance staff does not agree to the perception of urgency. This may lead to a weakening obligation to perform at high levels on the tasks needed to restore the equipment (Bashshur, et al., 2011)

5.4 Validation

The gains achieved through improvements in the system must be retained. Additionally, the objective is to satisfy the regulatory requirement that all customers be within voltage ranges for 10-minute periods with exception of accepted transient conditions noted previously. Distribution system operators recognize that past technologies were not equipped to monitor to ensure compliance with the voltage requirements and AMI may make this possible (Kemal, et al., 2020). The use of a key process indicator (KPI) to track the success of the program to reduce voltage noncompliance is an excellent method to maintain process control. A program to monitor and reduce voltage nonconformance is established to proceduralize the data collection and analysis efforts of AMI voltage records. The program will include instructions on reports. Written procedures will include step by step details to allow for training multiple staff members to work through the software process to generate the report. Microsoft Excel filtering and analysis instructions will be provided. Best practices from organizations such as ISO call for implementation of KPIs to monitor the program efficacy. Industrial maintenance KPI's call for easy calculation of the KPI from data that is readily collected (Ferreira, et al., 2019). The program for voltage monitoring and improvement generates reports with the number of violations that occur over time. It is recommended to use monthly data for calculation of a KPI. The seasonal variation of grid demand and voltage levels will cause swings in the data that would indicate a false negative or false positive condition if not considered. The KPI must account for variations by use of a month-to-month annual comparison. The larger the period of time that is used for the KPI the results will be less subject to outliers (Ferreira, et al., 2019). The advantage of an automated metering system with meter data management software is the ability to retrieve historical data. This allows for the generation of past KPI's for comparison purposes. Figure 3 shows a flow chart of the cyclical process. The chart below shows DMAIC steps except for define. The cyclical process is a Shewhart cycle.

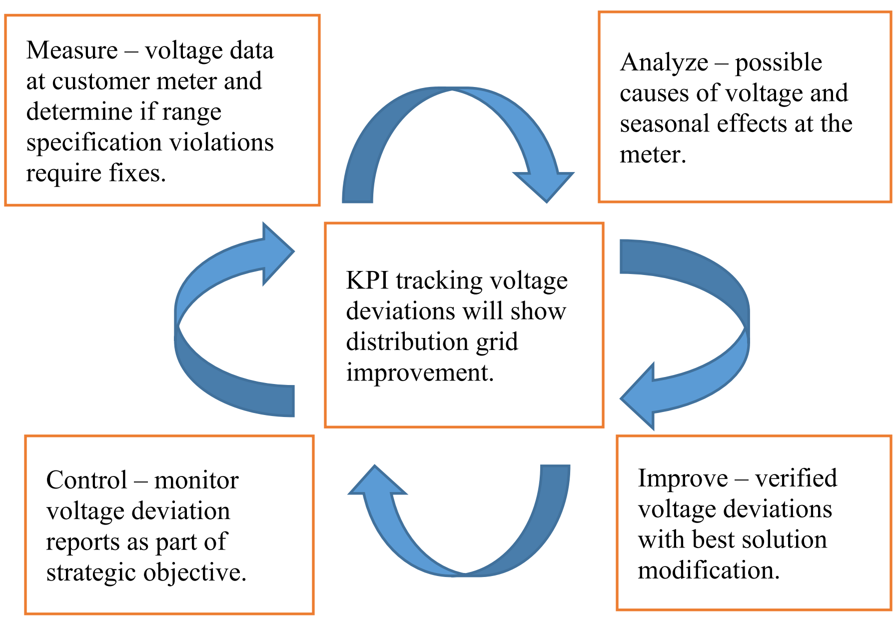

Figure 3. Cyclical Process to Improve System Voltage

A clear improvement in overall customer voltage quality is seen one year after implementation of this proposed program at an electric utility. Actual data has been used for KPI measures below which show the success of the program. The tables and figures also represent an effective way to communicate program effectiveness. Table 3 shows success for high voltage numerically. The number of days of unique meter violations were tracked and are presented.

A percentage of this number against the total number of meters in the system is also tabulated in Table 3. Figures 4 and 5 graphically represent improvement in high voltage violations and low voltage violations, respectively. Figure 4 is graphical representation of Table 3 percent data. Similar data for low voltage was used to develop Figure 5.

Table 3. One year comparative KPI data showing decrease in high voltage violations.

Daily Average Percentage of Meters per Day Reported High Voltage				
	October	**November**	**December**	**Quarter 4**
2021	0.754%	0.664%	0.608%	0.675%
2022	0.358%	0.304%	0.220%	0.294%
Calculated Daily Average Number of Meters per Day Reported High Voltage				
	October	**November**	**December**	**Quarter 4**
2021	125	110	101	112
2022	59	50	36	49

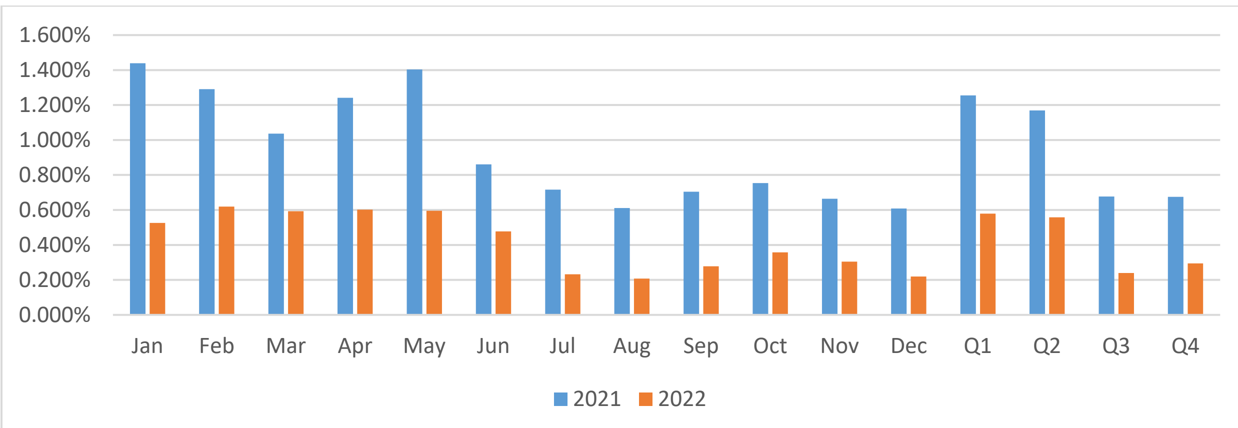

Figure 4. High voltage KPI daily average percent of meters

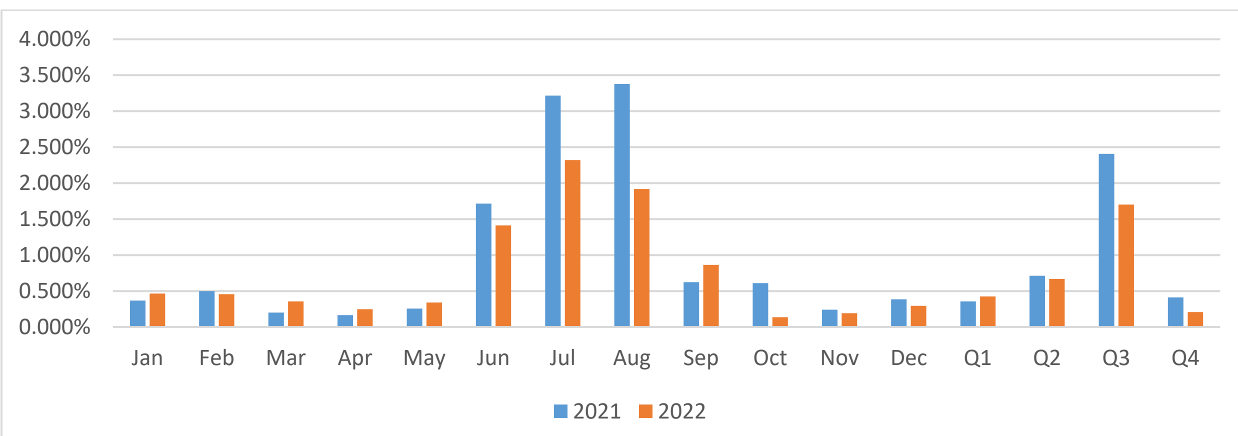

Figure 5. Low voltage KPI daily average percent of meters

6. Conclusion

This paper presents a method to implement a DMAIC process for an electric utility to make use of AMI data to detect and improve voltage deviations in customer service voltage. Several potential causes for the voltage issues are presented, along with discussion of future grid modernization efforts that are expected to increase instability, magnifying the importance of a good detection and improvement program. A universal method is presented to use AMI data to initially locate problematic areas and then use meter recording devices to show confirmation that a voltage deviation of regulatory duration has occurred. Statistical methods are employed to allow for a practical understanding of the relationship between the AMI and field recorder data. The validated data is then used to continue with the DMAIC process to analyze the causes of the deviations. The improvements available range from equipment setting changes, to physical removal and reinstallation of transformers. Removal of services from overloaded transformers has proven to eliminate voltage problems. Industrial distribution problems may be more involved and problems from unstable modern devices like EV charging and renewable power contribution may require major distribution system redesigns and significant capital investment. The process recommendation is to implement KPIs to monitor effectiveness and maintain process gains into the future. Engineering management is an ideal field to lead the implementation of such a program and the methods used in an engineering management program are used in this paper. A program to detect and improve voltage violations will result in improved customer satisfaction with the utility, less risk of damage to equipment, and cost savings as the utilities deploy systems to reduce overall system peaks with frequent monitoring intervals ensuring customers remain in specification. A clear improvement in overall customer voltage quality is seen one year after implementation of this proposed program at an electric utility.

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Biographies

Niamat Ullah Ibne Hossain, PhD., is an assistant professor in the Department of Engineering Management at Arkansas State University. Dr. Hossain received his PhD in Industrial and Systems Engineering in 2020 from Mississippi State University (MSU), Starkville, MS. He obtained his bachelor's degree in Mechanical Engineering in 2010 from Khulna University of Engineering and Technology (KUET) and his MBA in Management Information Systems in 2013 from the University of Dhaka, both in Bangladesh. His main research interests include systems engineering, systems model-based systems engineering/SysML, Systems thinking, Systems resilience, & sustainability management, System dynamics, and systems simulation.

Alexandr M. Sokolov, Ph.D., is a faculty in the Engineering Management Department of the College of Engineering and Computer Science at A-STATE. He holds a B.S., where he focused on Bioinformatics from the University of Tennessee Knoxville, an M.B.A., in Finance from Lincoln Memorial University, and a Ph.D., in Industrial Systems Engineering, Engineering Management from the University of Tennessee Space Institute. Alexandr has over 15 years of infield and teaching experience. His teaching experience includes multiple institutions dealing with Engineering, Management, and Technology disciplines. He is focusing on research dealing with Engineering Management, Performance Management, and Interdisciplinary Studies.

Scott Karbon, P.E. is an Engineering Manager at an Electric and Water Utility in Wisconsin. Mr. Karbon received a Master of Engineering Management in 2022 from Arkansas State University in Jonesboro, AR. He obtained his bachelor's degree in Mechanical Engineering from the University of Wisconsin-Milwaukee in 2000. He is a

Professional Mechanical Engineer in the State of Wisconsin. He has over 20 years of experience in power generation, electric distribution, and water/wastewater facility operation and construction. Work experience includes performing and overseeing engineering analysis for capital budgets, operations issues, and installation of new facilities.

Brian Merrill is a graduate student in the Management Department of the College of Engineering and Computer Science at Arkansas State and currently pursuing a Master of Engineering Management. He is an Electro-Mechanical Engineer at a Pharmaceutical Manufacturing Facility located in North Las Vegas, Nevada. Holds a B.S., in Electrical Engineering from Nevada State College, with minors in Mechanical Engineering, and Biomedical Engineering and a certificate in Engineering Management from the universities engineering department.