# Identifying Configuration and Monitoring Equipment Issues using PQ Interval-Data

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***Abstract*—This paper introduces an open-source tool capable of identifying issues utilizing trend data from revenue meters with power quality (PQ) functionality. The tool analyzes interval data such as average RMS voltage to identify any statistically significant changes in the signals that would indicate asset health issues. Configuration files are also downloaded from the meters to identify configuration and health issues. Continuous monitoring of interval data and analysis of the meter's configuration files enables the tool to identify issues such as malfunctioning or failed instrumentation. This paper also introduces a case study at the Tennessee Valley Authority with several issues identified by this tool.**

## I. Introduction

TVA is a generation and transmission owner and operator which serves 154 Local Power Company (LPC) customers which consist of municipalities and cooperatives that provide electricity to more than 4.6 million homes and businesses, 56 Directly Served Customers which consist primarily of large loads or federal agencies, and Off-System Customers which consists of 12 neighboring electric systems for which TVA has exchange power arrangements. This represents nearly 3000 points of interconnection for which revenue metering is required. Meter points are most commonly found on the distribution bus of a transmission-to-distribution transformer bank.

Since 2010, TVA has been deploying revenue meters that meet IEC 61000-4-30 [1] specifications for Class A power quality measurements. Over the past 15 years, this meter fleet has grown to over 2200 meters. These meters are configured to trend data in keeping with established power quality standards such as IEEE 519 [2] and IEEE 1453 [3]. This paper will focus on the ten-minute aggregated interval data, also known as short time values, recorded by these meters.

Meter interrogation software polls the meter fleet every ten minutes to download the latest ten-minute interval data, as well as the latest meter configuration data to a central database.

There are 1008 ten-minute intervals in a one-week period. Statistical analysis can be performed on this data set to identify any statistical outliers or anomalies. Specific logic has been developed to identify various failure modes including capacitor banks in bad health, malfunctioning voltage regulators or load-tap-changers, failing or failed Potential Transformers (PTs) and Current Transformers (CTs), loose connections in metering circuits, failing or failed fuses in metering circuits, and malfunctioning revenue meters.

In addition, the latest meter configuration can be analyzed to detect any changes to the configuration made by field technicians or malfunctions in the meter's firmware. Any misconfiguration can lead to inaccurate voltage and current readings or in some cases lead to complete recording failures.

Identification of these issues is important to utility companies as they can lead to loss of revenue, billing errors, relay mis-operation, and power quality impacts to customers.

## II. Cases, Trends, and Visualizations

This section provides illustrations for several different types of asset health issues that have been identified using a preliminary version of this open-source tool.

### *A. Failed Voltage Regulator or Load-Tap-Changer.*

Some of the first issues identified during the initial runs of the preliminary open-source tool were malfunctioning voltage regulators and load-tap changers (LTCs) at customer delivery points. Voltage regulators and transformers equipped with on-load load-tap-changers are commonly utilized to regulate the individual phase voltages within a desired voltage range. When a voltage regulator malfunctions, it can lead to a separation of the individual phase voltages as shown in Figure 1. This separation of individual phase voltages may result in the service voltage exceeding ANSI C84.1 [4] limits and could cause downstream equipment to trip offline or mis-operate due to voltage unbalance or overvoltage or undervoltage conditions.

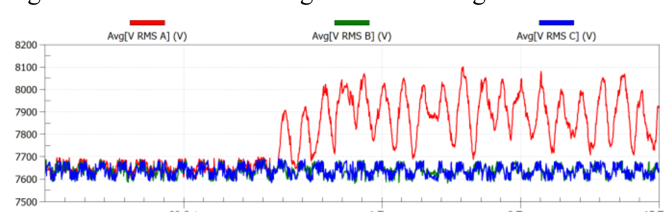


*Figure 1 Malfunctioning Voltage Regulator at a Customer Station*

In other cases, the contacts of certain tap positions of an LTC can wear out, becoming corroded or pitted, resulting in a lack of smooth transition between adjacent tap positions.

This is evidenced by elevated flicker levels as shown in Figure 2.

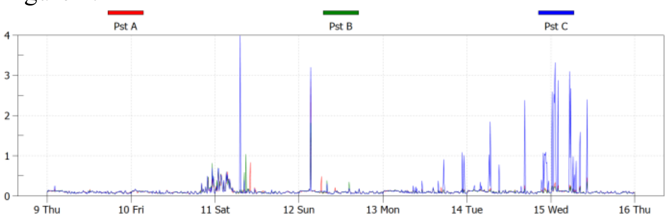


*Figure 2  Damaged Load-Tap-Changer at a Customer Station*

### *B.    Capacitor Banks with Blown Fuse or Bad Pole on Switch.*

A very common issue that is regularly identified with the tool is the health of distribution capacitor banks which can experience blown fuses on the capacitor units and bad poles on the capacitor switches.  Either failure can cause a noticeable increase in neutral current, reactive power unbalance, and voltage unbalance when the capacitor banks are switched in as shown in Figures 3 and 4.

Capacitor banks on transmission and distribution systems are used to provide reactive power for voltage support.  If one of the phases of the capacitor bank is not providing the same support as the other phases, then increased voltage unbalance could be noticed by customers served from the circuit as well as increased neutral current resulting in elevated neutral-to-earth voltages and possible nuisance shock complaints.

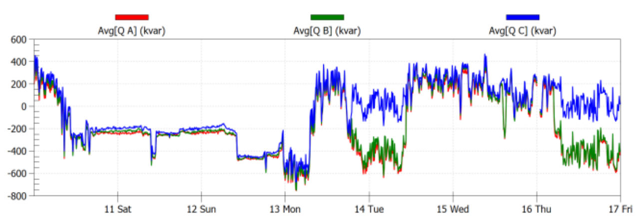


*Figure 3 Reactive Power Unbalance due to Bad Pole on Switch*

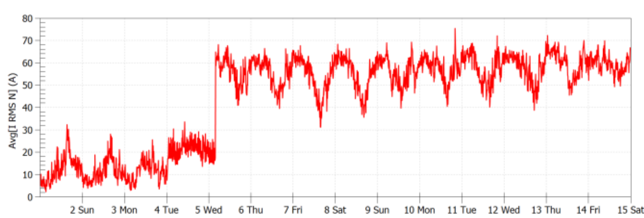


*Figure 4 Elevated Neutral Current due to Failed Fuse*

### *C.    Failed Potential or Current Transformers.*

PTs and CTs are used to scale down primary voltage and current to levels within design ratings of measurement devices like revenue meters and relays.  While PTs and CTs can fail catastrophically resulting in system faults that could impact customers, more commonly the secondary signals provided to revenue meters or relays may be completely lost, have elevated distortion, or other inaccuracies.  If unnoticed a PT/CT failure can be among the most financially and relationally impactful due to the utility not properly billing a customer for an extended period.

Figure 5 shows a case with a sudden VT failure where the metered voltage abruptly goes to zero. Figure 6 shows a case where a CT was beginning to fail evidenced by the intermittently lower current readings on one phase.

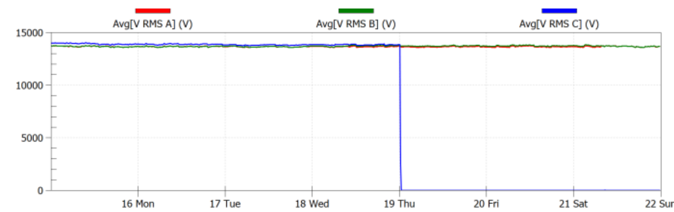


*Figure 5 Sudden Loss of Voltage on One Phase*

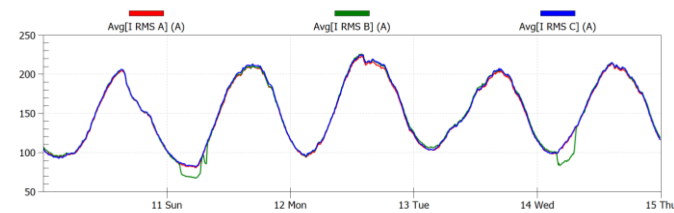


*Figure 6 Intermittent Variation in Current in One Phase*

### *D.    Loose Connections in Metering Circuits.*

A loose or dirty connection in the metering PT secondary circuit can result in intermittent and even sustained errors in the voltage readings by the meter with the voltage readings varying and typically reading lower than normal as shown in Figure 7.  Such conditions can also be evidenced by elevated flicker readings as shown in Figure 8.  Loose connections can result in metering and thus billing errors.  If the same secondary circuit also supplies voltage to protective relaying then such a condition could also result in relay mis-operations.

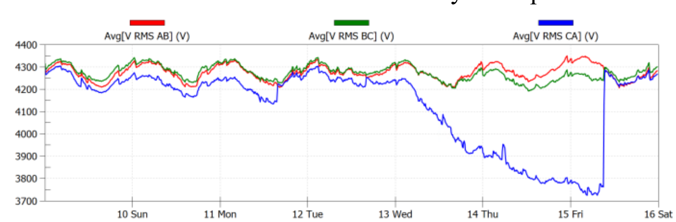


*Figure 7 Fluctuations in Voltage Readings*

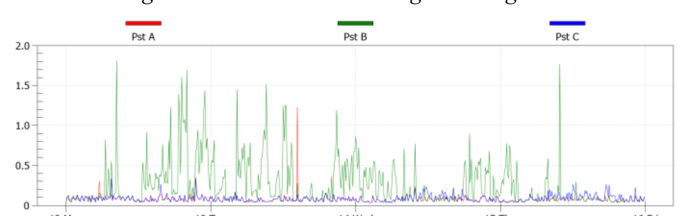


*Figure 8 Elevated Flicker Levels*

### *E.    Incorrect CT Strapping.*

It is common for CTs to have multiple secondary windings which provide multi-ratio options.  Sometimes a CT may be inadvertently set to an incorrect ratio, resulting in an unbalance condition in the secondary metering circuit.  Figure 9 shows an example of an incorrectly strapped CT on one phase.  Sometimes failures occur in the secondary wiring resulting in abrupt changes in the measured current.  Figure 10 shows a case where a butt splice separated in the CT secondary wiring doubling the measured current by the meter on one phase.

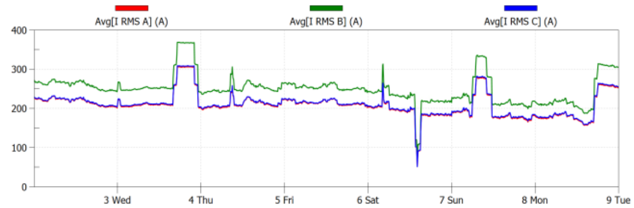


*Figure 9 CT Strapped on Wrong Winding / Ratio*

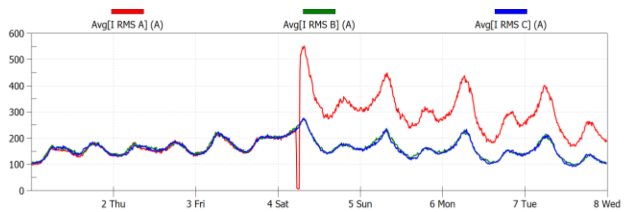


*Figure 10 Abrupt Change in Current in One Phase*

### F. Meter Failures.

Sometimes the revenue meter itself may become damaged or lose its memory and settings. Figure 11 shows an example meter failure where one phase current developed a large DC offset in the signal causing the RMS current reading to run-away.

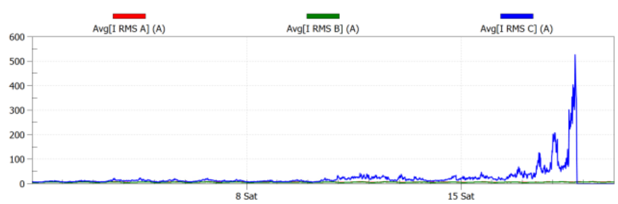


*Figure 11 Phase Current Runaway Due to Large DC Offset*

## III. Logic

This section provides an explanation of the logic used by the preliminary open-source tool.

### A. Collecting the Meter Data.

Prior to using the tool, data must be retrieved from the meter to a central database. The tool analyzes cumulative probability (CP) values that are derived from the 1008 ten-minute intervals over a one-week period for each meter. The analysis is performed on the following parameters: line-to-neutral voltage, line-to-line voltage, phase currents, flicker, harmonic distortion, active power, reactive power, all on a per-phase basis, and neutral current.

### B. Filtering Out Meters with Irrelevant Measurements.

Once all the CP values are calculated for each meter, the data is stored in an array. The tool goes through each individual meter's CP values and filters out meters that are deemed to have insufficient or irrelevant measurements for that week. Examples of meters with insufficient or irrelevant measurements are meters that are out of service for maintenance, not serving any load, or have an insufficient number of samples for the week. A meter is not considered for evaluation if it meets any of the following criteria.

1. The CP25 value for at least one of the three phase voltages is above 0.8PU. This determines if the meter was out of service for 25% of the week. If so, the meter is disregarded from the weekly evaluation.
2. The CP95 individual current values are all below the current threshold limit which is set as 5% of the primary CT rating. This filters out meters that have little to no load flow.
3. The CP values must be derived from a data set having at least 1512 ten-minute intervals among the three phases which equates to at least 50% of the one-week period.

### C. Evaluation of the CP Values.

After filtering the meters to only those with sufficient and relevant data, the tool analyzes the CP25, CP50, CP75, CP95 and CPstdev values for each parameter by using (1) to obtain a Ratio Value (RV) for comparison against predetermined thresholds to identify various asset health issues. The CP values are on a per-phase basis which allows identification of when one phase varies compared to the others.

$$\frac{Max(CP_{XX}) - Min(CP_{XX})}{((CP_{XX[0]} + CP_{XX[1]} + CP_{XX[2]})/3)} = RV \qquad (1)$$

Once RV is calculated for each CP value for each parameter, it is then compared against a threshold that is set for each unique parameter of interest. If RV exceeds the threshold for that parament, that meter is flagged for investigation by engineers to determine if an actual asset health issue exists or to further inform the tool of needed adjustments to the algorithms to avoid future false positives.

### D. Relationship of Parameters to Asset Health Issues.

There are specific parameters we can associate with each type of asset health issue. For PT, voltage regulator and load tap changer issues the individual voltage parameters are used. The CP standard deviation values for voltages are uniquely used in that their input into the above equation allows a user to identify when one phase is varying compared to the other phases which helps with locating failed voltage regulators and load-tap-changers. When looking for loose connections, the individual flicker measurements are used. The individual voltages could be used, but trials have shown more false positives than when using the flicker parameters. Lastly the individual current parameters are used to identify failed CTs, blown fuses, and bad poles on switches for capacitor banks.

## IV. Configuration Change Monitoring

TVA is also downloading the active configuration of each meter. These files are then analyzed by the open source tool and any changes in configuration are flagged.

There are several configuration parameters, such as sampling rates, active channel count, and time zone, that have been identified as critical for well conditioned data collection. Any changes to these parameters are identified and trigger an email alert to appropriate personnel. In addition, these parameters are compared to pre-defined defaults, and a daily summary email is sent highlighting any meters where the current configuration differs from the configuration of record.

In addition to email notification, engineers have access to a Dashboard, showing an overview of all monitored meters and their configuration status. Figure 12 shows the dashboard. It includes a geographic overview and a list of any misconfiguration issues identified.

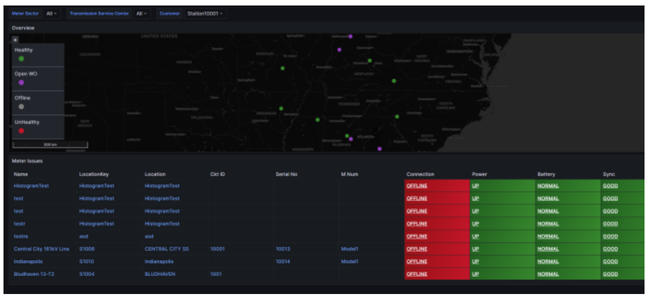

*Figure 12 Meter Configuration Status Dashboard*

## V. *CONCLUSION*

This paper describes an open-source tool used to identify asset health issues. The tool uses interval data as well as data from the meter's configuration files to proactively identify several issues, allowing TVA to resolve them early on.

A production ready version of this tool is under development to visualize the results as part of TVA's power quality data visualization tools and enable early detection and warning of any potential meter failures.

## *VI. REFERENCES*


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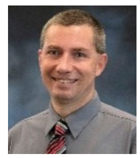

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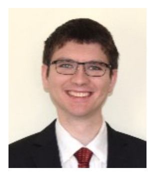

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