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Distribution System Monitoring for CVR Operation and Performance Evaluation: A Utility Experience

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- ✓ Introduction
- ✓ Developed analytics
- ✓ Developed dashboards
- ✓ Illustrations and demonstrations
- ✓ Discussions and conclusions

- Conservation voltage reduction (CVR) and volt var Optimization (VVO)
- Equipment
 - Substation transformer load tap changers (LTC)
 - Line voltage regulators (LVR)
 - Capacitor (CAP) banks
- Importance of monitoring CVR operation
 - Enforce CVR ON/OFF testing cycles or CVR 24/7 operation
 - Detect mechanical issues and failed equipment
 - Less anomaly data to be dealt with when quantifying the CVR effects

- CVR ON/OFF status needs to be detected for the CVR operation monitoring and performance evaluation
 - Despite the type of CVR activation schedule
- Variables
 - VO_{active} | Heartbeat | Setpoint | Secondary load voltage

The basic idea of the developed CVR status detection algorithm (full algorithm can be found in previous work [4])

- 1: at a substation transformer,
 - 2: if VO_{active} is ON, and *heartbeat* is greater than the lower threshold, and *setpoint* is smaller than the default bandcenter, and the *secondary load voltage* is smaller than the default bandcenter
 - 3: CVR status is detected as ON
 - 4: else
 - 5: CVR status is detected as OFF
 - 6: end if
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[4] A CVR On/Off Status Detection Algorithm for Measurement and Verification, 2021 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), 2021.

- Once CVR status is determined, the percentage time of CVR ON operation can be calculated
- This Calc is implemented as a 30-day moving average using the formula below,

$$CVR_{ON}\% = \frac{TM\{CVR\ ON\ time\ in\ 30\ days\}}{TM\{30\ days\}} \times 100$$

- If CVR is intended to run in 24/7 mode, the $CVR_{ON}\%$ would be 100%, ideally
- If CVR is scheduled to run ON/OFF testing, the $CVR_{ON}\%$ would be 50%, ideally

- The average voltage reduction percentage $\Delta V\%$ is one of the most important measures of CVR performance
- The average voltage reduction percentage Calc is implemented as a 30-day moving average using the formula below,

$$\Delta V\% = \frac{AVE\{V_{CVR_{OFF}}\} - AVE\{V_{CVR_{ON}}\}}{AVE\{V_{CVR_{OFF}}\}} \times 100$$

- The average voltage reduction at different levels reveals valuable information for monitoring CVR devices and performance,

Level of the Results	Revealed Information
Substation transformer level	Indicate whether a transformer/substation is working as intended, and if any equipment maintenance or reconfiguration is required
Substation level	
Substation type level	Provide an expectation of the average voltage reduction for a specific substation type or at the system level for future analysis (e.g., cost-benefit-ratio)
Program level	

- In practice, LTC can get locked at the bottom tap position
- This mechanical issue requires manual work to unlock the LTC tap
- A Calc is developed to automatically monitor whether a LTC is locked at the bottom tap position
- The Calc is described as follows. For a time-instance t , if the string value of LOLM_Alarm is ALARM-METER, and VO_Calc is OFF, then the substation transformer LTC is determined to be locked at the bottom tap position
- By monitoring whether an LTC is locked, it allows the working request to be created in a timely manner to notify the substation operators

- A frequently locked LTC indicates its no-load tap (NLT) setting may need an adjustment
- To detect such scenarios where NLT settings need a review automatically, a 30-day moving average Calc is developed

$$LTC_{Locked}\% = \frac{TM\{LTC_{Locked} \text{ in } 30 \text{ days}\}}{TM\{30\text{days}\}} \times 100$$

- If LTC_Locked% of a substation transformer is greater than the pre-determined threshold, then the NLT setting of its LTC needs a review and possibly a reconfiguration
- The threshold can be determined based on the substation operators' experience and historical performance of the LTC

- A CVR-enabled distribution circuit usually has one or more CAP banks installed
- When one of the CAP banks fails, the coordination between CAP banks and with LTC or LVRs can be affected
- A Calc was developed based on the CAP bank neutral current (NC)
 - The basic idea is that when the magnitude of NC is beyond a certain threshold, it indicates the CAP bank is experiencing issues
- The threshold used in this Calc is 5 Amperes

- It is desired to distribute Open-Close operations as evenly as possible to all CAP banks installed on the same feeder
- Once whether one or more cap banks are preferred to be switched is pinpointed, adjustments can be made in the CVR control platform to distribute such operations to other less preferred CAP banks
- As a result, less maintenance and longer equipment lifetimes are expected and thus deferring the needs of equipment replacement

- the substation health score (SHS) Calc is determined using the following formula

$$SHS = w_1 \Delta V\% + w_2 CVR_{ON}\% + w_3 LTC_{Locked} + w_4 LTC_{Locked}\%$$

where, w_1 to w_4 are the weighted factors of their associated variables

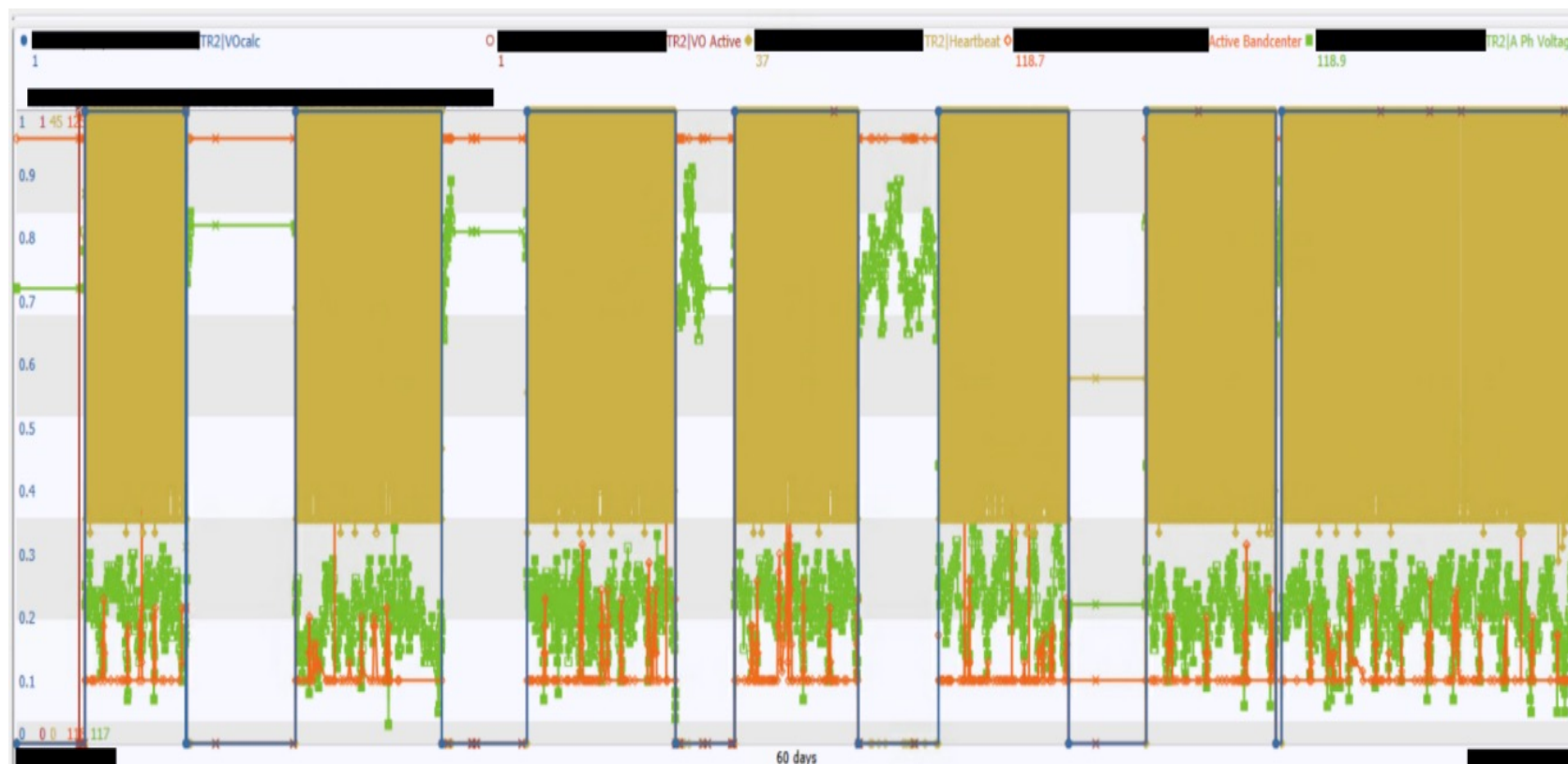
- Based on the magnitude of the obtained SHS, a color code can be assigned to each substation
- In this study,
 - Orange indicates a substation needs attention or action required
 - Yellow indicates there was a minor concern(s) of a substation
 - Green indicates no issue

- The field measurements, communication signals, and analytic results are brought to the front-end developed dashboards for direct visual access
- Two main dashboards were created,
 - Program dashboard
 - Substation dashboard
- The program dashboard provides an overview of the entire CVR activation at all substations
- The substation dashboard provides a clear visual of all CVR equipment status, SCADA point trends, and the analytic results at a substation

ILLUSTRATIONS AND DEMONSTRATIONS

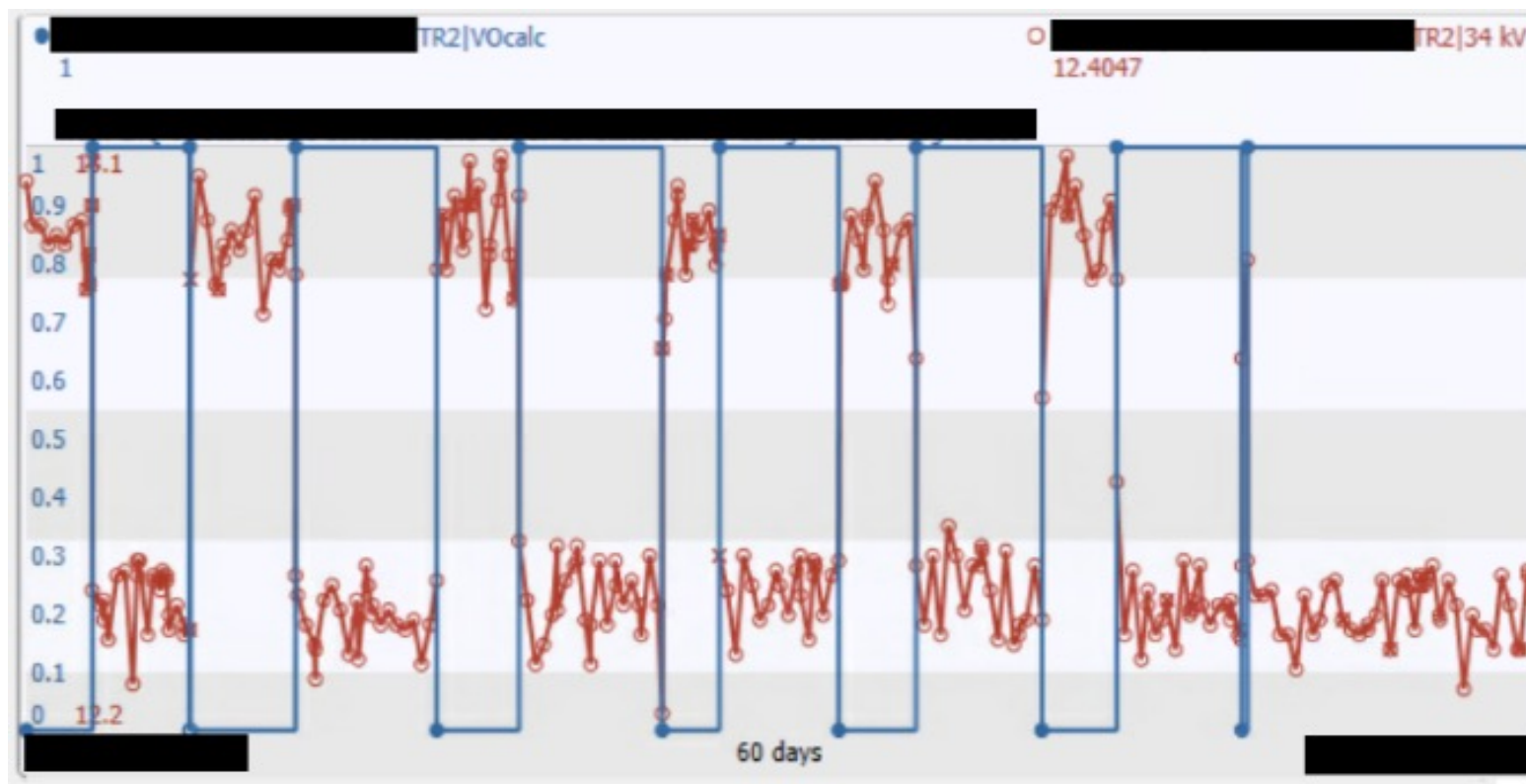
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- CVR Status Detection and ON Time Percentage



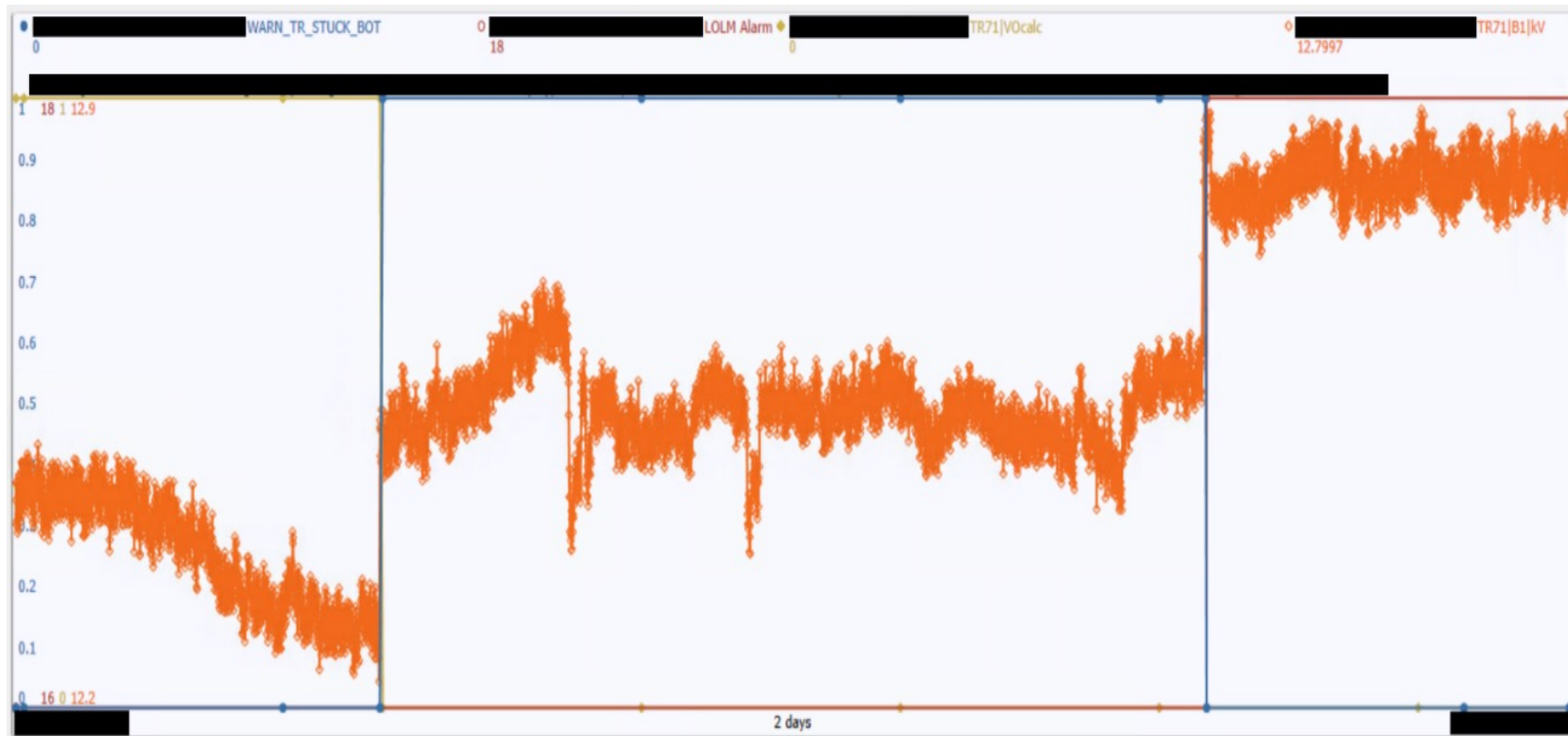
ILLUSTRATIONS AND DEMONSTRATIONS

- Average Voltage Reduction



ILLUSTRATIONS AND DEMONSTRATIONS

- Detection of Locked LTC and NLT Warning



ILLUSTRATIONS AND DEMONSTRATIONS

- Developed Station dashboard



- A utility experience of monitoring the CVR devices, operation, and performance
- Field measurements and communication signals are brought to the back-end environment to perform analyses
- The analytic results are displayed in the front-end along with the measurements and signals
- This tool helps to track the performance of CVR control devices, including substation transformer LTC and CAP banks, and raise situation awareness to promote timely actions
- An exemplary model for other electric utilities that have or are planning large-scale CVR programs