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# Maximizing Load Reduction Using AMI-Informed Emergency Voltage Reduction Ahead of Blackouts

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## SUMMARY

Preventing rotating blackouts in power systems is of paramount importance due to its significant impact on the stability, reliability, and safety of the grid and the well-being of the population. Emergency Voltage Reduction (EVR) is a strategy employed during periods of high electricity demand to prevent rotating blackouts. Instead of completely cutting off power to specific areas, voltage levels are temporarily reduced. While reduction in voltage may cause certain devices to operate less efficiently or experience performance issues, it is generally a preferable alternative to widespread blackouts, as it helps maintain a basic level of electricity supply to the customers (including critical infrastructure).

In this paper, Dominion Voltage, Inc. (DVI) proposes an EVR-based emergency load reduction solution using an Advanced Voltage Management (AVM) engine that integrates with the utility's Advanced Metering Infrastructure (AMI) system. The proposed solution offers a more informed, precise, and faster load reduction as it uses near real-time customer voltage feedback from the Advanced Metering Infrastructure (AMI) system and device voltages (setpoint and bus voltage) from the Advanced Distribution Management System (ADMS/SCADA). This approach adjusts voltages within emergency ANSI standards to maximize the aggregate load reduction, thus ensuring that the customer voltages do not go below the recommended thresholds. The proposed solution offers an edge over conventional voltage reduction techniques, as they are less efficient and more conservative due to lack of visibility into real-time customer point of service voltages [1].

## KEYWORDS

Advanced Voltage Management (AVM), Emergency Voltage Reduction (EVR), Emergency Load Reduction (ELR), Rotating Blackout, Advanced Metering Infrastructure (AMI), Conservation Voltage Reduction (CVR), Demand Voltage Reduction (DVR), Advanced Distribution Management System (ADMS), Supervisory Control and Data Acquisition (SCADA).

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## INTRODUCTION

Power system blackouts lead to the total disruption of electricity supply to a wide geographical area. To mitigate and avoid cascading blackouts, careful planning and engineering of the systems are necessary. Blackouts arise from a series of cascading failures caused by the combination of several low-probability events occurring in an unforeseen or unintended sequence. The Department of Energy lists nine criteria for filing a disturbance report, including the loss of 300 MW for 15 min or more and emergency load shedding of 100 MW or more [2].

The 1965 northeast blackout was the first widespread, cascading power failure in North America. Around 30 million customers were without power for up to 13 hours in eight states and Ontario. In 1998, an ice storm struck Quebec, causing accumulation of over 100 mm of freezing rain that severely damaged the Hydro-Québec electrical network, resulting in a blackout effecting more than 4 million customers. On August 14, 2003, in northeastern Ohio, three 345-kV transmission circuits touched overgrown trees, initiating a chain of events that led to the collapse of the electrical grid in the northeastern United States and parts of eastern Canada, leaving about 50 million people without power. Another huge blackout occurred in September 2003 in Italy. A series of problems in the high voltage lines in France and Switzerland caused a domino effect and left 57 million Italians without electricity. On 31 July 2012, 670 million Indians, or 10% of the world's population were left without power. In February 2021, Texas experienced a severe power crisis as temperatures dropped, demand rose, and capacity warnings were issued. The Electric Reliability Council of Texas (ERCOT) had to shed 10,500 MW of load due to an alarming mismatch between generation and demand on the Texas Interconnected System. This four-day blackout affected 4.8 million power customers and 14 million water users, causing over 246 deaths and widespread disruptions to transportation, industries, businesses, and people's daily lives across the state. On October 4, 2022, Bangladesh experienced a mysterious power grid collapse, resulting in 140 million people being plunged into darkness [2, 3]. In the early hours of Christmas Eve 2022, multiple mishaps due to frigid temperatures (including malfuntioning of three power plants due to frozen instrumentation lines, impeded operations in several nuclear units, demand surpassed predictions, and lack of surplus power in nearby utilities due to high demand) prompted Duke Energy for the first time in state history to inflict rolling blackouts on thousands of North Carolinians [4].

Despite the advancements in modern technology that have improved our resilience to blackouts, it is essential not to claim complete victory. The North American Electricity Reliability Council (NERC) recorded approximately 20 blackouts in the last two decades.

All North America Independent System Operators (ISO) have their own emergency response plans to prevent and mitigate a rotating blackout. Transmission system reconfiguration, reducing energy purchases, implementing voltage reductions, requesting voluntary customer energy conservation or load curtailment, implementing load shedding programs, such as PJM's Load Management (LM) program are part of the actions that PJM directs to manage or end the emergency situations. PJM aims to meet customer energy demands through available generating resources, power purchases from PJM Members, and planned load management programs. In situations where demand cannot be met, emergency measures, such as voltage reductions, and, as a last resort, manual load shedding, are employed [5]. NYISO has similar emergency remedial actions, including monitoring operating reserves for expected peak times. They may employ load relief measures using Quick Response Voltage Reduction within 10 minutes, if additional capacity is needed. Then, during Major Emergency situations, NYISO directs transmission owners to implement a 5% Quick Response Voltage Reduction system-wide [6]. ERCOT begins emergency operations using three levels of Energy Emergency Alerts (EEAs). In emergency conditions, import from neighboring electric grids, switching generation, paying to commercial/small industrial customers to reduce their power, load management program, voltage reduction and load reduction are the actions that are taken in different level of Energy Emergency [7]. Load management programs are part of CAISO’s Emergency response plans. Emergency Load Reduction Program (ELRP), as part of load management programs is triggered as a last resort, if the other measures are insufficient. The ELRP pays customers who voluntarily reduce electricity demand during a grid emergency [8, 9]. IESO also has voltage reduction as an emergency action and their voltage reduction test in July 2019 shows 0.96% and 1.68% demand reduction in Ontario, when voltage reduced three and five percent, respectively [10].

Studies on the emergency response program of north America ISOs shows that voltage reduction is one of their main plans to prevent cascading blackouts and mitigating the emergency events. By applying voltage reduction, the system operators deliberately lower the voltage levels in certain areas of the grid to avoid overloading and stabilize the system. Therefore, there is no doubt that voltage reduction is an effective strategy in emergency situations to prevent rolling blackouts. However, the implementation of voltage reduction, particularly during emergency scenarios, holds paramount importance for ensuring the stability and reliability of the power system. Limited visibility into real-time distribution system and customer voltages results in more conservative reduction targets that fail to fully realize the potential benefits of voltage reduction [1]. On the other hand, in some instances, certain customers may experience excessively low voltage levels due to this lack of monitoring and control.

This paper proposes a novel method that focuses on implementing AMI-informed EVR for load reduction during an emergency situation to avoid or minimize blackouts. An Advanced Voltage Management engine that possesses comprehensive visibility into the distribution circuit through AMI voltage data [11, 12], can precisely calculate the optimal amount of voltage reduction for each circuit to maximize the load reduction during emergency situation, while ensuring that customers remain within the acceptable voltage limits specified by the ANSI standard. During EVR operations the AVM engine can recommend new low setpoints which are communicated to the devices (substation transformer load tap changers (LTCs), substation regulators, and any downline regulators with communications) via ADMS/SCADA, enabling reduction of voltage across the circuit in a controlled manner. This precise and data-driven approach allows for efficient voltage reduction, resulting in maximum load shed across the distribution grid during an emergency.

## HOW DOES ADVANCED VOLTAGE MANAGEMENT (AVM) ENGINE INTEGRATE WITH UTILITY SYSTEMS?

An Advanced Voltage Management engine allows utilities to control their distribution circuits for CVR (Conservation Voltage Reduction), DVR (Demand Voltage Reduction), EVR (Emergency Voltage Reduction), and Stabilizer (Voltage Stabilizing to enable Distributed Energy Resource penetration) operations while observing real-time circuit conditions.

It is important to monitor a subset of AMI meters, called bellwethers (strategically identified low/high voltage points on the circuit). Using voltage reads from these bellwethers as feedback, an AVM engine can execute a precise voltage control setpoint to circuit devices. To ensure that the AVM engine is monitoring the most up-to-date low/high voltage points (AMI meters) on the distribution circuit it needs to adapt and update the bellwether set based on the low voltages alerts (sags) reported by the smart meters to the the AMI headend system. Figure 1 shows a high-level arhitecture diagram of an AVM engine and its integration with utility’s AMI and ADMS/SCADA systems.

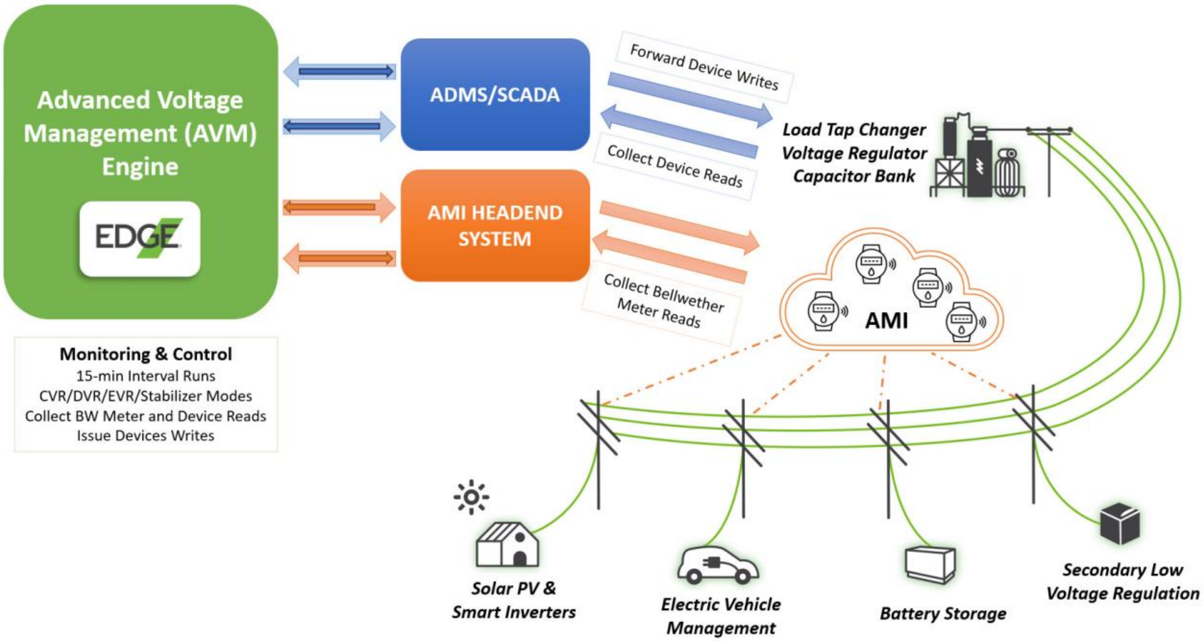


*Figure 1: High-Level Architecture - An AVM Engine Integrating with Utility Systems*

## PROPOSED SOLUTION: EMERGENCY LOAD REDUCTION USING AN ADVANCED VOLTAGE MANAGEMENT (AVM) ENGINE

Emergency Voltage Reduction (EVR) may be the difference in a close call and rolling blackouts. With precise voltage measurement, an AVM engine can rapidly and accurately adjust voltages within emergency ANSI standards to maximize the aggregate load reduction.

ADMS/SCADA operators can send an EVR command to the AVM engine for select (or all) circuits, taking customer voltages down to the lowest possible limits, thus maximizing the load reduction per circuit and across the distribution grid. Figure 2 shows the end-to-end EVR process using an AVM engine for load reduction when system is under emergency alert.

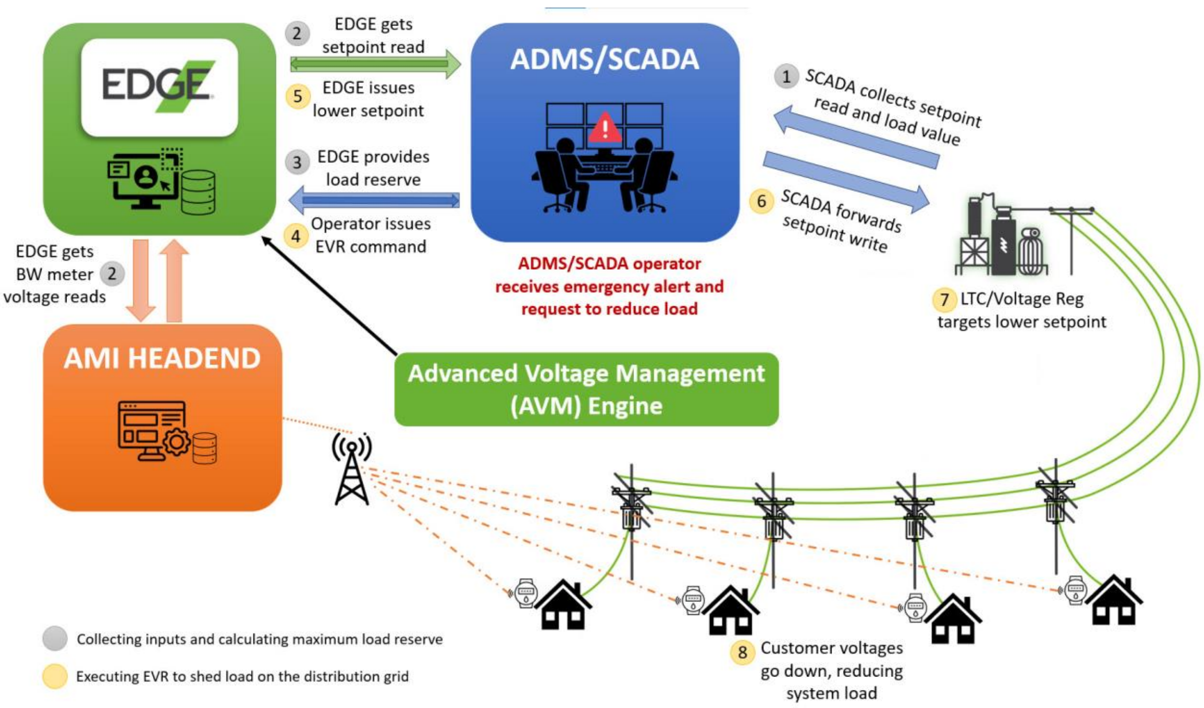


*Figure 2: End- to-End EVR Process Using an AVM Engine*

During normal operation, the AVM engine will run a monitoring and control algorithm on every circuit, every 15-minutes for the selected mode of operation (CVR/DVR/Stabilizer). It will collect the device reads from ADMS/SCADA (including setpoint, bus voltage, and load values from LTCs or voltage regulators) and bellwether meter reads from AMI headend and makes control recommendations. As part of this process it will also calculate the maximum load reserve available per circuit using the current customer and device voltages and their respective lower bounds for EVR operations.

Load Reserve = (% Voltage Reduction) X (CVR Factor) X (Current Load)

An operator can view the available load reserve across all the circuits in ADMS/SCADA screen. This provides visibility to the operator on load reduction potential across the distribution grid and helps in making informed decision during an emergency.

During an emergency, the operator will send an EVR command to the AVM engine for select or all circuits. On receiving the request, the AVM engine will run the EVR algorithm and send the lower setpoint recommendations to the LTC controllers (and any downline voltage regulators) via ADMS/SCADA. As a result, customer voltages will drop, resulting in load reduction across the distribution grid. ADMS/SCADA operators will see the drop in system load. In case the desired target is not achieved, operators can issue the EVR for additional circuits (if all were not selected in the first go).

The setpoint recommendations during EVR are based on the same algorithm used to calculate the maximum load reserve. Therefore, the outcome is the lowest possible setpoint that can be targeted by the controller to achieve maximum load reduction while keeping the customer voltages within emergency ANSI limits. During EVR operations, the AVM engine will not only immediately drop the voltage, it will continue to monitor customer voltages and it will recommend lower setpoint to the controller (only if setpoint is not already at the lowest limit and there is room to further reduce customer voltages) to achieve maximum voltage and load reduction.

This approach to EVR offers more **informed** (visibility of available load reserves), **faster** (lowest possible target setpoint recommended in one go), and **precise** (maximum voltage and load reduction using customer voltage feedback) load reduction. EVR can be implemented system-wide (across all circuits) with the click of a button. This approach also offers selectivity in case any sensitive circuits need to be excluded from the EVR operations.

## USE CASE: EVR IN ACTION

This section describes the emergency load reduction using EVR with the help of a use case. Let’s consider a distribution grid with several circuits fed by substation LTCs. At 16:10 on 27 April 2023, ADMS/SCADA operator receive an emergency alert to reduce load on the distribution grid. The operator selects 10 LTC fed circuits and issues an EVR command to the AVM engine.

The AVM engine receives the request, runs the EVR algorithm on those circuits, and issues new, low, setpoint recommendations to the LTC controllers via ADMS/SCADA. This causes the LTCs to lower the taps until the bus voltage comes within the bandwidth of the new setpoint targets. Because the voltages at the distribution buses are lowered, customer voltages connected to the feeders will also be reduced. This results in load reduction across the distribution circuits. Operators can see a 5 MW drop in system load (from 175 to 170 MW) in the ADMS/SCADA screen. If the required target is not met the operator can select other circuits and send an additional EVR command to the AVM engine.

Once the emergency is over, operator will send an EVR disable command to the AVM engine. On receiving the request, AVM engine will bring the circuits back to their original state by sending new higher setpoint recommendations to the LTC controllers via ADMS/SCADA. And thus, the customer voltages will recover back to the pre-emergency levels.

Table 1 shows the load reduction achieved using EVR across the 10 substation LTC fed circuits. An overall voltage reduction of 5.3% resulted in a 3% load reduction.

*Table 1: Load Reduction on LTC Circuits Using EVR*

| Circuit # | Load (MW) | CVR Factor | % Voltage Reduction | Load Reduction (MW) | % Load Reduction |
|---|---|---|---|---|---|
| LTC1 | 21.5 | 0.6 | 5.0% | 0.65 | 3.0% |
| LTC2 | 18.5 | 0.52 | 6.0% | 0.58 | 3.1% |
| LTC3 | 17.6 | 0.65 | 5.2% | 0.59 | 3.4% |
| LTC4 | 16.5 | 0.55 | 4.0% | 0.36 | 2.2% |
| LTC5 | 19.8 | 0.64 | 5.3% | 0.67 | 3.4% |
| LTC6 | 17.6 | 0.55 | 6.0% | 0.58 | 3.3% |
| LTC7 | 15.4 | 0.59 | 5.5% | 0.50 | 3.2% |
| LTC8 | 15.2 | 0.45 | 6.4% | 0.44 | 2.9% |
| LTC9 | 19.5 | 0.48 | 3.0% | 0.28 | 1.4% |
| LTC10 | 13.6 | 0.65 | 7.0% | 0.62 | 4.6% |
| | **175.2** | | **5.3%** | **5.26** | **3.0%** |

Figure 3 shows the LTC controller voltages (setpoint and bus voltage; top chart) and customer voltages (average and minimum of bellwether reads; bottom chart) in the AVM engine for "LTC1" circuit during EVR operation. As soon as the EVR command is received by the AVM engine (at 16:10), it sends 114 V as the recommended setpoint to the controller right away. As a result, customer voltages drop by 6 V (~119 to 113 V; 5% voltage reduction). Around 19:00, system is no longer under emergency alert, so the operator send command to disable EVR operation in the AVM engine. As a result, AVM engine sends setpoint recommendation of 123 V to the LTC controller, thus moving the customer voltages back to the pre-emergency levels.


*Figure 3: LTC Controller and Customer Voltages During EVR (Circuit: LTC1)*

Figure 4 shows the load reduction achieved using EVR on "LTC1" circuit. A 5% voltage reduction resulted in a 3% load reduction (0.65 MW) on this circuit.

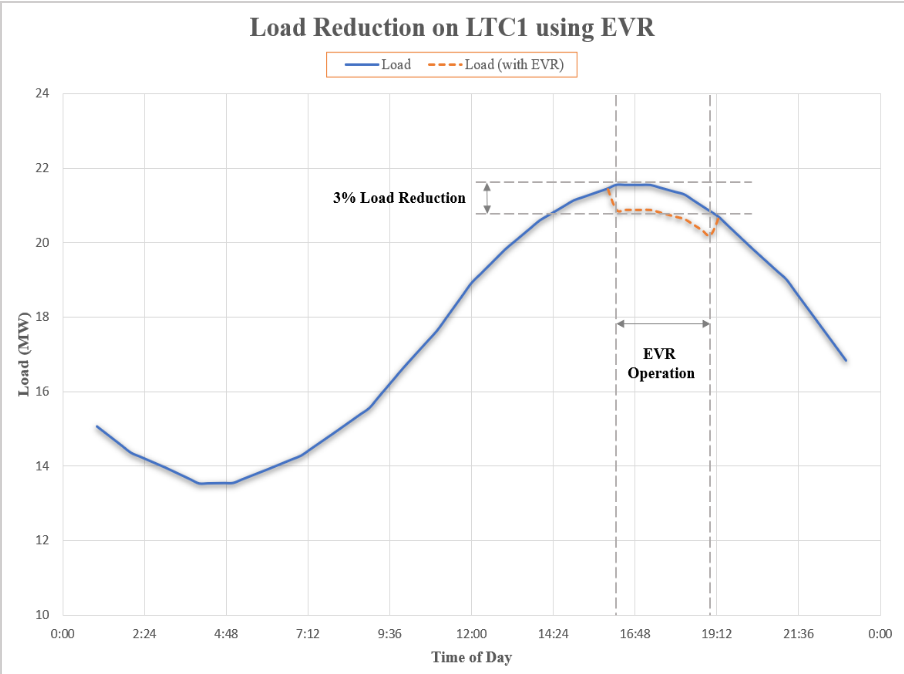


*Figure 4: Load Reduction Using EVR (Circuit: LTC1)*

## CONCLUSION

Emergency Voltage Reduction (EVR) is a voluntary measure aimed at reducing system demand during times of temporary electricity supply decrease. It's important to note that voltage reduction is a temporary measure and is typically used as a last resort to prevent cascading blackouts. The primary goal is to stabilize the grid and avoid further damage until the root cause of the initial disturbance can be identified and resolved. This is achieved by systematically lowering the operating voltage on the distribution system.

In this paper DVI has proposed a novel EVR based emergency load reduction solution using an Advanced Voltage Management (AVM) engine that integrates with utility's AMI headend system to provide visibility into the real-time distribution grid voltages and the available MW reserves. The proposed solution offers a more informed, precise, and faster load reduction as it uses near real-time customer voltage feedback from the AMI system and device voltages (setpoint and bus voltage) from the ADMS/SCADA. Emergency Voltage Reduction can now be executed with greater precision and control, while ensuring that customer voltages remain within the emergency ANSI standards. This solution has an edge over conventional voltage reduction techniques, as they are less efficient and more conservative due to lack of visibility into real-time customer point of service voltages.

By adopting the proposed solution, utilities can now implement effective voltage reduction measures in a targeted manner, thereby enhancing the overall efficiency and reliability of the grid in emergency situations.

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