Enabling Decentralized Conservation Voltage Reduction Through Distributed Intelligence

Background:

Conservation Voltage Reduction, commonly referred to as CVR, is a technique used by utilities to improve system efficiency and reduce demand by controlling the system voltage to the lower end of the acceptable voltage range. CVR has been shown to be very cost effective, in large part due to minimal implementation costs[1]. It is not unusual for utilities to see CVR factors close to 1, meaning a 1% reduction in Voltage results in a 1% reduction in energy consumption.

In a system with a centralized control architecture, the Distribution Management System (DMS) or Advanced DMS (ADMS) may decide when to enter CVR mode based on system conditions, operator input, or even fixed schedules. In such cases, the DMS/ADMS will generally issue commands directly to Automatic Voltage Regulators (AVRs) and other voltage control devices directing them to maintain a reduced voltage.

While CVR can have significant system impact, individual circuits or circuit segments may have characteristics that make CVR less effective and more challenging to implement. Circuits may have insufficient headroom to reduce voltage. Load make-up (e.g. high concentrations of constant power load) can diminish and even reverse CVR effectiveness. Distributed Energy Resources (DER) can cause challenges due to voltage rise as well as resource intermittency. Additionally challenges with centralized CVR may include:

- *Maximizing the CVR benefit*: On well behaved and lightly loaded circuits, there may be additional opportunity to lower voltage and increase CVR benefit. However, under centralized schemes it can be difficult to identify and capture this opportunity.
- *SCADA Scan Rates / Measurements make closed loop control using external measurements a challenge:* Voltage regulation is generally achieved using local voltage feedback.

Distributed CVR Architecture:

For utilities with DMS/ADMS systems already in use, these centralized control systems represent major investments for utilities. As such, distributed architectures should be flexible enough to work with centralized systems while supplementing their capabilities with precise control. Conversely, a distributed architecture should also be flexible enough to support utilities that don’t have DMS/ADMS systems or who are looking to replace these systems with a more distributed approach.

A laminar or layered architecture as shown in Figure 1 allows for both peer-to-peer and hierarchical design patterns. In a hierarchical structure, the ADMS may decide when to enter CVR mode. However,

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[1] https://www.tdworld.com/grid-innovations/smart-grid/article/20965787/cvr-is-here-to-stay

rather than issue commands directly to the control devices, commands would be sent to the relevant Coordinator which would then be responsible for implementing the CVR solution.

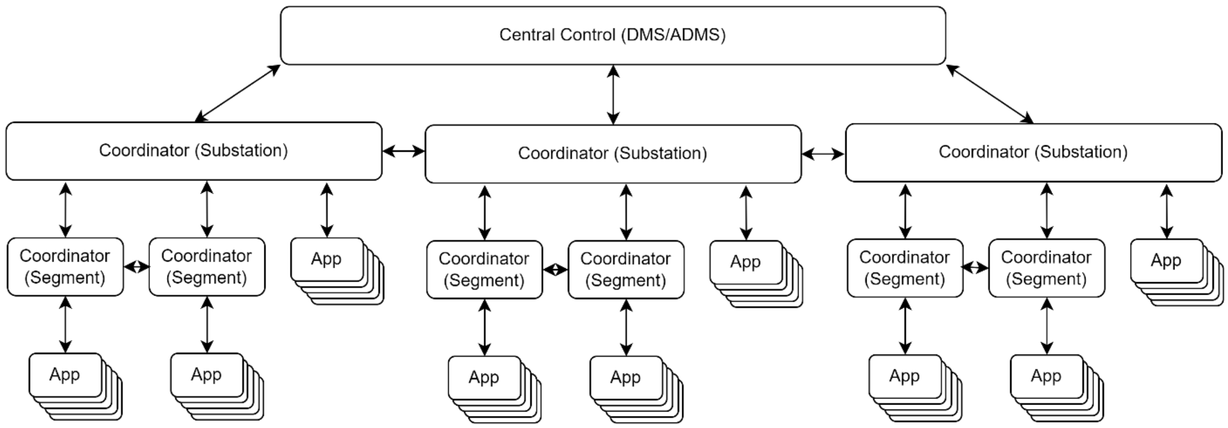

Figure 1 Example laminar architecture with central controller

The laminar architecture as shown above makes heavy use of "Coordinators". Coordinators handle information exchange both vertically and horizontally in the architecture. Additionally, they are responsible for coordinating the results of multiple applications and sending commands to devices in their jurisdiction. Note that in this architecture, segments may be defined as parts of feeders (e.g. between sectionalizing devices) or as entire feeders.

In addition to leveraging the investments in DMS/ADMS systems, a hierarchical laminar approach allows for incremental roll-out in trouble areas.

Distributed CVR Algorithm

When compared to a traditional, more centralized CVR approach, the distributed CVR application is different in several ways. The major differences are described below.

- The distributed CVR algorithm uses the publish-subscribe nature of Open Field Message Bus (OpenFMB) to monitor segment voltages.
- The application allows the user to select both the devices to participate in the CVR solution as well as the points to be monitored in the CVR objective

The objective of the CVR optimization is shown below.

$$Min\left(\sum \Delta V\right)$$

$$V_{Monitored} \geq V_{Limit}, \qquad \Delta V = \left|V_{Targer} - V_{Monitored}\right|$$

$$V_{Monitored} < V_{Limit}, \qquad \Delta V = \left|V_{Target} - V_{Monitored}\right| * K_p$$

Where

$V_{Monitored}$ is the voltage at the monitoring point

V_{Limit} is the low voltage limit

V_{Target} is the voltage target

AND K_p is the penalty factor for violating a voltage limit

The algorithm flow is shown in Figure 2. The primary objective of the CVR application is to maintain the voltage on the segment. However, laminar considerations (e.g. responding to neighbor requests) are included as a secondary objective. This laminar functionality may be enabled or disabled depending on end user requirements.

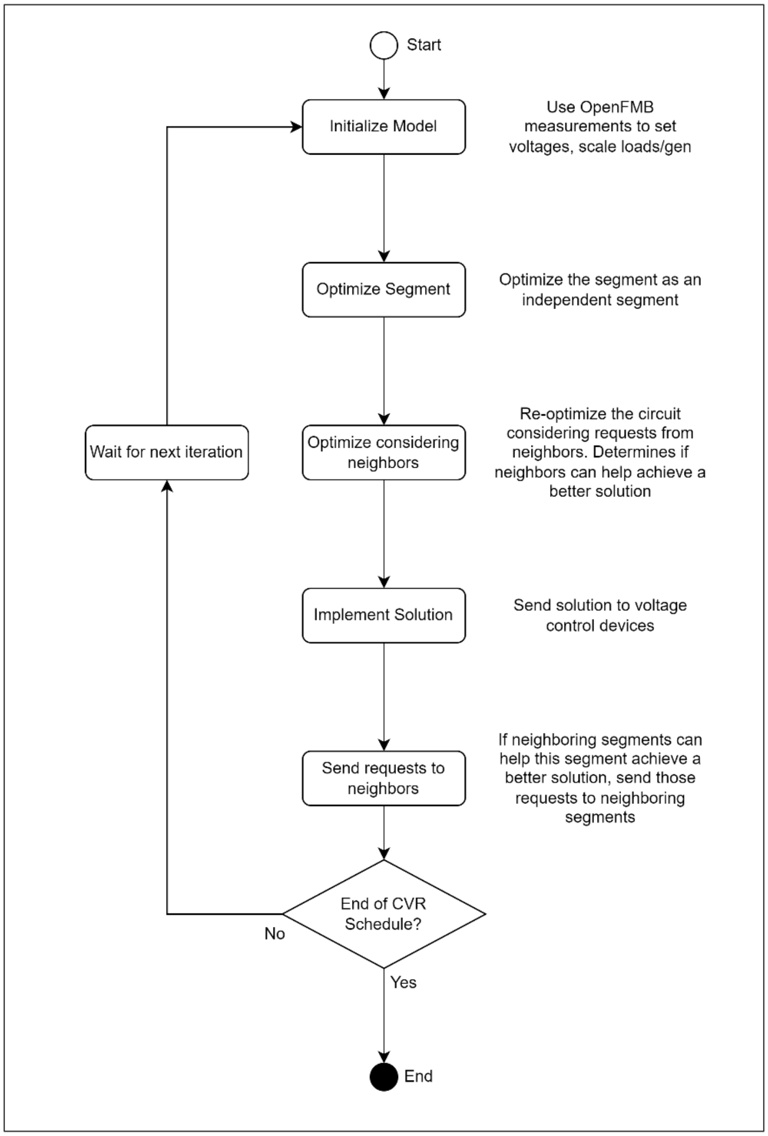

Figure 2 CVR application flow

A diagram of a representative application is shown in Figure 3. In this example, three single-phase voltage regulators and one capacitor bank are used for control. Additionally, two reclosers are included, one for start of segment measurements and the second for end of segment measurements. A DNP3 to OpenFMB adaptor is configured for each of these devices. The start of segment recloser is the segment boundary and is used to calibrate the model used by the CVR optimization.

In addition to the adaptors, an HMI application and a "Coordination Service" are deployed and attached to the OpenFMB NATS broker. The Coordination Service hosts the CVR application. In other scenarios, multiple applications can be hosted by the Coordination Service, and the Coordination Service will be responsible for determining the final solution delivered to the control devices. Note: All the software elements (adaptors, HMI and Coordination Service) are deployed as Docker containers on an industrial computer running Linux.

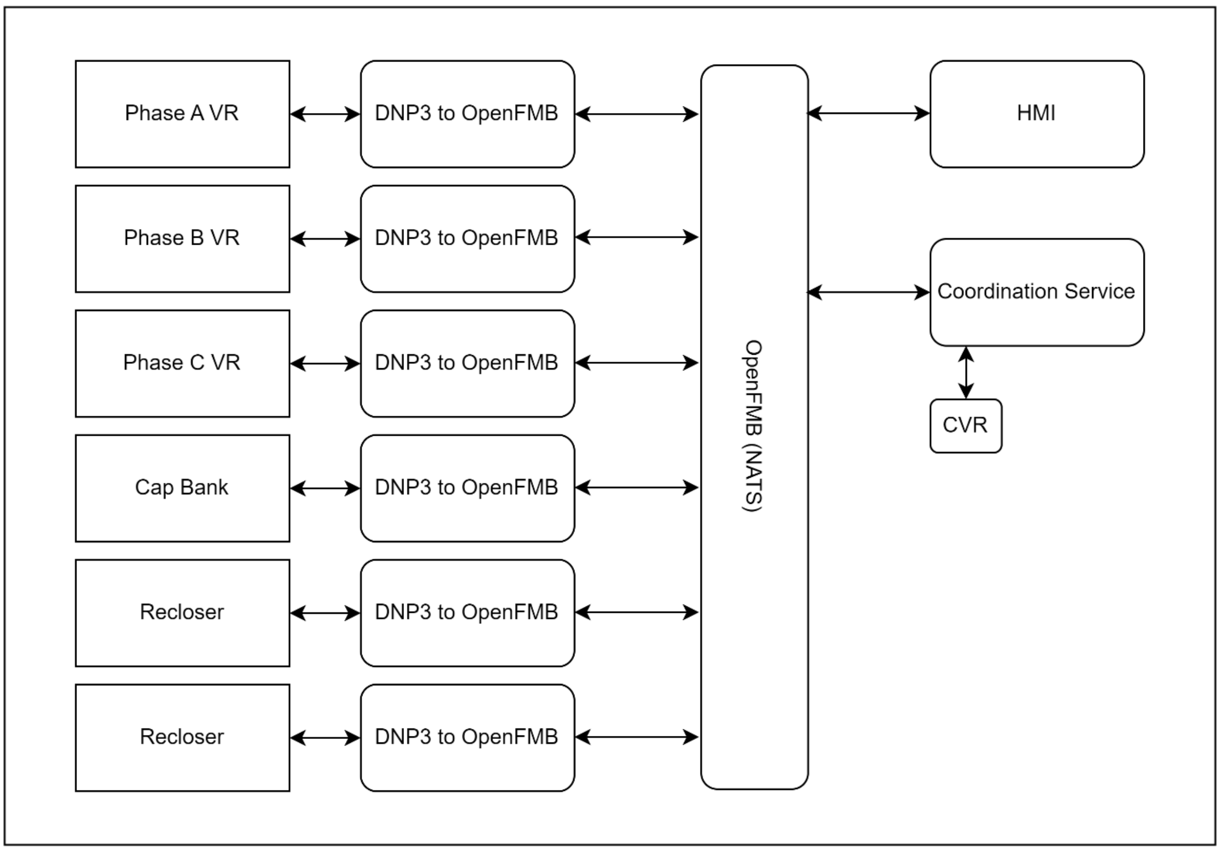

Figure 3 CVR deployment

Rather than rely on local measurements as in conventional CVR schemes, the CVR application utilizes measurements at the start and end of the segment to provide a more precise solution. The user may select any number of devices (provided they have OpenFMB translation) to monitor. This may be particularly useful in cases with high penetrations of distributed generation or edge of network grid optimization (ENGO) devices. Note the user may also choose to ignore voltage readings at the voltage regulating devices themselves.