CENTRALIZED VOLTAGE-VAR REGULATION IN DISTRIBUTION NETWORK

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ABSTRACT

This paper presents centralized voltage-var control solutions for capacitor banks, step-voltage regulators, load-tap changers, and reclosers. These systems include communications, a centralized automation platform, and software to control voltage profile and reactive power flow.

INTRODUCTION

Voltage regulation and reactive power (var) control in distribution systems can be performed using distributed or centralized methods. Distributed voltage-var (volt/var) regulations are performed locally by individual devices such as substation transformer load-tap changers (LTCs), line step-voltage regulators (VRs), and by switched capacitor banks based on the voltage and/or current data. Where volt/var corrections are required permanently, fixed capacitor banks are installed. Operational statuses of these devices are not continuously monitored; so, it is not possible to quickly respond to load changes in the distribution grid and no automatic reconfigurations can be performed to adjust for these load changes. As a result, optimal system conditions and feeder loading cannot be achieved. With a higher penetration of distributed generation (DG) (that may cause reverse power flow in distribution feeders), the impact on protection and control devices designed for radial systems becomes a serious issue since these devices may incorrectly operate or not operate at all (assuming, for example, that a feeder was reconfigured and no actions are taken).

Centralized volt/var regulation provides coordinated control of the system voltage and reactive power flow to achieve optimal distribution system operation. It is possible to simultaneously evaluate system conditions and perform adequate actions for LTCs, VRs, and capacitor banks. Actions such as preventing voltage violations, optimizing the loads peak requirements, and reducing power losses through voltage reduction result in economic benefits. For example, the system voltages can be reduced to minimum values without violating equipment operating limits and other constraints set by the user. This action enables utilities to meet the load requirements during high-demand conditions with the existing resources.

The centralized system presented in this paper is based on the Yukon advanced energy services platform (Yukon system) – a powerful software suite that is innovative, flexible, and scalable for all applications. The Yukon system automates the process of managing voltage magnitudes, reactive power, and power factor on the distribution system. The Yukon system analyzes (in real-time) feeder voltages obtained from capacitor banks, VRs, LTCs, from customer meters, and voltage sensors installed at various locations on the distribution system. These systems include communications, a centralized automation platform, and software to optimize voltage control and reactive power flow. Based on the assigned operational cost, the Yukon system sets a control period during which the measurement is performed. The operational cost is determined from the measurement data set compared against substation power factor and voltage magnitude targets. The objective is to minimize the operational cost by maintaining voltage magnitudes and power factor as close as possible to the target values.

At the beginning of each control period, the Yukon system simulates different capacitor bank switching status changes using an iterative process to determine if the system operation improves. Simulated changes in voltage magnitudes and power factor are compared to historical data archived by the Yukon system. If the operating conditions would improve by changing the status of a particular capacitor bank, the system will issue a command for that capacitor bank to change its status. Successful status change is confirmed via a new set of measurements. During each control period, if the Yukon system determines that no capacitor bank status change will improve the operating conditions, the system will analyze the measured set of voltages to determine if an LTC or VR operation would improve the voltage magnitude. If yes, the Yukon system issues a raise/lower command to the LTC or VR. After completion of the LTC or VR analysis, the Yukon system will wait until a new control period starts and a capacitor bank switching analysis is performed.

DISTRIBUTED VOLT/VAR REGULATION

The traditional method to improve volt/var conditions in distribution systems was to optimize placement of VRs and capacitor banks by computer software. In these arrangements, each device operates individually based on its local measurement data. Distributed volt/var control provides improvements such as reduced voltage violations, increased power factor, and reduced reactive power generation from the generators.

Disadvantages of distributed automation:

- Is not continuously monitored
- Does not adequately respond to changing conditions out on the distribution feeders – can incorrectly operate following automatic reconfiguration

– Operation may not be optimal under all conditions
– Cannot override traditional operation during power system emergencies
– May incorrectly operate when DG are present – reverse power flow from DG can cause standalone controls to believe feeder has been reconfigured

CENTRALIZED VOLT/VAR REGULATION

The centralized system presented in this paper is based on the Yukon advanced energy services platform (Yukon system) — a powerful software suite that is innovative, flexible, and scalable for applications. The Yukon system automates the process of managing power factor, voltage magnitudes, and reactive power on the distribution system. The volt/var management may be implemented encompassing hundreds of substations.

Centralized volt/var regulation (CVVR) provides improvements such as flattening feeder voltage profiles within the target limits; maintaining near-unity power factor (minimized losses); voltage change on demand (Demand response - conservation voltage reduction); prevents voltage limit violation; automated regulation coordination after feeder reconfiguration; and detection of voltage regulator and capacitor bank switching and operational problems.

For example, business cases for deployment of the Yukon system may be based on the fact that 1% voltage reduction results in 0.5% to 0.7% reduction in loading.

CVVR Principle of Operation

The Yukon system analyzes (in real-time) feeder voltages obtained from VRs, LTCs, capacitors banks, and voltage sensors positioned at various locations on the distribution system, and from customer meters (see Figure 1). Based on the assigned operational cost, the Yukon system sets a control period during which the measurement is performed. The operational cost is determined from the measurement data set compared against substation power factor and voltage magnitude targets. The objective is to minimize the operational cost by maintaining power factor and voltage magnitudes as close as possible to the target values.

At the beginning of each control period, the Yukon system simulates different capacitor bank switching status changes using an iterative process to determine if the operational cost improves. Simulated changes in power factor and voltage magnitudes are compared to historical data archived by the Yukon system. If the operational cost is improved as desired by a particular capacitor bank status change, the system will issue a command for that capacitor bank to change its status. Successful status change is confirmed via a new set of measurements.

During each control period, if the Yukon system determines that no capacitor bank status change will improve the operational cost, the system will analyze the measured set of voltages to determine if an LTC or VR operation would improve the voltage magnitude. If yes, the Yukon system issues a raise/lower command to the LTC or VR. After completion of the LTC or VR analysis, the Yukon system will wait until a new control period starts and capacitor bank switching analysis is performed.

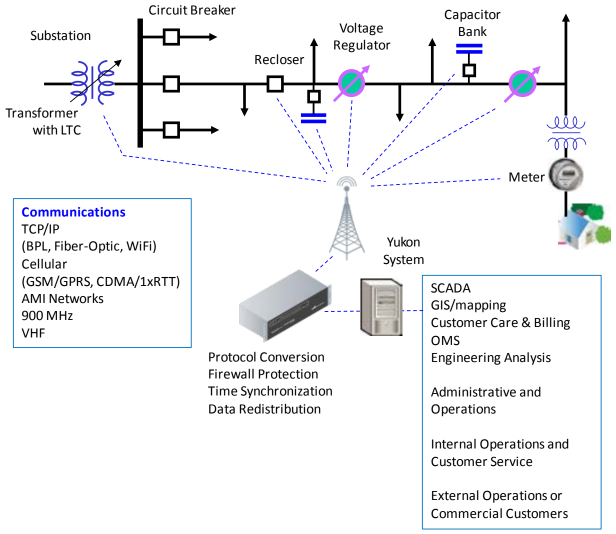

Figure 1 Example CVVR Network diagram

The power factor cost at the substation bus location is calculated from the difference between the measured power factor and the target power factor multiplied by the power factor weight. The voltage measurement cost is calculated based on the average and minimum voltage measurements multiplied by the voltage weight. Total calculated cost is the sum of the power factor cost and the voltage measurement cost. The Yukon system calculates the cost based on the real-time measurement data set and simulated status change of each capacitor bank, and compares the real-time cost with the estimated costs. If the lowest estimated cost associated with change in a capacitor bank status is less than the real-time cost, the system will issue command for status change of the capacitor bank.

Real and reactive power, current, and voltages are required in each control period. Voltages, current, and real and reactive power are measured at settable intervals such as 30-60 seconds. An LTC or VR tap position may change once every 15 minutes or a maximum of 50 times a day.

Controls support the identification of communication network failures and perform the transition to local automated control when a communication network failure has occurred. The Yukon system also supports loss of communications functionality. The state of communications is evaluated by validating device measurement data and device measurement data time stamps during each CVVR control period.

The CVVR supports a configurable percentage of stale data measurements. The Yukon system compares each device measurement date/time stamp to the present time. If the difference is greater than the specified configurable stale data time period, that particular measurement is marked as stale data. The Yukon system will tolerate a pre-defined number of stale device measurements based upon a utility specified configurable percentage. If for example, the 10% of the device measurements are stale, and the configurable percentage of stale device measurements is 20%, the Yukon system will continue to analyze and operate the devices to which it continues to communicate. However, if 30% of the device measurements are stale and the configurable percentage of stale device measurements is 20%, the Yukon system will disable automated control.

The Yukon system may be integrated with SCADA, DMS, or OMS systems to support the system reconfiguration. Also, less SCADA systems are required when the Yukon system is deployed.

Field Experience

This section summarizes field experience with the Yukon system implemented in the USA regulating three 12.47 kV feeders as shown in Figure 2. The first feeder was 30 miles long and included 6 capacitor banks. The second feeder was 8 miles long and included 5 capacitor banks. The third feeder was 0.5 miles long and no capacitor bank installed. These feeders are connected to a substation with a 15 MVA, 69 kV/12 kV transformer equipped with an LTC.

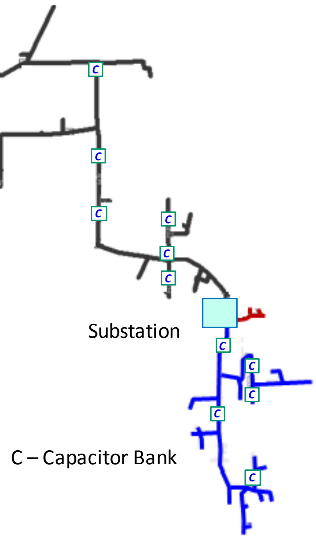

Figure 2 Feeders Regulated by the Yukon System

The system analyzes voltages at pre-defined locations (substations, capacitor banks, and other voltage monitoring points), then determines if any capacitor switching operations will flatten the voltage profile such as shown in Figure 3.

If all voltages are between the target ranges, the substation voltage is lowered. The extent of the voltage reduction depends on the utility load demand. However, voltage should not be reduced below the low-voltage limit (118 V in this case). Simultaneously, near-unity power factor is also maintained. The Voltage flattening solution may be overridden if the leading power factor would exceed the limits.

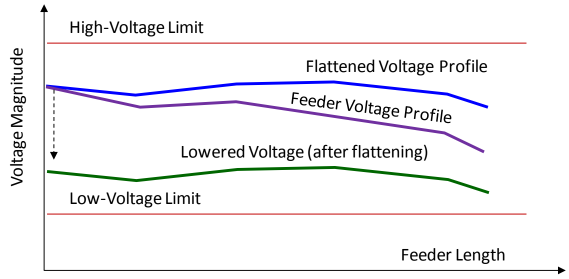

Figure 3 Flattening the Voltage Profile

Figure 4 shows actual voltage profile leveled and regulated by the Yukon system. Desired voltage regulation was performed by coordinated switching capacitor banks and LTC/VR control tap regulation. Figure 5 shows actual voltage profiles at the end of two feeders during one day of recording.

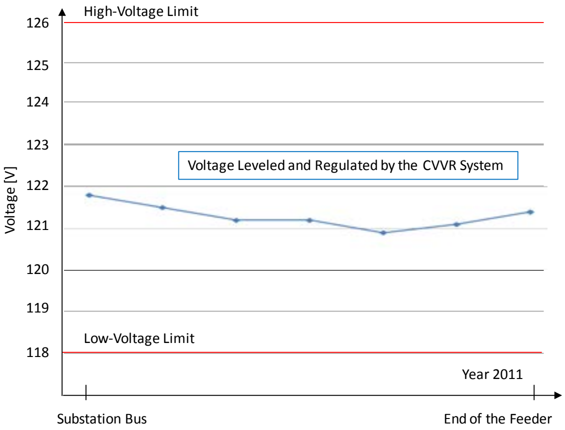

Figure 4 Voltage Leveled by the CVVR System

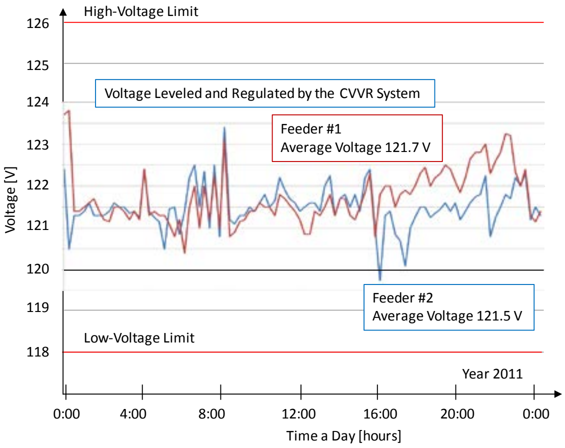

Figure 5 Voltage Regulation by the CVVR System (recorded at the end of two feeders during one day)

Figure 6 comparatively shows the voltage profile at the substation with and without the Yukon system, recorded during one week in April-May 2011. Figure 7 comparatively shows the voltage profile at the substation with and without the Yukon system recorded during one day. Figure 6 and Figure 7 show that the system voltage can be further reduced if required without violating the low-voltage limit.

CVVR Control Methodology

The utility adopted the following CVVR methodology:

a) Scan voltage magnitudes at sites such as the substation bus, capacitor banks, voltage regulators, and home meters

b) Determine if any capacitor switching operations will flatten the voltage profile – focus on flatness, not magnitude

c) Voltage regulation:
- If any voltage scanned is too high, lower LTC/VR tap
- If any voltage scanned is too low, raise LTC/VR tap
- If all voltages are between min and max, and substation voltage can be lowered without causing any voltage to be too low, then lower LTC/VR tap

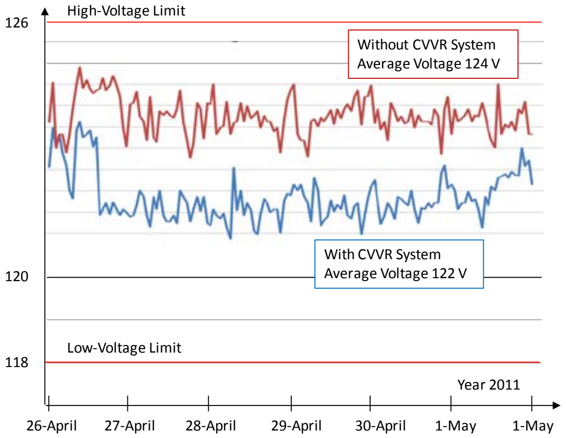

Figure 6 Voltage Regulation by Yukon System during one Week

Capacitor Bank and LTC/VR Controls

To operate capacitor banks and regulate LTC/VR controls remotely by the CVVR system, all controls are put in a manual control mode. However, if controls lose communication with the central CVVR system (loss of the communication signal; communication modem failure; unplanned shutdown of central control software) they are reverted to fully automatic mode after a pre-set time delay. In this way, devices perform traditional distributed volt/var regulation.

CVVR relinquishes control if loss of communication exceeds a pre-set number of devices for a specified period of time. However, if the number of devices that lost communication with the CVVR system is less that the pre-set number, the CVVR algorithm will run and make recommendations (taking into account remaining devices that have intact communication).

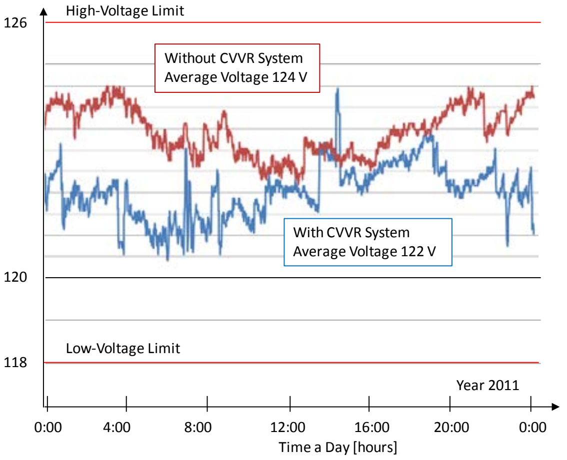

Figure 7 Voltage Regulation by Yukon System during one Day

Summary of Experience

a) Voltages were successfully leveled and maintained

b) Voltage reduction was successful. No violations of the voltage limit excursions

c) No customer complaints/inquiries related to power quality were recorded as a result of CVVR system operation

d) When the CVVR system was turned off, as a result multiple capacitor banks closed (based on the existing local control settings) which impacted the voltage profile along the feeder. After a pre-set time delay, voltages were regulated by the individual capacitor bank and LTC/VR controls.

e) Loss of communication for an extended period of time (such as CVVR relinquishing control) can also cause multiple caps to close at the same time. Here again, voltages are regulated by the individual capacitor bank and LTC/VR control operation after a pre-set time delay and pre-determined capacitor bank switching coordination.

REFERENCES

[1] Lj. A. Kojovic, C. Colopy, D. Arden, “Volt/Var Control for Smart Grid Solutions”, CIRED 2011, Frankfurt, Germany, June 9-11, 2011.

[2] “Voltage Regulators, CL-6 Series Control Installations, Operation, and Maintenance Instructions”, Cooper Power Systems, S225-11-1, February 2009.

[3] “CBC-7000 Series Capacitor Bank Controllers”, Cooper Power Systems, B1100-08303, October 2008.

[4] “Form 6 Recloser Control”, Cooper Power Systems, B280-08010, September 2008.

[5] CYME-Power Engineering Software Solutions, Cooper Power Systems, http://www.cyme.com/.

[6] Yukon-Integrated Volt/var Control Solutions, http://www.cooperpowereas.com/Products/CapacitorBankControl/CBCIntegratedVoltVARControl-IVVC.cfm.