

## COORDINATED VOLTAGE CONTROL AS A PART OF DISTRIBUTION MANAGEMENT SYSTEM

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### ABSTRACT

*Coordinated voltage control (CVC) can be used to mitigate the voltage rise caused by distributed generation (DG). This paper discusses implementation of CVC as a part of distribution management system (DMS). Practical issues regarding the implementation are covered and the benefits compared to a separate CVC system are represented. Also an example case is presented which shows benefits of CVC compared to passive network management. The operation of the studied CVC method has also been demonstrated in a real distribution network.*

### INTRODUCTION

In weak distribution networks the amount of DG is usually limited by the voltage rise effect. At present, voltage rise is usually mitigated using passive methods such as increasing the conductor size which can, however, be quite expensive. Also active voltage control methods can be used to mitigate the voltage rise which can in many cases decrease the connection costs of DG substantially. [1]

Active voltage control has been a subject of extensive research in the past decade and several active voltage control methods of different complexity and data transfer needs have been proposed in publications. The simplest methods are based only on local measurements (e.g. control of DG reactive power) whereas coordinated voltage control (CVC) methods use information about the whole distribution network when determining their control actions. CVC methods can determine their control actions based on simple rules (e.g. [2]-[4]) or use some kind of optimization algorithm (e.g. [5]-[7]). The most suitable method can be selected based on the structure of the distribution network, the number of components participating in the control, the objectives of control and the available measurement data and communication channels.

Thus, CVC algorithms for different kinds of situations already exist. The number of real implementations is, however, still very low. Several reasons for this exist:

- When active voltage control methods are taken into use the operational and planning principles of distribution networks need to be revised. This requires lots of work from the distribution network operator (DNO) and it might seem easier to use the same principles as previously.
- The current network planning tools are not capable of taking active voltage control into account.

- The current regulatory environment does not grant any benefits to DNOs that use active voltage control although active voltage control might decrease the connection costs of DG substantially. This holds true at least in Finland. Also, strict time limits for DG interconnection planning are set in some countries which rules out usage of voltage control methods that are only at the demonstration phase.
- Coordinated voltage control uses information about the state of the whole distribution network which requires measurements in the network. Traditionally, only few measurements have been available in distribution networks but installation of automatic meter reading (AMR) devices can enable more accurate state estimation also at the distribution network level [8].
- Most publications on coordinated voltage control concentrate on determining the control principles of the control algorithm and do not address the time domain implementation of the algorithm and practical issues in taking the algorithm in real distribution network use. This is particularly true for methods utilizing optimization algorithms.
- Only one commercial product that realizes CVC is to the authors' knowledge available [9].

Hence, some development is still needed for large-scale deployment of active voltage control. Demonstrations are needed to identify and solve possible problems in CVC algorithm utilization in real distribution networks. Also, the CVC methods should be implemented in such a way that taking them into use is as easy as possible to the DNO. Hence, it would be beneficial if the currently used network management tools could be used also for CVC. Development is also needed in the planning procedures and tools used by the DNOs [10] and also the regulation model should be dissected.

This paper discusses implementation of CVC as a part of distribution management system (DMS). The main purpose is to cover practical issues regarding CVC implementation and to represent benefits of CVC implementation as a part of DMS compared to a separate CVC system. Also an example case is represented. The example case compares passive network management to CVC and discusses costs of both network management methods. The main focus is not on simulation or demonstration results.

## DISTRIBUTION MANAGEMENT SYSTEM

The Finnish distribution management system combines static network data obtained from network information system (NIS) and real-time measurement data and control possibilities of SCADA. Static network information consists of network parameters stored in NIS database and load information obtained from hourly load curves. Network switching state and real-time measurement data is obtained from SCADA. SCADA can also be used to control network components. [11]

Because the DMS is integrated with NIS it is able to provide functions that are not available in a conventional SCADA. These include for instance real-time state estimation, fault location and automatic fault isolation and restoration. The DMS is equipped with a graphical interface and geographical background maps. [11]

## IMPLEMENTATION OF COORDINATED VOLTAGE CONTROL

Coordinated voltage control can be implemented as a part of DMS or as a separate controller. The commercial product GenAVC is implemented as a separate controller that contains state estimation and CVC algorithm [12]. The network model is incorporated in the controller and is static i.e. the switching state of the network is fixed.

In [13] CVC is introduced as a part of Aura-NMS that is an autonomous regional active network management system. Aura-NMS performs similar tasks as the Finnish DMS but is running on a distributed hardware platform. Every substation has its own hardware platform and these substation computers are connected to each other.

CVC could also be implemented as a part of a centralized distribution management system. In Finland, centralized DMSs are already used by most DNOs.

### Practical considerations

Several issues need to be taken into account when CVC is implemented.

The CVC algorithm should be such that it will always restore network voltages between acceptable limits within a predetermined time period if feeder voltage limits are violated. For example, convergence problems of optimization are not acceptable. Standard EN50160 [14] does not give strict time limits for under- and overvoltages but only limits for 10 min mean rms values are given. Hence, stricter time limits are set by the DNO. The algorithm should at least operate faster than DG's voltage protection to prevent unnecessary DG disconnection.

The inputs of the CVC algorithm can be either estimated or measured. The state estimation can be included in DMS or implemented as a part of the CVC algorithm and its accuracy has a crucial role in CVC.

When CVC is implemented to be operated in a real distribution network, also exceptional operational states should be taken into account. In practical implementations it is always possible that an important communication channel

fails and the inputs needed by the control algorithm are no longer available. The algorithm should be able to detect these situations and to function reasonably also in the absence of communication channels.

The interval in which the algorithm is executed has to be decided. In the viewpoint of CVC it would be beneficial to execute the control algorithm as often as possible but this is not practical in real systems. The execution interval should be such that the voltages are restored by control actions between acceptable limits within the predetermined time period. Also some kind of triggering system could be used to start CVC execution.

### Benefits of implementation as a part of DMS

As previously stated, one of the main barriers for large-scale CVC deployment is reluctance of DNOs to change their operational principles. Hence, taking CVC into use should be made as easy as possible to the DNO. The DMS is an everyday tool for DNO. Therefore, implementing CVC as a subprogram of DMS might encourage DNOs to take it into use. CVC would only be a new feature of DMS and not a completely new system. Also, the possible messages of the CVC algorithm to the operator would be available through DMS.

The Finnish DMS includes the network model and a state estimator. The state estimator can be used to obtain input data for coordinated voltage control and, hence, only the CVC algorithm needs to be added. No additional network modelling is needed when the CVC is taken into use and the network data is stored only in one place (NIS database). No need to maintain parallel data, therefore, exists.

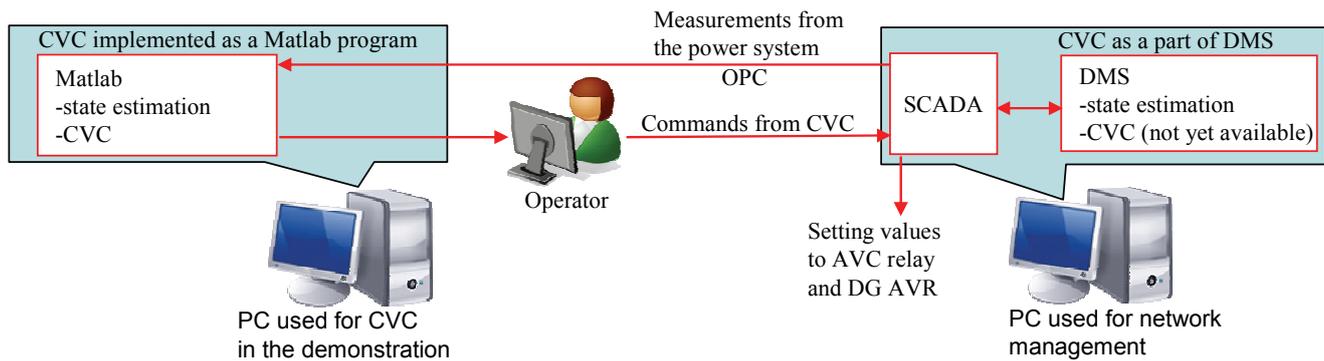
The DMS's network model is always at the same switching state as the real network which might not be the case when a separate control system is used. CVC implemented as a part of DMS can, therefore, be used also when the network switching state is unusual. This is often the case when the CVC is most urgently needed.

The DMS is integrated with SCADA and all control possibilities of SCADA are available also in DMS. Hence, CVC algorithm can give commands to network components directly from DMS.

## EXAMPLE CASE

In [15] operation of a CVC algorithm based on [4] was demonstrated in a real distribution network. The demonstration network experienced voltage rise problems without the CVC. The demonstrated CVC algorithm controls the set points of substation automatic voltage control (AVC) relay and DG automatic voltage regulator (AVR) and its objective is to keep all network voltages between acceptable limits. The algorithm contains also a restoring part that is used to restore DG power factor to unity always when possible and to normalize network voltages when the voltages in the whole network have remained in an unusually high or low level.

In the demonstration, the CVC algorithm was



**Figure 1. The arrangement used in the real network demonstration.**

implemented as a Matlab program that contained state estimation and CVC. Data transfer between Matlab and SCADA was realized using OPC Data Access. In the demonstration, the CVC algorithm was used only as an advisory tool and the network operator executed the control actions. OPC could, however, have been used also to transfer control commands to SCADA. The arrangement used in the real network demonstration is depicted in Figure 1 and the demonstration network is represented in Figure 2.

conducted in a university and it was not possible to code a new function to the commercial DMS. The operation of the Matlab implementation does not differ from the operation of the same CVC algorithm implemented directly as a part of the DMS.

The real network demonstration was successfully conducted. The CVC algorithm operated as expected and was able to keep network voltages between acceptable limits in all the demonstration cases. [15]

### Costs of coordinated voltage control

In the demonstration network, it was possible to take CVC into use without any device investments. All needed measurement data (substation voltage, feeder currents, generator real and reactive power and generator breaker status) was already available in SCADA. Also the substation AVC relay and DG AVR were suitable for the control algorithm i.e. their set points could be controlled from SCADA. [15] The only investment cost is the cost of the CVC algorithm which is quite difficult to estimate.

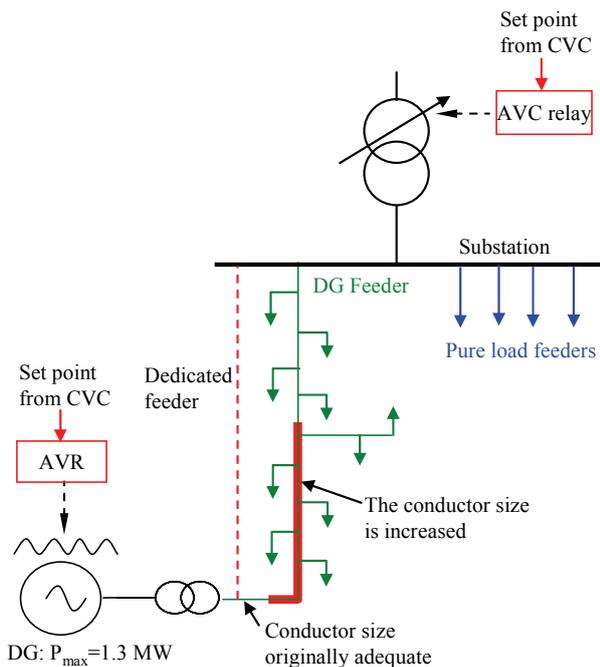
As the CVC algorithm affects reactive power flows in the network, it affects also network losses. In the demonstration network, losses increase. Also, CVC increases the number of substation main transformer tap changer operations and, hence, maintenance might be required more often. The costs of additional losses and tap changer operations can be determined using statistical planning method [16].

When CVC is taken into use for the first time, some cost is also associated with training of employees and development of network planning process.

### Costs of passive network management

The DG plant can be interconnected to the network also without alteration of network operational principles. In this case, DG is considered merely as negative load and the amount of DG is limited by two extreme loading conditions (maximum load/minimum generation and minimum load/maximum generation) [10]. If voltages are outside the acceptable range in either situation, the feeder is reinforced.

In the demonstration network, the set point of substation AVC relay is in the original state 1.03 pu and its deadband is 1.24 %. Therefore, substation voltage can vary between 1.0176 pu and 1.0424 pu. If the intention is to keep medium voltage network voltages in the range of 0.95-1.05 pu, only



**Figure 2. The demonstration network.**

The CVC algorithm can also be implemented directly as a subprogram of DMS. In this case, CVC implementation is even simpler because the state estimator already available in DMS can be used and only the CVC algorithm needs to be added. Also, the need for the OPC connection used in the demonstration no longer exists. Hence, in Figure 1 the PC used for coordinated voltage control (on the left) is no longer needed and the PC used for network management (on the right) executes also the CVC algorithm. In the demonstration, Matlab was used because the research was

a minimal voltage rise margin is in the original state available and interconnecting the 1.3 MW DG at the end of the feeder (see Figure 2) would in practice require building a dedicated feeder for the plant. The distance between the DG and the substation is almost 40 km.

In the demonstration network, it is possible to reduce AVC relay set point permanently to 1.00 pu in which case the substation voltage varies in the range of 0.9876-1.0124 pu if the deadband is not changed. With this setting the minimum voltage in the network is 0.9575 pu when the load is at its maximum value, the DG is disconnected and the substation voltage is at its lowest possible value. However, in minimum loading conditions with rated DG output and with substation voltage at the highest possible value the DG connection point voltage still rises to 1.094 pu which is substantially higher than the feeder voltage upper limit 1.05 pu. Restoring this voltage below 1.05 pu requires extensive network reinforcement. The conductor size has to be increased for a length of about 18 km (see Figure 2).

Hence, substantial investment cost is associated with passive network management in the example case. Network reinforcement has a reducing impact on network losses.

### **Selection of network management method**

The network management method should be selected using statistical planning [16] that compares total costs of alternative methods. The method's effect on voltage quality needs to be taken into account, too. Also, long-term planning issues have to be considered.

### **CONCLUSIONS**

Implementing coordinated voltage control as a part of DMS has many advantages: The Finnish DMS already includes a state estimator and, therefore, only the CVC algorithm needs to be implemented. The DMS's network model is always at the same switching state as the real network which might not be the case with a separate controller. Also, no additional network modelling is needed because DMS obtains its network model from NIS database. Additionally, the DMS is an everyday tool for DNOs. Hence, implementing CVC as a part of DMS might encourage DNOs to take it into use.

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