ACTIVE VOLTAGE CONTROL – FROM THEORY TO PRACTICE

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ABSTRACT

Active voltage control has been studied extensively in the past decade but only few real implementations have been realized although active voltage control can in many cases decrease the total costs of a distribution network and enhance the voltage quality. This paper discusses the barriers for active voltage control and also suggests measures to overcome these barriers. Also the development process of an active voltage control method is described.

INTRODUCTION

The connection of distributed generation (DG) to weak distribution networks is likely to cause voltage rise problems. The voltage rise can be mitigated using passive methods such as network reinforcement but this can lead to high connection costs of DG. Using active voltage control can in many cases decrease the connection costs significantly.

Active voltage control has been a subject of extensive research for years and various methods have been proposed in publications. The proposed methods range from simple methods based only on local measurements to advanced methods that use optimization algorithms to control all network components capable of voltage control. Although active voltage control methods for different situations have been developed, only few real network implementations have been realized. The penetration level of DG will, however, probably increase in the future. If all new DGs are connected to the network without changes in the operational and planning principles of the network, the utilization rates of the distribution networks will decrease and the total costs of the networks will be significantly higher than with using also active voltage control methods. Active voltage control can also be used to enhance the voltage quality.

ACTIVE VOLTAGE CONTROL

Distribution networks are traditionally considered to be passive systems that do not contain any controllable resources. Distribution network voltage is usually controlled only at the substation using the on load tap changer (OLTC) of the main transformer. If DGs or other active components are connected to the network, they do not participate in voltage control in any way. If voltage rise problems exist, they are solved using passive methods and the operational principle of the network is not changed.

Distribution network voltage can be controlled also by using active voltage control methods. Active voltage control can be based only on local measurements or utilize information on the state of the whole distribution network i.e. be coordinated. The reactive power of active resources can be locally controlled and also DG production curtailment can be based only on local measurements. These simple methods can increase the hosting capacity of a distribution network significantly. In many cases, however, they are not as effective as coordinated methods because coordinated methods can utilize all control possibilities of the network in an optimal way. [1] Coordinated voltage control (CVC) methods can be based on simple control rules (e.g. [2]-[4]) or utilize optimization algorithms (e.g. [5]-[7]). The most suitable active voltage control method can be selected based on the characteristics of the distribution network, the number of controllable components, the objectives of control and the available measurement data and communication channels.

BARRIERS FOR ACTIVE VOLTAGE CONTROL

Active voltage control can in many cases decrease the total costs of the network and enhance the voltage quality. Also, several active voltage control methods for different situations have been proposed in publications. Distribution network operators (DNOs) do not, however, usually consider active voltage control as a real option for network reinforcement and only few real network implementations of active voltage control have been realized worldwide. Several reasons for this exist. These barriers are discussed in this section.

Distribution network's operational and planning principles change

Active voltage control changes the operational and planning principles of distribution networks radically. The previously passive network becomes an active participant in voltage control and the number of components participating in the control usually increases. The previously used planning methods can no longer be used and the personnel will probably need training because many DNOs do not possess knowledge on active voltage control. Therefore, taking active voltage control into use for the first time requires lots of work from the DNO. Furthermore, when the distribution network is operated in the traditional passive way, the DNO owns all resources used in voltage control. Many active voltage control methods require also usage of customer owned resources (for instance control of DG reactive power) which is a completely new situation for the DNOs although common practice in transmission networks. Hence, taking active voltage control into use might seem too laborious for the DNO.

The reluctance of DNOs to change their operational and planning principles can be diminished by making the introduction of active voltage control as easy as possible to the DNO. Implementing active voltage control as a part of the currently used network management tools might be one way to encourage the DNOs to take active voltage into use. In Finland, distribution networks are managed using a distribution management system (DMS) that combines static network data obtained from network information system (NIS) and real-time measurement data and control possibilities of SCADA. If active voltage control would be implemented as a part of DMS it would only be a new feature of the DMS and not a completely new system. Also, the required changes to the network (e.g. additional measurements) affect the DNOs eagerness to take new control methods into use.

Established practices for making contracts with the owners of active resources would simplify the DNOs process when active voltage control is taken into use. The services of the active resources can be defined to be requirements for network interconnection or can be seen as ancillary services for which the DNO pays the resource owner.

One important factor that affects the DNOs decisions is naturally the regulation model.

Planning tools and procedures need development

The currently used network planning tools and procedures are not capable of taking active voltage control into account. At present, DG is considered merely as negative load in distribution network planning and the planning is based on two worst case loading conditions (maximum generation/minimum load and minimum generation/maximum load). DG is modelled as a passive negative load whose output does not depend on the state of the network. The planning procedure needs to be developed in such a way that active voltage control can be included and that different voltage control strategies and their costs can be compared.

Statistical distribution network planning is a method where load flow is calculated for every hour of the year using hourly load and production curves. As an output, statistical planning gives information on for instance network voltage level, network losses, the number of main transformer tap changer operations, the amount of curtailed production and the amount of controlled reactive power. Technical constraints of the network (i.e. voltage level) have to be taken into account naturally also in the statistical planning method. Alternative voltage control strategies can be compared by combining the investment costs and the results of hourly load flows. [8]

In Finland, distribution networks are planned using a network information system that combines technical, economical and geographical data and includes also network calculation functions. Network data is stored in databases and steady-state rms-values are used in the calculations. At present, NIS systems do not include adequate functionalities for modelling the operation of active resources. Active resources such as DG are modelled as loads with fixed active and reactive powers which is adequate in the presently used passive distribution network. When active voltage control is taken into use this approach cannot, however, be used because the outputs of active resources depend on the network state and are not constant. Hence, for voltage control studies the modelling of active resources should be extended to enable modelling of different control strategies. Also, models for different active voltage control methods (e.g. coordinated control of substation voltage) need to be added to the planning tools. When these models have been added to the NIS, implementation of statistical distribution network planning is quite straightforward because the NIS already includes load flow calculation functions and hourly load curves. Only the production curves need to be added.

Adequate measurement data might not be available

The simplest active voltage control methods operate based only on local measurements (e.g. operating DG in voltage control mode). Many methods require, however, data on the state of the whole distribution network which is not, at present, usually available. Adding extra measurements to the network only for voltage control purposes naturally increases the costs of active voltage control and also complicates the implementation process for the DNO.

Measurement data has been, previously, available only at the substation. Hence, although the Finnish DMS already includes a state estimator, the accuracy of the state estimate has not been very good. The amount of available measurement data is, however, constantly increasing as automatic meter reading (AMR) devices are being installed. The AMR measurements are not yet utilized in state estimation but they could be used to improve the accuracy of the estimate either by using the real time measurements as additional inputs to the state estimation algorithm or they can be used to review the load curves [9]. Utilizing AMR measurements instead of adding measurements solely for the purposes of voltage control decreases the costs of active voltage control.

The regulative environment

The current regulative environment, at least in Finland, does not encourage DNOs to take active voltage control into use. No benefits are granted to DNOs that use active network management methods instead of the passive approach although active network management can decrease the total costs significantly in many cases. The regulation model encourages DNOs to cut operating costs and to increase investments. Active voltage control usually increases the operating costs and decreases the investment costs and, therefore, is not encouraged by the regulation model. Large investments are not, however, in every case possible because the required capital for investments might not be always available. In these cases, active voltage control is an attractive option also in the current regulative environment.

In a deregulated electricity market the DNO is obligated to connect DGs into its network. In some countries, strict time limits for DG interconnection planning are set. This rules out usage of voltage control methods that are not previously familiar to the DNO. Hence, using the traditional passive approach might be the only alternative for the DNO. On the other hand, active voltage control can speed up the process of getting the network ready for DG interconnection because construction or reinforcement of the network usually takes more time than adding intelligence to its operation.

Active voltage control methods still need development

Active voltage control is still somewhat in its development phase and has not become an established way of action. Some methods, such as operating generators in voltage control mode, have been used in the transmission system for decades and do not need any further development for use in distribution networks. Also, the DG voltage regulators are usually capable of operating in voltage control mode. Only the DNOs' planning principles need to be developed to take these methods into use.

Many active voltage control methods (especially coordinated ones) are, however, still at their development phase. Most publications on coordinated voltage control concentrate on determining the control principles of the control algorithm and the operation of the algorithm is tested using only load flow simulations. The time domain implementation and practical issues in taking the algorithm in real distribution network use are usually omitted. These issues, however, need to be addressed before active voltage control can become a real option in DNOs' network planning.

Real distribution network demonstrations are needed before large-scale utilization of active voltage control is possible. The results obtained from demonstrations can be used to identify and solve possible problems associated with real distribution network implementation of active voltage control methods. They can also be used to convince DNOs that active voltage control is safe and can be taken into use relatively easily in many cases.

After the demonstration phase, the developed active voltage control methods need to be further developed to commercial products. When commercial products are available, taking active voltage control into use does not require extensive work from the DNO. At present, only one commercial product implementing coordinated voltage control is to the authors' knowledge available. It implements coordinated control of substation voltage [10]. No commercial products for more complex CVC methods are currently available.

EXAMPLE CASE: DEVELOPMENT PROCESS OF A COORDINATED VOLTAGE CONTROL METHOD

The development process of an active voltage control method consists of many steps. This section describes this process and uses the development of one coordinated voltage control algorithm as an example.

Determination of control principles

At the initial planning phase, the control principles of the algorithm are determined and the operation of the algorithm is tested using load flow simulations. Most publications on CVC concentrate only on this phase. However, the following phases cannot be omitted if the objective is large-scale utilization of the developed voltage control method.

The example CVC method controls substation voltage and DG reactive power based on voltages of the whole distribution network. Its operational principle is represented in [4].

Time domain simulations

After the initial planning phase, the algorithm is modified to time domain format and time domain simulations are conducted. These simulations are carried out to make sure that no adverse interactions such as hunting appear. These interactions are not visible in the steady state load flow calculations because in load flow simulations it is assumed that all control actions are executed instantly.

In many cases, delays need to be incorporated into the control algorithm. These delays are determined at this development phase. In the example algorithm, substation voltage is controlled by changing the set point of the automatic voltage control (AVC) relay of the main transformer. Because a relatively long delay is associated with the operation of the tap changer and because its operation causes a transient voltage variation in the whole distribution network, the CVC algorithm should not change the AVC relay set point in case of a short-time voltage variation. Therefore, the CVC algorithm changes the AVC relay set point only after a predefined delay. [4]

If the network state requires multiple control actions, the voltage control algorithm should know the order in which the control actions are executed. Delays can be used to determine the order and also blocking signals can be used. Both approaches are used in the example algorithm [4].

Real time simulations

Real time simulations are used to verify the correct operation of the real implementation of the voltage control algorithm. Also data transfer between the algorithm and for instance SCADA can be realized and tested at this stage and the delays of algorithm execution are visible. Conducting real time simulations before demonstration in a real distribution network decreases the amount of work required in the demonstration because the data transfer can be tested beforehand and also some deficiencies of the algorithm might be noticed at this stage. Real time simulations enable also examination of cases that cannot be realized in the real distribution network demonstration.

In the example case, the time domain simulations were conducted using PSCAD simulations [4]. In PSCAD, all calculations are conducted before proceeding to the next time step and, hence, the CVC algorithm's output is always based on the measured values at the same time step. In reality this is not naturally the case because the algorithm execution takes some time and also the measurement values are not updated continuously.

The real time simulations were conducted in Real Time Digital Simulator (RTDS) simulation environment where the RTDS emulated a real distribution network. The CVC algorithm was implemented as a Matlab program and the measurement values obtained from RTDS were given to the CVC algorithm through a real SCADA system. These simulations verified the operation of the Matlab implementation of the algorithm and the data transfer between Matlab and SCADA. Also the delay of the algorithm execution was visible. [11]

Real network demonstration

After the real time simulations, the operation of the active voltage control algorithm is demonstrated in a real distribution network. At this stage, the problems that may arise in real network implementations are identified. The practical issues such as the need of additional measurements are discovered and the operation of the real implementation of the developed control algorithm is verified also in the real distribution network. The delays of data transfer are realistic and their effect on the operation of the algorithm can be evaluated.

The example CVC algorithm was tested also in a real distribution network. The real network demonstration revealed that some of the assumptions on for instance accuracy of measurements were too optimistic. Also the delays of the algorithm had to be altered because the automatic voltage regulator of the DG unit was slower than expected. [12]

In the example case, all development steps gave new information on the algorithm operation and were, hence, necessary.

Commercial product

Real network demonstration is the final phase in a research project but development is needed also after this. If commercial products are available, the commissioning of active voltage control is easier to the DNO and, therefore, it is more probable that DNOs will start to consider active voltage control as a real option in network planning.

CONCLUSIONS

Some development is still needed before widespread utilization of active voltage control in distribution networks is possible. Real distribution network demonstrations are needed to verify the operation of active voltage control also in practical applications. Also, development of distribution network planning tools and procedures is needed. Moreover, the regulative environment should encourage DNOs to utilize active network management when it is cost-effective.

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