FLEXIBLE VOLTAGE CONTROL IN DISTRIBUTION NETWORKS WITH DISTRIBUTED GENERATION – MODELLING ANALYSIS AND FIELD TRIAL COMPARISON

Maciej FILA  
Brunel University/EDF Energy Networks - UK  
maciej.fila@edfenergy.com

David REID, Peter LANG  
EDF Energy Networks – UK  
david.reid@edfenergy.com

Jonathan HISCOCK  
Fundamentals Ltd - UK  
jhiscock@fundamentalsltd.co.uk

Gareth A. TAYLOR  
Brunel University – UK  
gareth.taylor@brunel.ac.uk

ABSTRACT

The presence of distributed generation (DG) significantly changes the nature of a distribution network. The original design of distribution networks does not consider bi-directional power flow, voltage rise and other issues associated with the operation of DG. Consequently standard operational strategies are unable to deal with those challenges [2] and novel schemes are required. SuperTAPP n+ is one of the innovative voltage control schemes to support DG in the distribution networks [1, 3]. This scheme, based on estimation techniques, uses only local measurements to adjust the voltage target at the primary substation in order to optimise the voltage profile of the network and increase its ability to accommodate DG. This paper presents a SuperTAPP n+ trial and its outcome in part of the EDF Energy distribution network. The paper also demonstrates simulation software which allows planning engineers to determine whether a SuperTAPP n+ scheme could resolve voltage rise issues associated with the presence of DG or increase the amount of DG in a particular network. Results from both the simulation software and the SuperTAPP n+ field trial, presented in this paper, give an opportunity to validate the modelling process and software simulation tool as well as providing evidence of effectiveness of the scheme in distribution networks with DG. Finally, suitability of the SuperTAPP n+ scheme and its applications are discussed and detailed conclusions are presented.

INTRODUCTION

Distribution Network Operators (DNOs) design, operate and maintain their networks in order to provide a reliable and efficient connection to all customers with a high quality of supply. Historically, the state of the distribution networks was determined predominantly by the load demand. To comply with the regulatory requirements and statutory limits stated for the UK in [2], DNOs adopted the approach based on “worst network conditions” scenarios. In order to ensure that the network is maintained within statutory limits two extreme load conditions are considered: minimum (no load) and maximum load demand. Similar practice has been adopted by DNOs when DG is connected to distribution networks. In such a situation four extreme network conditions are considered:

- minimum load and no generation,
- minimum load and maximum generation,
- maximum load and no generation,
- maximum load and maximum generation.

This passive approach guarantees operation of the system within statutory limits and compliance with contractual obligations. However, it can significantly limit utilization of the network even though any violation of the constraints can be very sporadic. As a result the amount of DG which can be connected to the network is considerably constrained. Alternative approaches to operation of the distribution networks are based on active network management (ANM) techniques. They comprise of continuous monitoring and control of the system in order to take pre-emptive actions to maintain the system within normal operating parameters. These solutions can significantly increase the ability of the network to accommodate DG in a secure and efficient manner.

Presence of the DG affects the voltage profile in the system and an unacceptable voltage rise at the point of common coupling (PCC) is identified as the main factor preventing the integration of DG to 11 kV networks [6]. The voltage level at the PCC depends on the output and power factor of the generator as well as load conditions on the network.

Active voltage management schemes can require significant investment costs and as a result the connection of the DG may be suspended or its output constrained.

In order to increase the ability of the system to accommodate DG and improve voltage control in distribution networks, several active voltage management techniques were proposed and have already been available or at the trial stage.

ACTIVE VOLTAGE MANAGEMENT IN DISTRIBUTION NETWORKS

The objective of the active voltage management schemes is to maintain the network voltage profile within the statutory limits whilst maximising the output of the DG.

In order to achieve these objectives, novel techniques such as distribution state estimation or remote measurements can be used along with the control of various parameters which include: - real power output of the generator, - power factor of the generator, - voltage level at the primary substation.
A range of active voltage management schemes have been proposed with a variety of complexity and effectiveness. The simplest schemes control a single parameter while the more complex are based on the coordinated management of the various techniques and parameters. However, due to the low observability of the distribution network and lack of monitoring equipment the installation of remote terminal units at critical points on the network and communication channels back to the control unit is required in order to take full advantage of ANM techniques. This can increase installation and operation costs of the scheme.

One of the coordinated voltage control techniques for active network management is SuperTAPP n+. The main characteristic of the scheme is that it uses only local measurements and does not need remote measurements in order to estimate the voltage profile of the network with DG.

**SUPERTAPP N+ NETWORK TRIAL**

**SuperTAPP n+ principles**

SuperTAPP n+ is described in detail in [1, 3] and general principles are outlined in this paper. The simple arrangement of the scheme is shown in figure 1.

![Figure 1. SuperTAPP n+ scheme arrangement.](image1)

SuperTAPP n+ actively controls the voltage target at the primary substation in order to maintain the voltage profile in the network within statutory limits and maximise the output of DG. Load drop compensation (LDC) voltage bias ($V_{LDC}$) and generator voltage bias ($V_G$) are used in order to determine the optimum voltage target. LDC voltage bias produces a necessary voltage increase in order to maintain all customers above lower voltage limit and is applied in proportion to the ratio of the actual load to the full load. Generator voltage bias provides voltage attenuation in order to maintain the voltage level at the PCC below the upper voltage limit and is applied in proportion to the output of DG [3].

An estimation technique is used to determine the output of the DG connected at a remote point of the feeder. This is accomplished by an additional current measurement on the feeder with DG and the resemblance of its load profile to the reference load profile. This resemblance is represented by the $E_{ST}$ factor which is calculated prior to the connection of the DG or when DG output is zero.

**Network Trial**

A SuperTAPP n+ trial has been set up in the EDF Energy distribution network at a primary substation in the south of England (Horsham area). The substation consists of three 132/11 kV transformers. Two of them are operated in parallel and the third transformer is used in case of an outage. The substation supplies the local load via thirteen 11 kV feeders. At a remote point on the network 5 units of DG are installed with the total capacity of 5 MW. Under normal network configuration the DG is fed from feeder 3, however an alternative connection can be provided through feeder 1 or 2. The simplified diagram of the network is presented in figure 2.

![Figure 2. Network diagram of SuperTAPP n+ trial.](image2)

Due to the voltage rise at the PCC above the upper limit of 6%, the output of the DG needed to be frequently restricted to 4 MW. Additionally, there is a proposal to increase the export capacity of DG. The novel SuperTAPP n+ scheme was identified as a feasible and cost effective solution in order to overcome voltage issues in the network and increase network capacity in order to maximise output of the DG.

The trial is designed to test the scheme as well as to obtain expertise and confidence with its performance and provide evidence of the effectiveness of the scheme in distribution networks with DG and voltage issues. The scheme consists of three SuperTAPP n+ relays, one for each transformer, which control on-load tap changers (OLTC) and the voltage target at the 11 kV busbars. It also includes three additional current transformers (CT) on feeders 1, 2 and 3 in order to estimate the output of the DG as shown in figure 2.

As the system is based only on the local measurements and estimation techniques, additional measurement units were temporarily installed to provide essential information about the state of the network. Real and reactive power meters were installed at the generator and several voltage measurement units were placed at the critical points in the network in order to verify voltage profile. These readings in conjunction with measurements from the SuperTAPP n+ relays are then used to evaluate the accuracy and efficiency of the scheme.
Assessment Software

Before an ANM technique is selected all of the available schemes need to be evaluated on the basis of their ability to increase network capacity, the conditions and time duration when the DG need to be constrained as well as installation and operation costs. This evaluation can be performed by the use of appropriate simulation software.

The SuperTAPP n+ assessment software is based on a load flow algorithm with the load and voltage drop estimation techniques, advanced AVC scheme and SuperTAPP n+ functionality. It uses a model of the network and historical SCADA data in order to estimate performance of the scheme in the particular network and in a certain period of time. The output of the software indicates the amount of DG which can be connected, a period of time when the scheme is able to accommodate the required amount of DG and a period of time when the DG export needs to be curtailed. It also indicates any possible violation of the voltage limits. Moreover, the software assists with the selection of appropriate relay settings and assessment of their effect on the performance of the scheme. The simplified model of the SuperTAPP n+ simulation is shown in figure 3.

RESULTS

Due to the fact that the generator output estimation technique in SuperTAPP n+ is based on the $E_{ST}$ factor it is necessary to investigate load profiles in the network and how this factor fluctuates under various load conditions. In a network with existing generation, calculation of the $E_{ST}$ factor can be problematic. With the provision of feeder current measurement and generator output data the assessment software estimates true load current in the network and calculates the actual load ratio. The graphs in figure 4 show the $E_{ST}$ factor over a one week period. The black line represents simulated load ratio while the red line illustrates the load ratio based on the trial measurements.

It can be noted that simulation results adequately represent the network conditions and the graph can be used to determine the $E_{ST}$ setting for the scheme. In an ideal situation the $E_{ST}$ factor would have a constant value. However, the load profile on the feeder with the DG does not always follow the exact pattern of the reference load profile. Any deviation of the $E_{ST}$ factor from the setting value produces an error in the calculation of the generator output. A comparison between the estimated and measured generator output is represented by the graphs in figure 5.

The estimated value of the generator output is satisfactory as it always corresponds with the measured value within the tolerance of +/-20%. However, these discrepancies, caused by the fluctuation of the $E_{ST}$ factor, affect the generator voltage bias and LDC voltage bias calculations. As a result the voltage target contains an error which needs to be taken into account in the performance evaluation and setting selection of the scheme.

The aggregated value of generator voltage bias and LDC voltage bias corresponds to the required change in the voltage target as shown in figure 6.

![Figure 4. Comparison between simulated and measured $E_{ST}$ factor.](image)

![Figure 5. Comparison between estimated and measured generator output.](image)

![Figure 6. Generator voltage bias, LDC voltage bias and aggregated voltage bias in the scheme.](image)

It has been determined that the optimum performance of the scheme under current network conditions is with the LDC voltage bias settings at 3% and generator voltage bias setting at 2% when the generator is exporting its maximum installed capacity of 5 MW.
Before the generator is connected an assessment of the network capacity needs to be performed. The voltage headroom in the network indicates the amount of DG which might be accommodated. However, this cannot be completely utilised because SuperTAPP n+ is based on local measurements and estimation techniques and appropriate safety margins need to be employed. By the use of historical load measurements, network models and “worst load distribution” techniques, the simulation software estimates the amount of DG which can be supported by the SuperTAPP n+ scheme. Figure 7 shows the software assessment results of the performance of the scheme when 7 MW of DG is connected. This is the maximum DG which can be accommodated on this network using SuperTAPP n+.

The graphs show estimated maximum and minimum voltage levels in the network. It can be noted that the scheme is able to maintain the voltage profile within the operating limits of +6% at the PCC and maximum voltage drop of -5%. However, occasional restrictions of the generator due to high voltage may occur.

CONCLUSIONS

In order to be able to accommodate an increasing amount of DG in distribution networks new voltage control techniques are required. The SuperTAPP n+ scheme has been developed to solve voltage rise issues at the PCC and increase the capacity of a network with DG.

The simulation software and trial in EDF Energy’s distribution network demonstrate that results obtained from the simulation software correspond to the actual performance of the scheme. Hence, the software can be used to analyse the load profile of the network, select appropriate relay settings as well as evaluate the efficiency of the scheme for a particular network.

The SuperTAPP n+ trial is currently in the appraisal stage and only shows the potential actions. However, the outcome from the trial provides evidence that the scheme is able to accurately estimate the generator output and calculate the required voltage target in order to maintain the voltage profile within the limits and support DG output.

The next stage of the trial is to allow the scheme to actually manage the voltage profile in the network. In addition, new techniques to improve the generator output estimation process and LDC technique will be tested.

REFERENCES