A DIRECT COMPARISON OF VARIOUS ACTIVE NETWORK MANAGEMENT TECHNIQUES

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ABSTRACT

Over the past decade a number of academic and commercial organisations have been developing techniques to actively manage the existing distribution system to avoid costly infrastructure upgrades. This paper discusses and evaluates five different types of Active Network Management technique. A brief description of each technique is presented. The comparison takes into account the amount of additional Distributed Generation and demand that could potentially be connected to the existing distribution network with no significant infrastructure improvements. Communication and monitoring equipment requirements are assessed and finally the total cost of implementing such schemes is evaluated.

INTRODUCTION

Increasing quantities of Distributed Generation (DG) are being connected to the distribution network at a rapid rate. Distribution Network Operators (DNOs) in partnership with industry and academia are researching methods of actively controlling the grid to save costly infrastructure alterations. Active Network Management (ANM) is believed to be an effective method to permit additional DG connection without costly infrastructure enhancements. There are several problems which need to be addressed, which include: power flow management; steady state voltage control; and automatic restoration. For ease of comparison this paper will only consider the problem involving Steady State Voltage Control. When connecting any type of generation to the distribution network, one major issue encountered is a variation in voltage and particularly, voltage rise. This voltage rise may be outwith the statutory limits which DNOs are required to comply with. A range of papers have been dedicated to this subject and several novel techniques are described in the next section.

ACTIVE NETWORK MANAGEMENT

AuRA-NMS is an autonomous regional active network management system which has been developed in the UK through a partnership involving several UK Universities, EDF Energy, Scottish Power and ABB [1]. The AuRA-NMS is a centralised ANM technique that requires monitoring equipment throughout the network in which it controls. A case-based reasoning (CBR) approach was developed by the University of Strathclyde and Durham University for voltage control [2]. CBR is said to have potential for a flexible and extensible approach to coordinated voltage control [2]. As an artificial intelligence system, CBR aims to solve a problem by re-using saved matched cases located in a case base library. The closest matched solution is tested online for success. If effective this result is then implemented into the control strategy. More details can be found in papers [2], [3] and [4].

The SuperTAPP n+ automatic Voltage Control Relay (VCR) is a decentralised scheme that has been tested on the UK distribution network. It is based on local measurements taken at the substation integrated with a state estimation system [5]. The current introduced into the network from the DG is estimated by the VCR; this is summed with the supply current measured at the feeders within the substation to provide an estimate of the total load. This value is used to set the Load Drop Compensation (LDC) and the set point voltage [6]. If voltage rise occurs due to increased amounts of DG, it is vital that the voltage is reduced. The estimated DG current is used to decrease the set point voltage. In depth details can be found in [6] and [7].

Optimal Power Flow (OPF) has potential as a centralised ANM technique. Information gathered at local nodes is used to solve the OPF problem. The OPF minimises DG curtailment to allow more generation to be connected to the network. Paper [8] explains the use of the OPF analysis to minimise curtailment within the thermal and voltage constraints. The role of the algorithm in [9] is to take full advantage of the total active power of controllable DG plant. Paper [10] demonstrates a Receding-Horizon OPF which uses network measurements and forecast data to allow network control decisions to be implemented with a degree of confidence that it won't lead to inappropriate control switching.

Now a commercial product in operation in the UK, GenAVC is a balance between a centralised and decentralised ANM scheme. The purpose is to maintain the voltages of the 11kV feeders connected to the primary transformer within the prescribed statutory limits [11]. Information collected from key remote measurement units (RMUs) forms the inputs to the GenAVC state estimation [12]. This computation obtains as true an image of the actual system state as possible without having to over provide RMUs which are costly and require additional communications.

Model Predictive Control (MPC) is an advanced process control method that originally was used in the process industries. More recently it has been incorporated into power system modelling to actively control the distribution network. MPC is described as an optimization based control scheme that uses dynamic modelling to determine control inputs that generates the best predicted performance of the network over a prediction horizon [13]. The theories and formulations of MPC are explained in [14].

BOOSTING DG CAPACITY

AuRA-NMS

The AuRA-NMS CBR voltage control technique has been tested on a real-time (RT) power network simulator. The test network consisted of a simplified model of a UK 40 busbar 11kV radial network incorporating two DG schemes and three transformers. A detailed description of the test network and testing procedures can be found in [15] and [3]. Figure 1 displays the voltage excursion at the DG locations and it can be seen that the CBR technique identified the voltage excursion and implanted a series of control strategies. These strategies are able to establish and instruct a set of control actions which are essential to removing an overvoltage and keep the voltage within statutory limits. This is possible by changing P and Q set points and controlling the on load tap changer (OLTC). Being able to control the voltage within the limits will allow additional DG and demand to be connected to the existing network without having to made substantial infrastructure upgrades. The actual figures for the volume of extra DG and demand that can be connected have not been published. Due to the amount of data sent back to the control algorithm it is thought to be fairly high.

SuperTAPP n+

A trial of the SuperTAPP n+ relay was carried out on the EDF Energy distribution network at a primary substation in the Horsham area in the south of England [16]. Results indicate that a maximum of 7 MW of DG could be connected utilising the SuperTAPP n+ relay, compared to the original 5 MW capacity. Due to the SuperTAPP n+ relay using local measurements and estimation techniques the full voltage headroom cannot be completely used as suitable safety limits need to be observed.

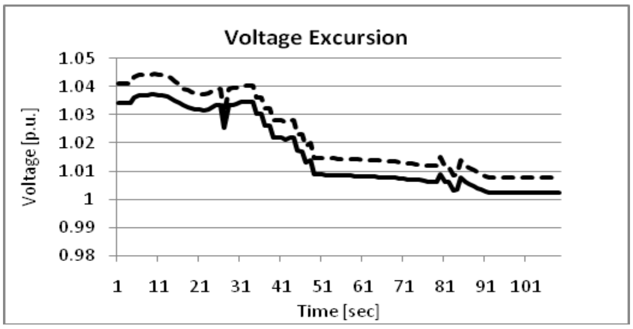

Figure 1 – Voltage excursion at DG1 (solid line) and DG2 (dashed line) busbars (limit at 1.03 p.u) [15].

OPF Approach

Simulation of the OPF approach was carried out on the 33 kV UK GDS EHV1 model network with multiple DG and resources, detailed data and procedures for testing on the network can be obtained in [17]. Utilising the control strategies of coordinated voltage control (CVC), adaptive power factor control (PFc) and energy curtailment as a last resort, headroom for connecting additional DG and demand is substantially increased. From results in [17] exploiting CVC, PFc and curtailment, the capacity of DG can be increased by three times the capacity versus passive management.

GenAVC

Testing of the GenAVC ANM system within the UK distribution network was achieved at the Steyning 33/11kV Primary Substation in West Sussex [18]. The results indicate that an existing landfill gas generator was able to increase output from 2 MW to 3 MW thus demonstrating a 50% increase in generation without any alteration to the existing distribution system [11], [17].

Model Predictive Control

Paper [19] demonstrates that the MPC strategy can achieve load shifting, plus using suitable predictions an improved matching of demand and supply can be accomplished. This will allow for more DG to be connected to the distribution network when demand and generation is high utilising the existing headroom that would otherwise be unexploited. However, when demand is low the MPC algorithm will continue to control the voltage levels using the power factor at the DG and finally curtailment of energy. The capacity benefit is not published but might be expected to be comparable to the OPF technique.

MONITORING AND COMMUNICATIONS

AuRA-NMS

Measurements are recorded and transmitted to the central controller from critical points throughout the network the ANM scheme controls. The critical points include DG connections and all main feeders. The measurements allow the CBR technique to perform the comparison of case features. It is assumed in [15] that the testing network has the necessary instrumentation. The communication requirements will depend on the type and location of the network. In urban locations an Ethernet interconnected in a local area network could be used which is relatively inexpensive, commonly available and allows high-speed data transfer and is, therefore, the preferred option. Rural installations will benefit from using a General Packet Radio Service (GPRS) router which enables communications using the GSM mobile phone network. This option is more expensive as ongoing costs are charged for transferring data over the GPRS network.

SuperTAPP n+

The SuperTAPP n+ relay uses existing Voltage Transformers (VTs) and Current Transformers (CTs) which are located in most substations. Each medium voltage transformer is measured and the data sent back to the relay via a CAN communication bus [20]. The only other monitoring equipment required is current measurements on the feeder which has DG connected to it. This is also local to the substation.

OPF Approach

In [9] a Supervisory Control and Data Acquisition (SCADA) system is proposed for measuring local data taken at key local nodes throughout the network, particularly DG sites and at other troublesome nodes. Remote Terminal Units (RTUs) take the local measurements and convert the signals to digital data, which is sent usually by telephone lines to the control centre.

Gen AVC

Measurements of both voltage and current are logged via a data acquisition unit. These values are transmitted to a control unit which is located in the primary substation via an Ethernet interconnected local area network connection if available. However, in remote parts of the country a GPRS router might be required which is more expensive. Also there is more vulnerability to the ongoing data transfer due to low redundancy within rural local GSM network coverage, signifying the possibility of loss of signal and data transfer. A detailed insight can be found in [11].

Model Predictive Control

Line flow, bus voltage information and switch status is measured by phase measurement units (PMUs) and the data is collected by Phasor Data Concentrators (PDCs) as described in [21]. The PDCs send the information via existing Ethernet interconnected local area network communication connections where available.

TOTAL COST

The cost of communications and monitoring equipment is one of the most significant factors in ANM alongside the development and upkeep of the software. The AuRA-NMS scheme is expected to be the most expensive option owing to the quantity and location of measurement apparatus required throughout the network for the control strategies to be implemented. In comparison the SuperTAPP n+ relay is the least expensive due to utilising existing measurement devices such as CTs and VTs within the local substation. The other three techniques have a range of outlays depending on the quantity of monitoring and therefore the type and volume of communication requirements. Table 1 demonstrates the level of total cost of each scheme alongside the amount of communications and monitoring equipment. The table also identifies the volume of additional DG/demand that could potentially be connected to the network.

DISCUSSION

Comparison of several different ANM techniques demonstrates that additional DG and demand can be connected to the network if more sophisticated control approaches are utilised. However, more information is required from within the network with communication and monitoring equipment bringing in associated costs. More DG can bring both beneficial and detrimental elements to DNOs, due largely to infrastructure investment. Depending on DG type, quantity and location, network upgrades could be deferred.

DNOs have a decision to make: to spend money on ANM methods that can actively control the network and make it much easier to manage or to upgrade the infrastructure that will allow additional DG and demand to be connected in the future. What is essential is that robust cost benefit evaluations are carried out to ensure that the implications are understood across the whole life cycle.

Table 1 – Classification of requirements and benefits

Type of ANM	Additional DG/Demand	Communications/Monitoring	Total Cost of Scheme
AuRA-NMS	Medium -High	Medium - High	High
SuperTAPP n+	Low	Low	Low
AC OPF Approach	Medium - High	Medium - High	High
GenAVC	Low – Medium	Low - Medium	Low – Medium
Model Predictive Control	Medium	Low – Medium	Medium

CONCLUSIONS

This paper presents five different ANM techniques which are either commercialised or in final stages of field testing. A comparison considered the amount of additional DG and demand that could potentially be connected to the network. Communication and monitoring requirements alongside the total cost for implementing each ANM was discussed.

ACKNOWLEDGEMENTS

This work is funded by an EPSRC Studentship and the School of Engineering, University of Edinburgh.

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