ASSESSING THE IMPACT OF ACTIVE POWER FLOW MANAGEMENT ON SCADA ALARM VOLUME

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ABSTRACT

This paper presents some of the results of studies into the impact of extending the connection capacity available for distributed generation (DG) on the volume of SCADA data generated in an actively managed distribution network. The number of voltage alarms, overload alarms and tap changer operations are recorded to permit further investigation and discussion of results. The analysis is performed through the application of an Active Power Flow Management (APFM) scheme to a generic distribution network. A set of tools developed at the University of Strathclyde – as part of the United Kingdom Generic Distribution System project – are used to investigate the impact of the implementation of APFM. The results of the study show that in certain conditions, increased DG connections enabled by active management can reduce the number of voltage alarms and tap changer operations.

INTRODUCTION

Renewable energy sources are playing an increasingly important role in the international drive to reduce emissions from the electricity generation sector. The renewable resource in the UK (as in other countries) is located in remote areas serviced by low capacity distribution networks. Connecting distributed generation (DG) to these networks poses a technical and economic challenge to the generator developer and distribution network operator (DNO). The traditional connection solution of reinforcing the network acts as a financial barrier to many DG connections. Active management is now emerging as an economically viable alternative to network reinforcement. This paper considers the impact of an APFM scheme on under and over voltage alarms, thermal limit alarms and the number of tap-changer operations. A case study is presented to illustrate the impact of APFM on the above metrics over a 24hr period of high load demand and high generation output. The case study utilises a set of analysis tools developed at the University of Strathclyde through the DTI Centre for Distributed Generation and Sustainable Electrical Energy. The tools are part of the United Kingdom Generic Distribution System Project, which supports the modelling and analysis of UK-style distribution networks.

ACTIVE POWER FLOW MANAGEMENT

The APFM discussed in this paper has been the focus of much recent work by the authors [1, 2, 3, 4]. The scheme facilitates increased connection of DG units beyond the traditional limits adopted by distribution network operators (DNOs). If active management is to be effectively deployed then schemes that ensure network security for the DNO and a fair operating environment for the generator developer are required. In addition, the incentives for the implementation of active management need to recognise the risk of changing the mode of network operation as DG is integrated within the operation of the distribution network.

In the UK, it is common for DG connected to a distribution network to be limited to the Firm Generation (FG) capacity. This is the capacity of the network with the loss of the largest circuit plus the minimum load level. This approach imposes a pre-fault constraint on the level of DG that can connect. The capacity for DG connection can be extended beyond FG to Non-Firm Generation (NFG) capacity. The implications of which have been considered elsewhere [5]. The NFG capacity is equal to the total or intact network capacity during normal operating conditions, plus minimum load, minus the FG capacity. NFG operates freely during normal operating conditions but is intertripped in the event of a critical contingency, i.e. NFG are subject to post-fault constraints. In summary, the combined FG and NFG capacity is equal to the capacity of the network plus the minimum load.

The APFM scheme enables the connection of Regulated Non-Firm Generation (RNFG) (also referred to as New Non-Firm Generation (NNFG) in other work by the authors [1, 4]). RNFG units access capacity available due to load variation and reduced output from the FG and NFG units (below their contracted level). The RNFG units are trimmed or tripped based on real-time measurements of power flows on the distribution network. The scheme utilises a zonal approach to control, with different zones identified on the distribution network being coordinated or nested within each other. The approach taken by the APFM scheme to curtailing RNFG depends on the topology of the network and the location of power flow measurement(s).

MONITORING AND CONTROL OF ACTIVE DISTRIBUTION NETWORKS

Existing distribution networks in developed countries were designed in a ‘fit and forget’ fashion. This has resulted in a largely passively managed distribution infrastructure with little monitoring and control functionality. Existing distribution networks were not designed to accommodate a significant amount of DG. The communications and control requirements for the connection of a DG unit or implementation of an active management scheme can therefore represent a significant capital investment.

Many options exist for modifying the Supervisory Control and Data Acquisition (SCADA) system employed in distribution networks [6]. The gradual development of active networks according to sequential DG connections is suited to a cellular or zonal approach to monitoring and control [6]. The lack of available measurement points and the implications for active management has been discussed elsewhere [6]. State estimation incorporated within an active network control scheme, as identified in [7], is an example of how insufficient online monitoring can be compensated for within the design and operation of an actively managed network. The interaction with SCADA and DMS systems must be carefully considered.

Existing SCADA or Distribution Management Systems (DMS) do not trigger alarms in the fashion suggested within this paper, but as more active control of distribution networks and DG is adopted it will become necessary for the violation of limits to trigger active management control instructions.

UNITED KINGDOM GENERIC DISTRIBUTION SYSTEM PROJECT

The United Kingdom Generic Distribution System (UKGDS) project was undertaken through the UK DTI Centre for Distributed Generation and Sustainable Electrical Energy. The UKGDS provides a range of resources for the simulation and analysis of the impact of DG. The purpose of the UKGDS is to help facilitate the innovation that is essential to meet 2010 objectives, within the Centre, within DNOs and elsewhere in the academic, industrial and utility sectors. More information on the centre and the UKGDS project can be found at [8]. The UKGDS models and tools are extensively used in the studies in this paper.

CASE STUDY: MODELLING AND QUANTIFYING THE IMPACT OF APFM ON VIOLATIONS OF OPERATING LIMITS

The UKGDS-EHV1 network is representative of a typical radial distribution network in the UK, see Figure 1. The network consists of an equivalent swing generator representing the transmission network at 132kV, stepping down to 33kV circuits and 11kV busbars with amalgamated loads. The profiles for load and generation were obtained from the UKGDS project resources. The load on the UKGDS-EHV1 network varies from a summer minimum of 5.7MW to a winter peak of 36.89MW. For the purpose of this analysis DG units were added to the network as shown in table 1.

Table 1. Location, size, generator type and nature of FG, NFG and RNFG.

Category	Bus Number	Size (MW)	Generator type	Nature
FG1	307	7	Induction	Wind
FG2	1107	10	Synchronous	Gas CHP
FG3	314	4	Induction	Wind
FG4	1114	4	Induction	Wind
FG5	335	6	Induction	Marine
FG6	332	4	Induction	Micro Hydro
NFG1	1102	2	Inverter connected	Solar
NFG2	316	6	Doubly fed	Wind
NFG3	311	7	Induction	Wind
NFG4	323	3	Induction	Wind
NFG5	326	5	Doubly fed	Wind
NFG6	331	1	Induction	Wind
RNFG1	313	22	Doubly fed	Wind
RNFG2	314	2	Doubly fed	Wind
RNFG3	321	3	Induction	Wind

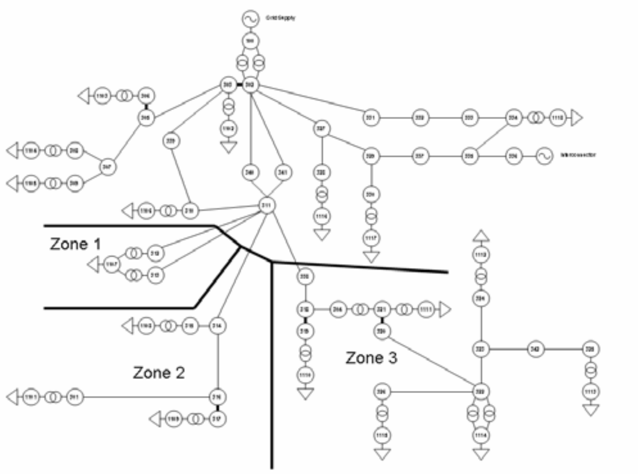

Figure 1. UKGDS-EHV1 network including active management zones.

Switched shunt reactors were added to buses with NFG in 2MVAR blocks until steady state network voltages were within +/-3% per unit limit. This resulted in reactors at bus 326 and bus 311, both with a reactive range of -4 MVAR to 0 MVAR. A dynamic reactive compensation device was added at bus 302 with a +/-10MVAR capability. The ability of such devices to alleviate short and long term voltage fluctuations has been noted elsewhere [9, 10].

Analysis Method

The studies involved temporal analysis, i.e. multiple load flow solutions covering a period of time. Loads and generators are specified in the scenarios initially as peak values. At each ½ hour time step, these values were adjusted according to UKGDS profile data. At each time step, the solved load flow solution was used to estimate the number of SCADA/DMS alarms that might be generated. In reality, the actual number of alarms generated will depend on: the type of SCADA/DMS system installed and its coverage, the steady state voltage limits employed by the Distribution Network Operator (DNO), the dynamic nature of the system and the statutory limits in the country of operation. However, for the purpose of these studies, the volume of alarms was assessed according to the following:

- An undervoltage alarm was recorded if the per unit voltage at a bus fell below 0.97.
- An overvoltage alarm was recorded if the per unit voltage at a bus rose above 1.03.
- An overload alarm was recorded if the MVA flow on a branch or transformer exceeded 100% of its capacity.
- A transformer tap change alarm was recorded if the tap position reached by the load flow solution changed from one time step to the next.

The load flow studies were performed in PSS/E version 29 using a combination of IDEV macros and IPLAN programs to automate the analysis and collate results quickly. PSS/E was used in these studies for load flow analysis. IDEV is the tool that allows the recording and manipulation of activities in PSS/E. IPLAN is a programming language that facilitates further simulation control and interfacing with PSS/E. The load flow solutions were reached using the fixed slope decoupled Newton-Raphson solution method with transformer taps being adjusted in steps. Successive solutions were found until the total system mismatch was less than 0.005MVA. The IPLAN program examines the load flow solution and extracts summary results into text files. It also produces a text file that lists the alarms being generated. This text file represents a much-simplified simulation of the alarm list that appears on the terminals of the SCADA/DMS system in control rooms. The text files produced were collated in spreadsheets and processed for presentation.

The DG units were added to the UKGDS-EHV1 network in the order represented in Table 1. The APFM scheme was then applied based on the thermal overload problems resulting from the connection of RNFG. This was done using a constraint analysis tool developed by the authors [4] and adapted for use with this network. Studies were performed of 24 hour periods with various combinations of high/low load and high/low generation output.

Case Study Results: High Load - High DG scenario

Due to the diversity in output between different FG, NFG and RNFG and the high electrical demand on the network, there were no overload alarms generated for this scenario. The highest measured loading was 80% of the MVA rating of a circuit, well within safe operating limits.

The impact of the reactive compensation equipment on the voltage alarms and number of tap changing operations will be investigated by running parallel simulations with and without the equipment online.

Voltage alarms

Figure 2 shows the impact of incrementally increasing the level of connected DG on violations of the +/-3% voltage limit. The figures show the number of alarms only, not the severity, as we are concerned with the number of alarms generated. The severity of the alarms is being considered in ongoing work by the authors. The results are displayed with and without reactive compensation equipment online.

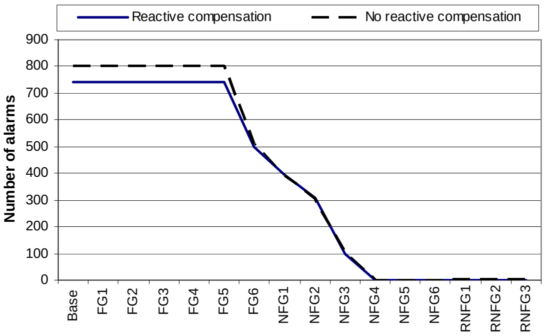

Figure 2. Voltage alarms during the 24 hour period of high load and high DG output for incremental DG

The number of voltage alarms remains constant as the FG units are added until the FG5 is connected at bus 335. This is due to the other FG being connected in areas where there are no voltage violations. The area of the network where the majority of voltage alarms occurred is identified as zone 3 in figure 1. The number of alarms during FG connection is reduced when reactive compensation is connected. This is due to better regulation of the voltage at the grid supply point and at key locations on the UKGDS-EHV1 network. As NFG and RNFG connect it can be seen that the introduction of reactive compensation has little or no impact on the number of voltage alarms generated. There are little or no voltage alarms during the 24hr period for DG connected from NFG4 and all of the RNFG connections.

Tap changer operations

Figure 3 shows the impact of incrementally increasing the capacity of DG connected on the number of tap changer operations in the 24 hour period considered. The results confirm the relationship identified in Figure 2; as the amount of DG connected increases there is a gradual reduction in the number of alarms generated, reaching a minimum level towards the connection of NFG4 at bus 323. The results are dependent on the placement of DG, which has been at the discretion of the authors. Figure 3 shows that the number of tap changer operations reduces from the addition of FG6 (at bus 332) onwards; however there is a brief increase in the number of operations when NFG6 (bus 331) and RNFG1 (bus 313) are connected. This suggests that the use of reactive compensation may not benefit the network at all times. Further investigation of this is required; considering different profiles, wider variations in load and DG output, different DG locations, consideration of the operational responses of generator excitation, tap changes and reactive compensation devices.

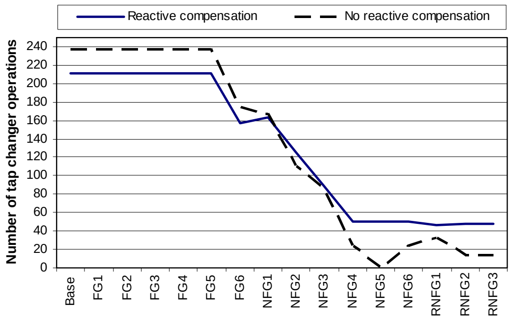

Figure 3. Number of tap changer operations during the 24hr period of high load and high DG output for incremental DG

Both Figure 2 and Figure 3 demonstrate that for the scenario considered the number of voltage alarms and tap-changer operations is reduced, with reference to the base case scenario. The base case scenario considers no DG connected with all loads fed from the transmission network, modelled in this case as an equivalent swing bus generator at bus 100.

FUTURE WORK

The results presented point to a reduction in the volume of alarms or alerts as the penetration of DG increases through the deployment of active network management. However, further analysis is required considering short-term fluctuations in DG output, interaction of DG control systems and reactive compensation devices and the settings employed on tap changing transformers. Future work will focus on:

- Developing an integrated modelling platform of active management technologies and SCADA/DMS.
- Asset utilisation and asset management implications for different strategies and scenarios.
- Extended time periods with higher load/DG variation.

CONCLUSIONS

This paper has presented some results of an ongoing study into the impact of the implementation of active management on SCADA/DMS systems. The studies presented showed the effects of incrementally increasing the level of DG from FG into NFG and RNFG, the RNFG being enabled by the implementation of an APFM scheme. The diversity in output from DG units and load variation resulted in the APFM scheme curtailing no RNFG units. As the level of DG connected increased, a trend of reducing voltage alarms and tap changer operations was identified. This can be enhanced through the implementation of reactive compensation, although it is clear that the reactive compensation may not benefit the network at all times. This will be investigated in future work through more detailed studies as the authors attempt to develop their platform for modelling active management schemes and the impact on SCADA/DMS.

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