AUTOMATION TO MAXIMISE DISTRIBUTED GENERATION CONTRIBUTION AND REDUCE NETWORK LOSSES

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ABSTRACT

This paper demonstrates the potential benefits of utilisation of distributed generation (DG) in reducing network losses and of automatic post-fault actions in maximising DG output. A number of quantified examples are presented, based on simulations, for two actual distribution networks in the UK using reconfiguration of normally open points and inter-tripping of generation. The results show that a noteworthy reduction in losses might be achieved, and demonstrate the extent to which the actual results depend on the configuration of the network, the level of demand and the amount of DG in operation. It is argued that the benefits in terms of reduction of losses and maximisation of DG output are significant enough and the automation technology mature enough to justify investment in appropriate metering, communication and control, but that current commercial arrangements often prevent appropriate automation measures from being implemented.

INTRODUCTION

It has been argued that reduction of distribution network losses might be achieved by operation of distributed generation (DG) to reduce the power flows from grid supply points to customers. Automation solutions are likely to be important to the facilitation of maximum DG output on an existing network with the greatest impact expected to come from automatic re-despatch of the DG active power output, e.g. by operational inter-tripping, and voltage regulation.

Although distribution networks are designed in accordance with statutory security standards, because the duration of a post-fault state is very much less than that of the pre-fault state (because fault outages are comparatively rare), the total losses arising on a distribution network are dominated by those arising under planned, i.e. pre-fault, conditions. However, it should be noted that operational measures for the management of post-fault conditions can give rise to pre-fault constraints that will impact upon losses, and these should be taken into account in any assessment of losses. Such measures include the splitting of networks pre-fault to mitigate the number of customers that might be affected by individual unplanned outage events or to avoid post-fault overloads, and the limiting of exports from sites containing DG. It is in this last respect in particular that the benefits of automatic control actions can be seen with restriction of exports implemented only once a fault outage has occurred and rapidly enough to avoid the violation of time-related thermal limits.

This paper demonstrates the potential impact of DG on losses and of automatic post-fault actions on the facilitation of DG. A number of quantified examples are presented, based on simulations, for two UK distribution networks.

AUTOMATION SOLUTIONS

To date, three main automation solutions have been deployed on distribution networks or discussed in the literature: network reconfiguration (switching); active generation control; and active voltage control. Since the Case Studies described below exhibit no particular voltage problems, the work here has concentrated on the first two.

Network reconfiguration

While the application of pre-fault network reconfiguration has been identified as a mechanism by which network losses can be reduced [1], much of the literature on reconfiguration has been concerned with supply restoration (i.e. post-fault) and fault level control. Exceptions include [2]-[4]. As yet, however, it is not clear how many have a reached an implementation trial stage [5].

Active generation control

With the increasing presence of DG on distribution networks, power flows resulting from multiple DGs must be controlled in order to ensure that no overloading of circuits occurs. Myriad generation tripping and trimming schemes have been proposed to address this, of which a number are being trialled, e.g. those in [6] and [7].

STUDY METHODOLOGY

The objectives of the simulation tasks were:

- to verify that network automation solutions succeed in
    - respecting network thermal and voltage limits;
    - reducing pre-fault constraints.
- to quantify the reduction in losses and improvement in utilisation of DG.

The above were achieved by a series of load flows, each representing the new steady state arising after an event, e.g. a fault outage or a control action such as tripping or trimming of generation or closing of a normally open point.

In determining which initial conditions were viable and in seeking to quantify their benefits, it was noted that annual losses mainly depend on pre-fault power flows; pre-fault network configuration and DG operation may be constrained by post-fault conditions; and implementation of sufficiently fast post-fault automated actions may reduce pre-fault constraint of network configuration and DG.

The demand cases considered in the study were:

- Winter maximum demand (Winter ratings and maximum import from grid);
- Summer minimum demand (30% of winter peak; Summer ratings and possible export to grid);
- Summer peak demand (75% of winter peak; Summer ratings and high import).

A number of assumptions were made.

1. Transformers and cables: assumed that emergency post-fault ratings are 200% of pre-fault continuous ratings, and are available for up to 24 hours.
2. Transformer reverse flows: in the absence of available data on limits – arising from tap changer configuration – on flows in the reverse of the normal direction, the thermal limit in the reverse direction was assumed to be the same as that in the forward direction.
3. Overhead lines: assumed that an emergency 5 minute post-fault rating is 140% of the continuous rating.
4. Overcurrent protection assumed not to operate provided branch loadings are within emergency ratings and restored to within normal ratings within the times specified above.
5. A suitable communications infrastructure is provided for the modelled automation schemes

Cyclic ratings of transformers were not considered. Due to this and because – since they have enhanced cooling equipment – some transformers can actually be continuously operated to 'emergency' ratings, the transformer ratings applied may be regarded as conservative.

The methodology included performing a N-1 security assessment in order to identify those fault scenarios that impose post-fault restrictions on DG operation, and subsequently testing automation schemes to remove such restrictions. Planned network outages and restrictions on network configuration due to fault levels were not considered in this study.

CASE STUDIES

Two networks for which models are available in the UK 'Typical Networks' data were considered – the Mannington group currently operated by SSE and the Wymondley group currently operated by EDF Energy [8]. Their main characteristics are summarised in Table 1. In order to explore the impact of DG, a number of locations in these networks were considered for addition of DG. These locations were selected based on advice from the respective distribution network operators (DNOs) regarding those places in which interest had been expressed by generation developers, and are therefore considered realistic. The 'base case' amount of additional DG was determined as that level for which there are no pre-fault overloads. This amounted to a total of 346 MW of generation in the Mannington group (compared with 9 MW at present) and 76.5 MW in the Wymondley group (compared with 4.5 MW at present).

Table 1: main case study characteristics

		Mannington	Wymondley
Buses	Total buses	44	94
	400 kV	1	1
	132 kV	13	16
	66 kV	0	0
	33 kV	19	63
	11 kV	11	14
Branches	Total number	44	89
Transformers	Total number	24	35
Loads	Number of loads	11	14
	Peak total P	101.6 MW	218.4 MW
	Peak total Q	29.6 MVAr	71.9 MVAr

RESULTS

Pre-fault reconfiguration to reduce losses

Comparison of the Mannington network with the present total of 9 MW of DG with that with a total of 346 MW of DG revealed a reduction in losses at winter peak demand from 22.5 MW to 18.3 MW (a saving of almost 19%). However, as may be expected, the introduction of DG into a network typically changes the optimal planned configuration of the network in respect of network losses. For example, in the Mannington network, of the 20 different re-configuration options studied (closure of different combinations of normally open points), a further 0.7 MW loss can be avoided by use of the best reconfiguration.

The extent of loss reduction that can be achieved by reconfiguration depends on the nature of the network. For example, for the Wymondley group, the losses at winter peak with the present level of DG are 6.2 MW; the 'base case' level of additional DG reduces this to 5.6 MW (a reduction of nearly 10%) and to 5.5 MW with the best pre-fault reconfiguration. However, the extent of loss reduction also depends on the level of demand in the network. Compared with the situation for the present levels of DG, losses are increased at summer minimum demand with the assumed additional DG, for Mannington from 1.7 MW to 5.5 MW without any network re-configuration or 5.2 MW with reconfiguration.

Maximisation of DG output using automation

Often, the level of output of generation is restricted by system security considerations, i.e. that there should be no overloads after the occurrence of a single fault outage on the network. However, in practice, the permissible level of network loading is a function of time in that, depending on how protection is set, overhead lines, transformers and underground cables can be safely loaded quite heavily for a short period provided the loading is subsequently sufficiently reduced. This utilisation of short-term post-fault ratings, even down to 5-minute ratings, permits less restriction of generation pre-fault, provided the necessary post-fault reductions can be achieved. One way to do this is by automatic trimming or tripping of DG.

The benefits in terms of facilitation of DG can be quite considerable. The Boscombe East bulk supply point in the Mannington group gives an illustration (see fig. 1). The limiting factor here is the possible overloading of the series branch comprising transformer T1 and a stretch of overhead line in the event of a trip of transformer T2. At winter peak demand, the maximum generation that could be accommodated at Boscombe East without breach of continuous thermal ratings would be 37 MW. However, utilisation of post-fault short-term ratings and automatic trimming after occurrence of the critical fault would permit 51 MW to operate.

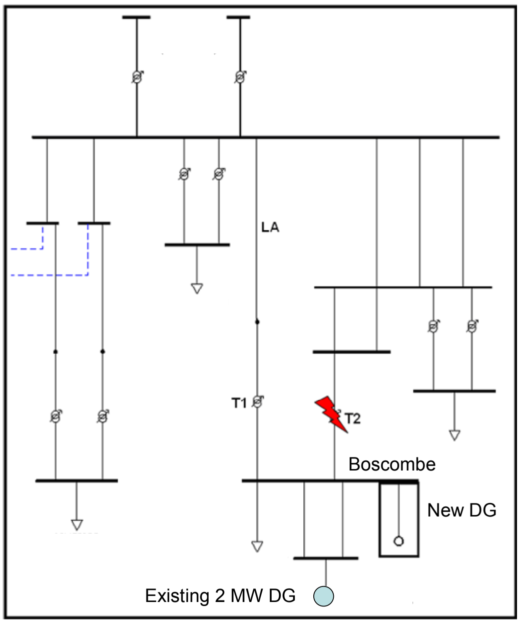

Figure 1: Constraints on generation at Boscombe East

Figure 2 shows the possibilities afforded by automatic post-fault actions for the Mannington group as a whole and the impact on losses. It can be seen that almost any level of DG offers benefits in terms of network loss reduction at winter peak demand compared with the present level. However, depending on the DG location, increases in output above a certain level increase net power flows and therefore losses.

For high post-fault loadings on transformers up to their emergency ratings, automatic actions are less necessary due to there being more time available for corrective action. However, the long-term impact of fault loadings on transformers above the emergency ratings for very short periods, e.g. 1-5 minutes, may need to be considered.

Impact on annual losses

While it has been shown above that selective reconfiguration of a network can achieve a reduction in losses for a given level of DG output, it has also been speculated that increased use of DG will bring about a general decrease in network losses. Although only a few demand cases have been studied here and variation in DG output has not been explored, based on the results that have been obtained, it is possible to make a rough estimate of the annual loss reduction associated with DG operation.

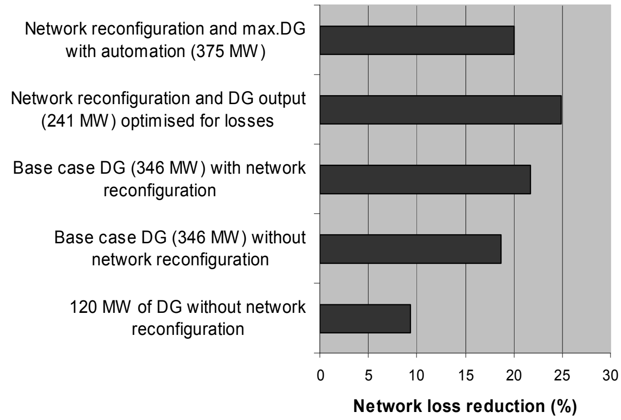

Figure 2: losses at Winter peak in Mannington group

The losses for each case study for each of the three demand levels modelled – 100% of winter peak, 75% and 30% – are shown in figs. 3 and 4, always for the 'base case' DG utilisation and the best network configuration in terms of loss minimisation for that demand level and DG output. The result is compared with the losses for the default network configuration with only the existing DG. Annual loss estimates have been achieved using interpolations of losses versus demand and a convolution with the load-duration curve [8]. (DG output is assumed at 100% throughout).

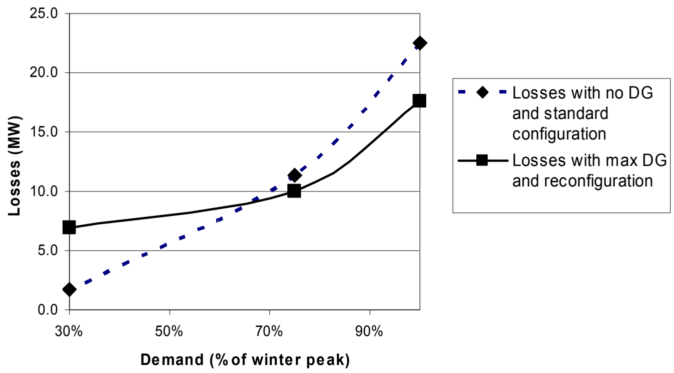

Figure 3: Annual losses in Mannington group

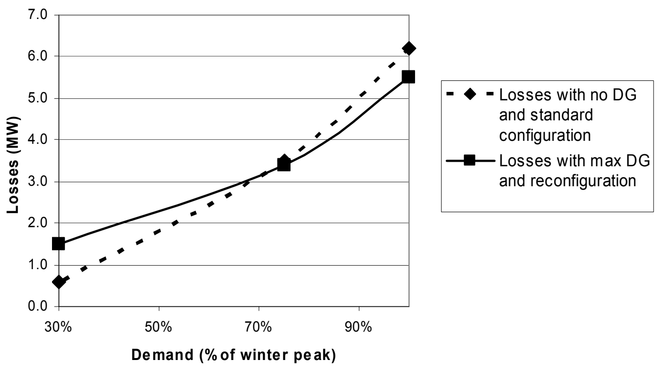

Figure 4: Annual losses in Wymondley group

The estimates obtained are as shown in Table 2. It can be seen that the loss reduction in the Mannington case is 6.9%. Costed at £20/MWh, this is worth £122k per annum.

However, for the Wymondley case, there is an increase in annual losses of 1.7%. Even though the variation in DG output throughout a year of operation has been neglected, it can be seen that increased penetration of DG does not guarantee a reduction in losses. Rather, it depends on the network and the level of DG penetration.

Table 2: reductions in annual network losses

	Mannington	Wymondley
Existing DG, default configuration (MWh)	88,887	26,841
Max. DG with reconfiguration and automation (MWh)	82,789	27,306
Reduction (MWh)	6,098	-465
Reduction (%)	6.9	-1.7

ECONOMICS OF DG IN NETWORKS

While automation can permit utilisation of an increased level of DG, without a detailed economic assessment (outside the scope of this study), a distribution network operator (DNO) may be reluctant to undertake the investment in the metering, communication and control equipment required to implement it. Such an assessment should address: a number of different demand levels; accurate representation of emergency ratings and post-fault actions; the impact of planned outages; a range of levels of DG output; and the financial impact of increased DG utilisation.

The last of the above aspects is dependent upon the prevailing commercial and regulatory environment, in particular: the benefit of avoided reinforcements to accommodate DG and who realises that benefit; access rights and charges for DG; and commercial arrangements for restriction of output. Moreover, while DG can help reduce network losses, the commercial and regulatory environment also affects the valuation of losses and who realises the benefit of reduced losses.

CONCLUSIONS

The results of simulation studies have demonstrated that DG can help to reduce losses under high demand conditions but operation of DG might increase losses when demand is low. It has been shown that the utilisation of DG can be significantly increased by the use of short-term ratings on the network and automatic post-fault actions – mainly DG power output trimming or tripping of the generation – to restore loadings on overhead lines in particular to back below normal ratings after a fault outage.

It has been demonstrated that some moderate – but, over the course of a year of operation, potentially significant – reductions in losses for a given demand and level of DG output can be achieved with appropriate network reconfiguration. However, depending on the nature of the network and the location of DG within it, at times of high demand the full benefits may depend on automation, e.g. tripping or trimming of DG output which may not be possible given contractual arrangements for existing DG.

It seems that distribution network automation is now technically feasible and has the potential to be cost-effective for the accommodation of increased levels of DG. However, unless suitable commercial and regulatory arrangements are put in place to incentivise appropriate actions by DNOs and contracts with DG operators, it is not certain that the benefits will be realisable. For as long as such arrangements remain under development, it will not be possible to undertake a full and accurate economic appraisal of the benefits of network automation and loss reduction. Resolution of these arrangements should now be regarded by those interested in DG as a priority.

ACKNOWLEDGMENTS

The work reported in this paper was supported by the UK government Department for Business, Enterprise and Regulatory Reform (BERR) Emerging Energy Technologies Programme in conjunction with the Distribution Working Group of the Electricity Networks Strategy Group.

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