ASSESSING THE VALUE OF ACTIVE CONSTRAINED CONNECTION MANAGERS FOR DISTRIBUTION NETWORKS

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ABSTRACT

This paper presents the technical considerations and economics of a number of solutions that would allow a greater installed capacity of distributed generation to be connected to, and operated within, the distribution network. After describing the various solutions, an energy yield and financial evaluation demonstrates that an active constrained connection manager informed by dynamic thermal ratings is the most attractive solution for developers wishing to connect distributed generation to this case study network when compared to alternative solutions.

INTRODUCTION

Power flows within distribution networks will become increasingly congested with the recent growth in distributed generation (DG) connections, both in the United Kingdom and internationally. This may to lead to a curtailment in the amount of DG that can connect to the network and will impact on the energy yield (and hence profitability) of such schemes as network capacity becomes saturated. The current practices regarding DG connections may:

(a) Constrain the size of schemes at the planning stage to the existing capacity of the network based on static component thermal ratings.
(b) Entail relatively high network reinforcement costs to connect schemes in excess of the network's current capacity.
(c) Involve basic 'tripping' schemes to manage the DG output at times of constraint.

For the case study considered, comprising DG with intermittent power output, this paper demonstrates that the energy yield from the unconstrained reinforcement solution is only slightly more than that delivered by an alternative 'active' operational solution utilising dynamic circuit ratings. Active constrained connection managers (ACCMs) are one approach that facilitates a greater energy yield from DG schemes based on the available network capacity. It is acknowledged that asset ratings are not a static phenomenon but vary as a result of the prevailing meteorological conditions throughout the year. Thus it is possible to take advantage of the dynamic nature of the network availability when connecting and operating DG schemes.

Engineering Technical Recommendation (ETR) 124 [1] presents a number of different solutions that may be developed to actively manage the power flows associated with the connection of a single DG scheme. The control techniques involve tripping and regulating the DG output based on the monitoring of power flows and considering static or dynamic thermal ratings of the infrastructure.

The 132kV section of network presented in this paper is a subsection of a wider trial network forming the research basis for the 'Active Control of Distributed Generators based on Component Thermal Properties' [2]. The collaborative project (involving AREVA T&D, Durham University, Imass, PB Power and Scottish Power) aims to develop, install and test an ACCM informed by dynamic thermal ratings (DTRs). A key outcome of this project will be to develop a strategy to control the output of multiple DG schemes by taking a system-wide view of operational constraints.

This paper makes a comparison between a network reinforcement solution, a basic tripping solution and three ACCM solutions that would allow a greater installed capacity of DG to be connected to a single point within the distribution network. The ACCM solutions increase in sophistication both in the manner in which the DG power output is controlled (tripping or regulating) and by utilising different component rating regimes (static, seasonal or dynamic). By incorporating a backup trip protection system into the more sophisticated solutions, the risk of ACCM system failure is minimised and thus the security of the network is maintained. An energy yield and economic evaluation show that, in this case, an ACCM informed by DTRs is the most attractive solution for facilitating DG developer revenue gains when compared to the alternative solutions.

THE CASE STUDY NETWORK

The case study network shown in Figure 1 is derived from a section of Scottish Power's distribution network. Although it is not displayed in Figure 1, Engineering Recommendation P2/6 [3] 'security of supply' requirements are met for the connected load through an underlying meshed 33kV infrastructure. An installed wind capacity of 150MW was selected to create a constrained connection. It is assumed, for the purposes of this analysis, that the DG would not be required to ride through faults but would be tripped off completely and brought back online when the system was restored.

Analytical Considerations

The constrained connection configurations were simulated through an offline analysis of the typical half-hourly regional loading and wind farm output data for the calendar year 2005.
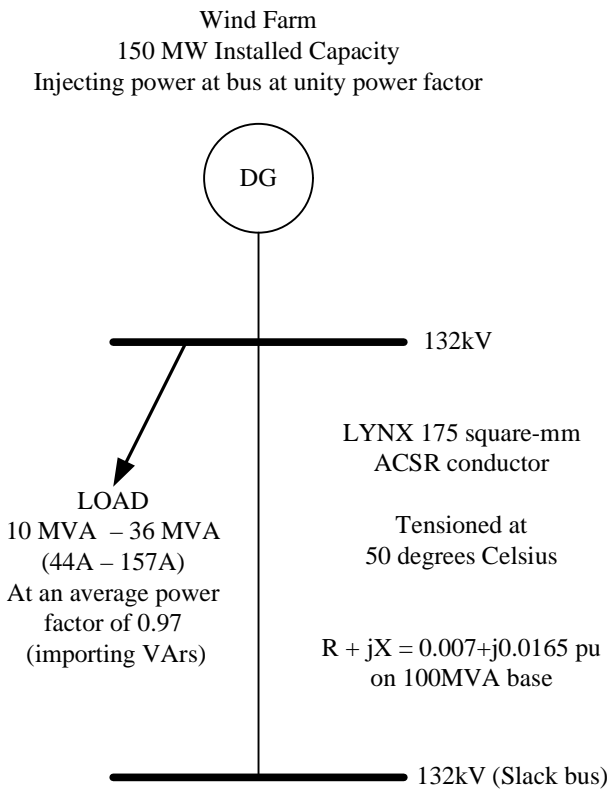
Wind Farm
150 MW Installed Capacity
Injecting power at bus at unity power factor

DG

132kV

LYNX 175 square-mm
ACSR conductor

LOAD
10 MVA – 36 MVA
(44A – 157A)
At an average power
factor of 0.97
(importing VArs)

Tensioned at
50 degrees Celsius

$R + jX = 0.007 + j0.0165$ pu
on 100MVA base

132kV (Slack bus)

Figure 1 – The 132kV network

Table 1 displays the ratings used in the analysis. The static and seasonal ratings were based on the SP Manweb Long Term Development Statement [4] and a modest Aeolian up-rating [5] of 30% above the 'static' rating was used for the dynamic rating analysis. This latter assumption was deemed appropriate as the up-rated line is geographically close to the wind farm site and thus at times of maximum power output from the DG scheme there would also be a maximum wind-cooling effect on the line. Offline analysis showed that a thermal constraint would be met in this section of the network before voltage or fault-level limitations.

SOLUTION DESCRIPTIONS

Solution 1: DG tripping based on a static assessment of network availability
Solution 2: DG tripping through an ACCM based on component seasonal thermal ratings
Solution 3: DG output regulation through an ACCM based on component static thermal ratings and load demand
Solution 4: DG output regulation through an ACCM based on component dynamic thermal ratings and load demand
Solution 5: Network Reinforcement to provide unconstrained connection.

Each section below assesses the strengths and weaknesses of the particular solution, describes the control algorithm used for the DG output regulation and gives an approximate estimated cost of the solution installation.

Rating Condition	Rating (A)	Rating (MVA)
Static	390	89
Seasonal Summer Continuous	390	89
Seasonal Spring / Autumn Continuous	450	103
Seasonal Winter Continuous	485	111
30% Dynamic Up-rating	506	116

Table 1 – Summary of Ratings Utilised

Tripping Solutions

The tripping solution schematic is shown in Figure 2 and implements the control algorithm (1).

IF: CURRENT > RATING   (1)
THEN: 'TRIP' DG to RATING + BASE LOAD

DG

Static / Seasonal
Ratings

Trip
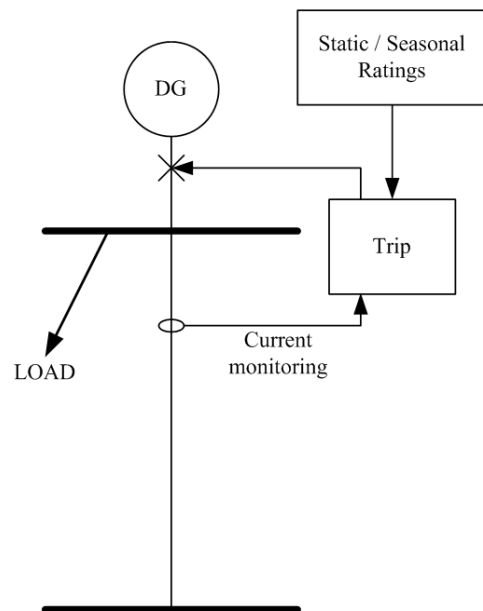
Current
monitoring

LOAD

**Figure 2 – The DG trip solution with static or seasonal thermal ratings**

When this algorithm is implemented with the static rating of 390A (RATING), the DG output will be tripped to 434A at unity power factor (390A rating + 44A base load) if the current flow in the line (CURRENT) exceeds 390A. This corresponds to the implementation of Solution 1. Similarly, in a seasonal rating implementation [6], such as Solution 2, the DG output will be tripped to the seasonal rating plus the base load if line flow exceeds the seasonal rating. These solutions represent a conservative management approach as they do not account for the dynamic nature of the load and thus they trip generators off rather than constraining them back. Furthermore, the seasonal rating approach bears the latent risk of an anomalous 'hot day' where the prevailing meteorological conditions mean that infrastructure may be rated higher than it should be.

Estimated Basic Tripping Relay Cost:
Local tripping relay   £10k

DG Regulation Solutions

Figure 3 shows the schematic that allows the control algorithm (2) to be implemented to regulate the DG output based on static or dynamic network availabilities and load demand.

IF: CURRENT > RATING   (2)
THEN: 'REGULATE' DG to RATING + DEMAND
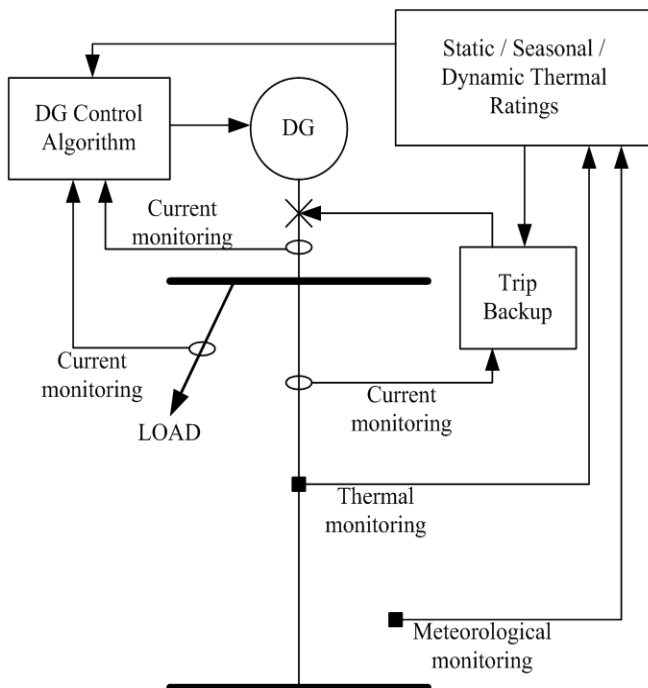
Figure 3 – The DG output regulation solution with static or dynamic thermal ratings

When control algorithm (2) is implemented with a static rating of 390A, this corresponds to Solution 3. The DG regulation solutions are more sophisticated than the DG trip options and have the potential to offer energy yield gains by taking into account the dynamic nature of the load. Additional power flow monitoring equipment is required to facilitate a demand-following DG regulation regime and, in the case of the DTR-informed system (Solution 4), additional thermal and meteorological monitoring is also required. To ensure the safe and secure operation of the assets, each regulation solution requires an auxiliary trip system, which is informed by the same ratings as the regulation system, to act as a backup in the case of control system operation failure.

Estimated Cost of DG Regulation based on Static/Seasonal ratings:
Monitoring and Regulation Equipment: £50k

Estimated Cost of DG Regulation based on DTRs:
Monitoring and Regulation Equipment: £100k

Reinforcement Solution

The reinforcement solution (Solution 5) would require a replacement 132kV overhead line to be constructed and the existing overhead line to be de-commissioned. It is assumed that the replacement line conductor is 'Upas' 300mm^2 AAAC. If this conductor is tensioned to maintain statutory ground clearances [7] at an operational temperature of 75°C, the minimum 'system intact' rating would be sufficient to provide an unconstrained annual energy yield from the DG scheme. However, it requires the largest capital investment [8] and could take several years to be installed due to the lengthy environmental assessments, planning, commissioning and building processes.

Estimated Reinforcement Cost:
Installation of up-rated 132kV line (7km)   £2M

QUANTIFICATION METHODOLOGY

Control algorithms (1)-(2) were applied to the constrained connection case study with the relevant rating operating regime and the necessary constraints were implemented offline. Thus the annual energy yield was calculated for each solution by integrating the real power output of the DG scheme across the year in 30 minute intervals. The annual revenue for that operating year was then calculated by multiplying the annual energy yield by £101.43/MWh (£52.15/MWh wholesale electricity price [9] + £49.28/MWh 'Renewables Obligation Certificate' sale price [10]).

The basic tripping scheme based on summer static ratings (Solution 1) was taken as the datum solution with a capital cost of £10k and annual revenue of £42.5M based on an energy yield of 419 GWh (32% capacity factor). The estimated marginal costs (due to additional network costs) and predicted marginal revenues (due to additional energy yield) were compared to this solution. This allowed a basic Net Present Value (NPV) comparison of the alternative solutions, based on their relative marginal costs and marginal revenues. A 10% discount rate and 20 year economic life was assumed [11]. The capital cost of the wind farm itself was neglected as this would be constant across each solution. Furthermore, because the wind farm is connected at via a single overhead line, any faults or scheduled maintenance on this line will cause it to shut down. Since such events have an equal constraint on the energy yield of each solution this effect was neglected. All the costs within the financial evaluations are estimates of equipment costs, based on the most appropriate data available at the time of consideration.

RESULTS

The results from the quantification methodology are summarised in Table 2.

Solution 1: DG tripping based on a static assessment of network availability

Solution 2: DG tripping through an ACCM based on component seasonal thermal ratings

Solution 3: DG output regulation through an ACCM based on component static thermal ratings and load demand

Solution 4: DG output regulation through an ACCM based on component dynamic thermal ratings and load demand

Solution 5: Network reinforcement to provide an unconstrained connection

Solution	Marginal Cost (£k)	Marginal Annual Revenue (£M)	Marginal Energy Yield Increase (%)	Marginal 20 Year NPV @ 10% dcf (£M)
1	0	0.0	0	0
2	0	2.4	6	20.5
3	40	2.2	5	18.3
4	90	4.4	10	37.3
5	1990	4.5	11	36.2

Table 2 – Quantification Methodology Results

DISCUSSION

For this case study, it appears that switching ratings on a seasonal basis and tripping DG as a result (Solution 2) yields greater revenue for the developer than regulating DG output based on a single summer static rating (Solution 3). DG tripping through an ACCM based on seasonal thermal ratings (Solution 2) requires a lower initial investment, however, the risk on the part of the DNO is greater if seasonal ratings are utilised. This is to due the possibility of an anomalous hot day occurring when ratings have been relaxed. This risk may be mitigated by investment in a dynamic thermal ratings system to provide accurate knowledge of the current thermal status of the network. Economically, the most attractive solution to the developer is the ACCM based on component dynamic thermal ratings and load demand (Solution 4), the annual revenue of the project is increased by £4.4M and shows the highest NPV at £37.3M. For this case study, this solution appears to be more attractive than the alternative reinforcement option (Solution 5) that provides and unconstrained energy yield (and hence maximum annual revenue) but would require an extra capital investment of £1.99M to upgrade the overhead line. It is of note that network reinforcement would achieve the least network losses since the larger cross-sectional area of the conductor would reduce the electrical resistance to power flow. However, this factor has been excluded from the economic assessment in this particular case study.

CONCLUSION

This paper has presented the technical solutions that would allow a greater installed capacity of distributed generation to be connected to, and regulated within, the distribution network. This could be of value in situations where power flows have become congested as a result of DG proliferation. For each solution the annual energy yield was quantified and used as a basis to compare solutions using an estimate of their relative Net Present Value to the DG developer. It was demonstrated that an active constrained connection manager informed by dynamic thermal ratings was the most cost effective solution for facilitating distributed generation access to the case study network when compared to alternative solutions. Work is continuing in this area to realise the potential of ACCM solutions.

ACKNOWLEDGEMENTS

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