AN ASSESSMENT OF THE ECONOMIC IMPACT OF ACTIVE NETWORK MANAGEMENT ALTERNATIVES

Andrea MICHIORRI
Smarter Grid Solutions – UK
andrea.michiorri@smartergridsolutions.com

Robert CURRIE
Smarter Grid Solutions – UK
robert.currie@smartergridsolutions.com

Gareth McLORN
Smarter Grid Solutions – UK
gareth.mclorn@smartergridsolutions.com

Colin FOOTE
Smarter Grid Solutions – UK
colin.foote@smartergridsolutions.com

ABSTRACT

This paper presents a quantitative and qualitative analysis of the technical and economical impact of different ANM technologies. The technologies considered are power flow management, voltage management, dynamic line rating, demand side management and energy storage. Benefits and limits of each technology are assessed individually for a base case scenario using a simple case study.

INTRODUCTION

Load growth, distributed generation connection and ageing assets are typical challenges faced by network operators. New operational schemes, designed to overcome these problems, have emerged as advancements in information and communications technologies have gathered pace. These schemes, based on monitoring, telecommunications and distributed control, have the potential to considerably improve the utilisation of network assets, delay network reinforcements and reduce connection cost, and represent a shift in network operation towards Active Network Management (ANM). On the other hand, the adoption of such new technologies is approached cautiously due to the lack of a track record.

A significant challenge for network operators and users of the network is to assess the value of ANM technologies and to compare them with traditional connection solutions, such as network reinforcement. A cost benefit analysis may be facilitated by methods which evaluate innovative and traditional solutions across common parameters. It is expected that such an approach will be effective in ensuring that ANM solutions will emerge as suitable alternatives in cases where they make most economic sense.

The work presented builds upon the examples shown in [1], [2] and on the experience garnered within Smarter Grid Solutions. The technologies considered are: power flow management [3], voltage management [4], dynamic line rating [5], and demand side management [6]. The performance of each technology is assessed in terms of operational cost and network losses. The same analysis is then repeated for a more complex scenario where the different technologies are applied together to solve several problems and finally, examples from real life implementations are illustrated.

METHODOLOGY

A series of case studies with the same network is used in the analysis. The network used, shown in Figure 1, is composed of a 33 kV substation (Sb2) connected through a circuit (C1) to a 132 kV grid connection point (Sb1). A load (L) is connected to the substation Sb2. A generator (G), geographically close to Sb2, can be connected at Sb2 through a circuit C2 or to Sb1 with a longer circuit C3. For each case, network electrical parameters are modified to highlight the effect of the different connection challenges faced.

The constraints considered are:
- Circuit static rating
- Circuit dynamic thermal limit
- Voltage rise

The parameters that are modified are:
- Circuit C1 rating
- Circuit C1 impedance
- Load L minimum value
- Load L maximum value
- Load L power factor
- Generator G rating
- Generator G power factor
- Substation Sb1 network impedance

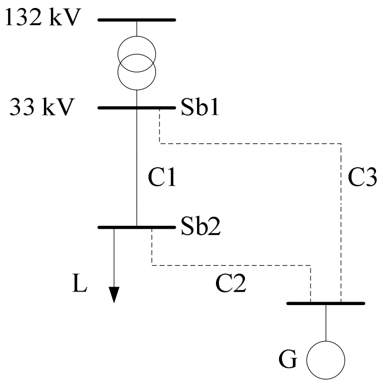

Figure 1: Network topology

The values used in the different cases are summarised in Table 1. Two profiles, for the generator and the load respectively, are built for each case, considering minimum and maximum values for both generation and load. For each case, a curtailment analysis is carried out, as described below, through which the energy generated, curtailed and lost in network losses, over a period of one year, is calculated.

The results are used to derive an overall cost of the ANM scheme. This is achieved by multiplying the energy curtailed, expressed in MWh, by the wholesale electricity price. The net present value of this cost is then considered in subsequent calculations. In this example a wholesale electricity price of £40 /MWh, a time horizon of 25 years and a discount rate of 10% were considered. The electricity price is increased by £36 /MWh in the case of renewable generators to take into account incentives in the form of Renewable Obligation Certificates (ROCs).

For each case the operation is repeated by increasing the size of the generator or load in increments of 1 MW, up to a maximum of 30 MW. The ANM cost is summed with the cost of the infrastructure needed to connect the generator or the load at substation Sb2. Finally, the values obtained are compared with the cost of the new infrastructure that would otherwise be required to overcome the constraints by using traditional network reinforcements. In this example, the reinforcement alternative considered is the construction of a new circuit (C3 in Figure 1), which directly connects the generator or load to the HV grid at Sb1. It was assumed that the length of C1, between Sb1 and Sb2, is 10 km, and is the same length as circuit C3. The length of C2 is 3 km. The cost of a new circuit is assumed to be £150k /km. Circuit C3 is considered to have a resistance equal to half that of circuit C1; this data is used to calculate the losses. Other costs relative to the expansion of Sb1 or Sb2 are considered equivalent and are therefore not included in this analysis. This scenario was conceived to represent a typical wind farm connection problem, where the location of the generator does not depend on the disposition of the loads or the topology of the network.

Curtailment Analysis

For each time step, potential curtailment is carried out using the following actions:

a) The reactive power flows at the generator and load are calculated with fixed power factor considered.

b) The apparent power ($S=P+jQ$) flowing in the circuit is calculated from the power balance between the generator and the load at Sb2. A positive value represents an export to the grid at Sb1, whilst a negative value represents an import to Sb2.

c) The voltage rise (ΔV) at Sb2 is calculated via Equation (1)

$$\Delta V = S \cdot Z_{tot} / V^2 \qquad (1)$$

where $Z_{tot} = R_{tot} + jX_{tot}$ is the sum of the impedance of circuit C1 and of the network impedance at Sb1

d) The apparent power flow (S) is compared with the conductor rating (Sr) and, if it is larger, the power to be curtailed (Sc) is calculated using Equation (2)

$$Sc = MAX(S - Sr, 0) \qquad (2)$$

e) The voltage rise (ΔV) is compared with its maximum allowable value (ΔV_0) and, if it is larger, the power to be curtailed (Sc) is calculated using Equation (3)

$$Sc = MAX((\Delta V - \Delta V0) \cdot S_0 / Z_{pu,tot}, 0) \qquad (3)$$

where S_0 is the base apparent power and $Z_{pu,\,tot}$ is the per unit total resistance

f) The excess power flows calculated in steps d) and e) are compared. The larger value is used in the last part of the analysis.

g) If the excess power flow is positive, it is subtracted from the output of the generator to obtain the curtailed generation value (Sc, g). For negative values, the excess power flow is added to the load to obtain the curtailed load value (Sc, l)

Table 1: Study cases network parameters

		Case 1 Generation Power Flow	**Case 2** Generation DLR	**Case 3** Generation Voltage Rise	**Case 4** Generation PF, DLR, VR	**Case 5** Load Power Flow
C1 rating	[MVA]	15	15	30	15	15
C1 impedance	[Ω]	1.38+j2.75	1.38+j2.75	1.38+j2.75	1.38+j2.75	1.38+j2.75
L min	[MW]	5	5	5	5	Up to12.5
L max	[MW]	12	12	12	12	Up to 30
L Power Factor		0.9	0.9	0.9	0.9	0.9
G rating	[MW]	Up to 30	Up to 30	Up to 30	Up to 30	0
G Power Factor		0.9	0.9	0.9	0.9	
S1 network impedance	[Ω]	0.14+j0.82	0.14+j0.82	0.14+j0.82	0.14+j0.82	0.14+j0.82

h) The new power flow is calculated as in b) and it is verified that the circuit rating and the voltage rise limits are not breached.

i) Conductor losses (Wl) due to the new power flow are calculated as in Equation (4)

$$W_l = (Sc^2 \cdot R_{C1})/(3 \cdot V^2) \qquad (4)$$

where RC1 is the resistance and V is the voltage level of circuit C1.

j) Points a) to i) are repeated across the 8760 steps that represent the hourly data for one year. The values calculated are stored for further analysis.

k) The total curtailed energy for the generator (*Sc, gtot*) and the load (*Sc, ltot*) are calculated by summing the difference between the non curtailed (*Sg, Sl*) and the curtailed (*Sc,g, Sc,l*) power generated (or consumed) at the generator (and the load) for all the time steps, as in Equation (5) and (6)

$$Sc,gtot = \Sigma_i(Sg_i\text{-}Sc,g_i) \qquad (5)$$

$$Sc,ltot = \Sigma_i(Sl_i\text{-}Sc,l_i) \qquad (6)$$

l) The total energy dissipated in losses (*Wl, tot*) is calculated with the sum of the losses determined at each time step (*Wl, i*) using Equation (7)

$$W_{l,\,tot} = \Sigma_i W_{l,\,i} \qquad (7)$$

CASE STUDIES

Case 1

In Case 1 a generator is connected to substation Sb1. As summarised in Table 1, the local load L has minimum and maximum values of 5 MW and 12 MW respectively, and the rating of Circuit C1 is 15 MVA. The connection of a generator rated at up to 18 MW, operating with a power factor of 0.9, may be accommodated in this situation.

Case 2

In Case 2 the same hypothesis for Case 1 is applied once more. However, on this occasion the rating of circuit C1 is considered to be variable as dynamic line ratings (DLR) are used within the system.

DLR is based on the concept that overhead line ratings are strongly influenced by environmental conditions such as air temperature or wind speed [5]. It is normal practice for network operators to apply static seasonal ratings based on conservative assumptions for seasonal variations in conditions. A DLR system monitors conductor temperature or meteorological conditions. It seeks to maintain conductor temperature below its maximum operating value by reducing the output of non firm generators. In this study conductor ratings were calculated using hourly weather data supplied from the Kirkwall airport. This technique was also used in [7]. The thermal model for conductor rating calculations is described in [8].

Case 3

In Case 3, a generator is connected to substation Sb1. As in Case 1, the local load L has minimum and maximum values of 5 MW and 12 MW respectively, but the rating of Circuit C1 is set to 30 MVA.

Case 4

The first three cases were characterised by a single constraint: thermal rating or voltage rise. This is representative of many real world cases, especially radial networks, where either thermal or voltage limits are the dominating constraint. In more complex networks these two limits may each take priority at different times under different conditions. An example could be a network where substation Sb1 does not connect directly to the HV grid, but to other MV substations through other circuits.

In Case 4 the combined effect of power flow management, with DLR, and voltage management on the generator's annual energy yield is studied for more complex networks than those explored for the previous scenarios. The effect of two possible constraints on the network was simulated via the following approach. The network conditions applied were the same as those used in Case 3, with the exception of the base voltage. For each time step, the voltage varies randomly, within a range of ±5% of nominal and within a normal distribution, with standard deviation of 1.5%.

Case 5

Previous cases focused solely on the connection of distributed generation but ANM schemes where controllable load is applied are similarly adept in facilitating the connection of new customers to congested networks. Case 5 is modelled on Case 1, where the generator, G, is set to zero and the load L is increased, but the ratio between maximum and minimum load is maintained. In this case it should be noted that the cost of curtailed generation (revenue of generated electricity forgone) is not equivalent to the cost incurred by the owner of the load. In such cases it can be assumed that the electricity is intended to be used as an input to a process which will produce an output of greater value than the electricity itself. The existence of commercial processes which can be time-shifted adds value to demand side management approaches as possible alternatives to network reinforcements. In this Case, the value of ROCs was not considered.

RESULTS

The results of this analysis are summarised in Figure 2 and Table 2. Figure 2 shows the cost of curtailment for the different options and its comparison against the alternative network reinforcement. In Table 2 the amount of generation (or load) that can be connected for each of the different ANM topologies highlighted above is depicted with a cost comparison with the reinforcement alternative also being presented.

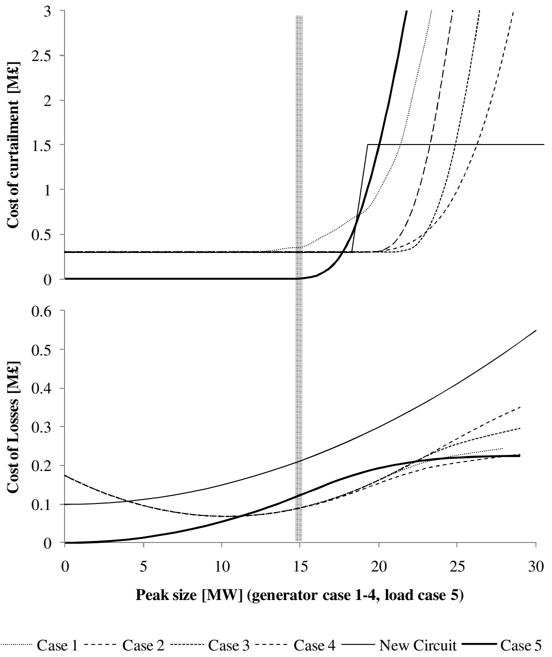

Figure 2: Cost of curtailment and cost of losses

The analysis of the lifetime cost shows that for small increases in power, above the static limits of conductor rating, or of voltage rise, curtailment cost is negligible. However, curtailment costs begin to increase rapidly for increases in power above a certain threshold. If network losses are considered, ANM will tend to lead to an increase in system losses as schemes push existing networks closer to saturation. However, further analysis shows that the losses associated with the alternative to the hypothetical ANM scheme, i.e. the construction of a new circuit, will be higher due to the generator not feeding the local load directly.

Table 2: Increased maximum generation connected above the existing limit

	[MW]	[%]
Case 1	7	47%
Case 2	10	67%
Case 3	9	60%
Case 4	6	40%
Case 5	4	27%

The analysis of newly connected generation shows that DLR provides significant advantages with respect to power flow management for networks where static ratings are employed. It is also shown that ANM provides considerable benefits in more complex scenarios, such as that described in Case 4. The performance of demand side management in accommodating additional load is shown to be cost effective. This is mainly due to the absence of a generator in Case 5.

CONCLUSION

This paper has presented a quantitative analysis of the economical value of different active network management technologies for integrating distributed generators, or additional loads, onto the distribution network. It was shown how power flow management could integrate distributed generation in a cost effective manner compared with traditional network reinforcements. Power flow management techniques were able to integrate an additional 47% of generation whilst dynamic line rating increases this value to 67%. Voltage management techniques were able to accommodate an additional 60% in generation. Demand side management enabled an additional 27% in load to be connected. A similar study, conducted for a more complex case, encompassing voltage and rating constraints, was able to accommodate an additional 40% of generation.

The analysis of losses suggests that active network management technologies allow for the increased penetration of distributed generation, and may serve to reduce total system losses when compared to network reinforcement alternatives.

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