TOWARDS A FRAMEWORK FOR MODELLING ACTIVE NETWORKS

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ABSTRACT

The emerging international concepts for future distribution networks represent a more active mode of operation. This is now being reflected in the power industry, particularly within the UK, as distribution networks begin to become more active with a view towards facilitating the connection and operation of Distributed Generation (DG). Active Network Management (ANM) schemes are emerging that address the communications and control requirements of managing constraints on the distribution network in real time. This represents a significant change to the mode of operation, which is something the existing distribution network was not designed to support.

This paper presents the issues associated with active networks, with a view towards the development of a modelling and analysis framework. The authors present the fundamental layers of the framework – to be expanded upon in future work – and a case study of the implementation of the proposed framework on a generic distribution system.

INTRODUCTION

An important characteristic of SmartGrids and other future distribution network concepts is the more 'active' nature of the distribution network. Active Network Management (ANM) is expected to emerge as the preferred solution to the connection and operation of DG in the near-term. The deployment of ANM presents the DNO and DG developer with a new modelling challenge, not addressed by the existing connection process for DG. The approach to the connection of DG in the UK is described in [1].

Figure 1 presents the high-level overview of this process with new requirements due to ANM as identified by the authors. At the *project planning stage* there is a requirement that opportunities for ANM be identified or communicated to the developer. At the *information phase* there is a new requirement for a 'first pass' of studies of the deployment opportunities for ANM and the implications for the DNO and developer, which may involve the modelling of scenarios. At the *design phase* it is necessary to perform a detailed study of the ANM scheme selected, which will allow the full economic and technical implications of deployment for all parties to be identified. At the *construction phase* the ANM equipment will need to be installed and coordinated with the DNO, developer or any other third party who are performing the connection. Finally, the ANM scheme will go through the *testing and commissioning phase* to ensure correct operation, which will require the testing of the various functions performed by the ANM scheme.

The framework presented in this paper is relative to the *information phase* and *design phase* of the DG connection process.

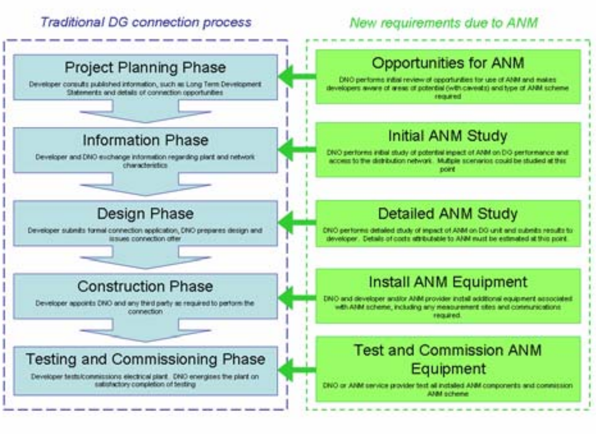

Figure 1: DG connection process in UK and new requirements due to ANM

ACTIVE NETWORK MANAGEMENT

ANM involves the real-time management of distribution network constraints to support the increased deployment of increased DG. A recent review of ANM projects, at varying stages of maturity, is available online [2] and is the subject of another paper at this conference [3], these sources act as a useful access point for interested parties. ANM schemes are in research and development that address the main technical challenges associated with the connection and operation of DG: voltage control, power flow management and fault level management.

The traditional solution to DG is to reinforce the network to avoid network constraints during normal operation and the first circuit outage (FCO). This results in under utilised distribution capacity in most instances. ANM schemes are emerging that provide access to the capacity available in real time due to load and generator output diversity [4].

An active network is shown in Figure 2. The ANM scheme is receiving measurements from multiple locations on the distribution network and can control DG, an Energy Storage System (ESS), Demand Side Management (DSM) and network devices, such as a Static Var Compensator (SVC) for voltage control. The network experiences bidirectional power flows due to the level of DG connected.

A variety of ANM solutions are in research and development. The authors have been developing a power flow solution based on a preventive-corrective approach to controlling DG output [5]. Other solutions are in development for voltage control [6].

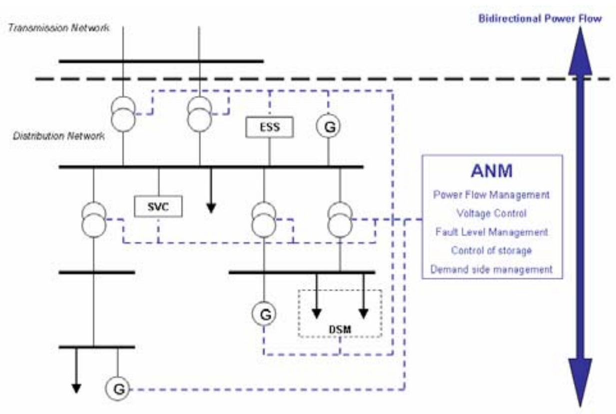

Figure 2: Example of an active network

A FRAMEWORK FOR MODELLING ANM

A high-level framework for modelling an active network is shown in figure 3. The framework presented has five key layers; these layers should be approached in order to allow the full impact of ANM on the distribution network to be understood and quantified.

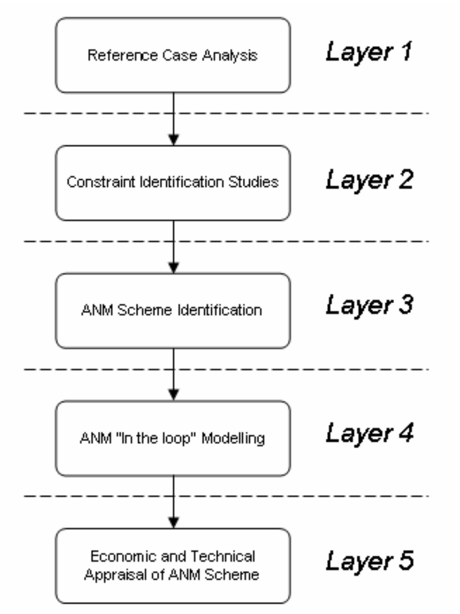

Figure 3: High-level overview of framework for modelling active networks

Layer 1: Reference case analysis

In order to assess the impact of the deployment of ANM it is necessary to understand the performance of the existing distribution network. A model of the existing infrastructure, including any DG or other components should be created. This model should be subject to power system analysis based on existing profile data. Upon completion of this task the voltage profile and power flows on the distribution network should be known, including any breaches of constraints that exist.

Layer 2: Constraint identification studies

Data regarding the proposed DG connection and any additional components should be added to the network model. Power system scenarios should then be studied (perhaps including profile-based analysis) to identify the constraints caused by the addition of the new elements over a typical annual period. These constraints and the overall network performance should be compared to the results from the reference case analysis.

Layer 3: Identification of ANM scheme

Based on the constraints identified, the modeller should select an appropriate ANM scheme, i.e. power flow management solution or voltage control solution. A library of different ANM schemes will be required, including additional items that may be considered as part of the analysis, e.g. reactive compensation devices.
The library of ANM schemes should be structured to guide scheme selection based on which network constraints they help alleviate. The modeller should attempt to select a scheme which addresses all of the constraints identified in Layer 2, but which is not intended to address any irrelevant network issues.

Layer 4: ANM "In the loop" modelling

The model of the ANM Scheme must then be incorporated within the power system analysis process performed in layer 2. The purpose of this layer is to assess the performance of the ANM scheme in terms of the reduction in constraint violations and the impact on the performance of the distribution network. The results of these studies should be compared to the results from Layer 1 and Layer 2.

Layer 5: Technical and economic appraisal of ANM

Using the outputs from the analysis performed in Layer 4 the DNO and DG developer will need to assess the implications of ANM against their own economic and technical criteria. This will involve considering the main business drivers, regulation, incentives and penalties.

CASE STUDY – APPLICATION OF ANM MODELLING FRAMEWORK

A generic distribution network was used to demonstrate the application of the ANM modelling framework. The network is UKGDS-EHV1, which is one of the outputs from the United Kingdom Generic Distribution Network project [7]. UKGDS-EHV1 is shown in Figure 4.
UKGDS-EHV1 consists of three voltage levels: 132kV, 33kV and 11kV. The connection to the transmission network is modelled as an equivalent swing generator connected to a 132kV bus, stepped down to 33kV at the bulk supply point (BSP). The total load on the network varies from a summer minimum of 5.7MW to a winter maximum of 36.89MW.

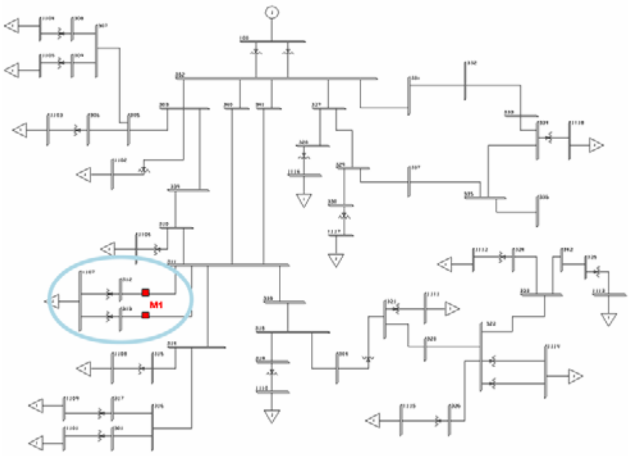

Figure 4: UKGDS-EHV1 with DG location and measurement points identified

A 30MW wind farm was added to the network at bus 1107, modelled as a doubly fed induction generator. This generator is attempting to maintain the voltage at bus 1107 to 1pu and has a power factor range of 0.95 leading to 0.95 lagging.

All system studies were performed in PSS/E using the full Newton Raphson solution method.

Layer 1: Reference case analysis

Generation was added to the network as described in [8] until no capacity was available during the N-1 contingency (the loss of one transformer at the BSP). Load flow studies were performed using PSS/E to establish power flows and voltage profiles. No thermal violations exist on the network. The voltage profile of the network with no DG present led to some low voltages (around 0.92 per unit) at periods of high demand. The addition of DG has reduced the magnitude and number of low voltages and all 11kV supply terminals are within +/- 3% per unit.

Layer 2: Constraint identification studies

The 30MW wind farm was added to the network at bus 1107 (circled in figure 4) and load flow studies were again performed using PSS/E. The load at bus 1107 has a peak of 18.5MW. The additional power flows from the new DG causes the thermal limits to be breached on the export branches at location M1 on figure 4. No further or exacerbated voltage issues were found.

Layer 3: Identification of ANM scheme

The ANM scheme described in [5] was chosen to manage the power flows at M1. The ANM scheme has been developed by the authors to take a preventive-corrective approach to ANM. Upon measuring the overloading of circuits at M1 (by reference to current thresholds with operating margins), the ANM scheme requests a reduction in output from the DG unit – this is the preventive action. If this reduction is unsuccessful or a period of time has passed, the ANM scheme will trip the DG unit – the corrective part of the algorithm.

Layer 4: ANM "In the loop" modelling

The ANM scheme may be represented at a high level as follows, for the example of an overload at M1:

```
if M1.overloaded?
  DG.trim((M1.loading – M1.rating)* Factor)
  Start timer x
  Timer x expired
  if M1.overloaded?
    DG.trip
  end
end
```

Code to permit the inclusion of the ANM scheme in the power system analysis procedures was written using iPLAN and iDEV macros in PSS/E.

Load flows were performed automatically based upon the status of the branches under consideration, with the size of the DG being dynamically adjusted to reduce thermal breaches and then tripped off if breaches continued.

The reduction required is calculated as the measured breach of the rating, multiplied by a sensitivity factor (Factor) to ensure the output reduction of the DG unit is adequate. It is worth noting, however, that load variation and the variation in output from other DG could potentially impact on the effectiveness of the DG output reduction.

Some results from the ANM "in the loop" modelling are presented in Table 1. At maximum demand, the connection of the 30MW generator causes the export at M1 to reach 23.7MVA, representing a 118.6% loading. In response, the ANM scheme trims the DG output to 26.3MW, but in the scenario considered the export branch loading at M1 is only reduced to 20.3MVA or 101.3%. The continuing overload causes the ANM scheme to trip the DG unit and the power flow at M1 returns to reference case levels.

Table 1. Some results from ANM "in the loop" simulations

Case	Power Generated (MW)	Export branch loading (MVA)	Loading (%)
Reference	0	9.6	48
30MW DG at full output	30	23.7	118.6
Trim DG	26.3	20.3	101.3
Trip DG	0	9.6	48

In other studies that were performed, the trimming operation successfully eliminates the branch overload. Other scenarios considered different response characteristics of DG and also the use of short term ratings of critical plant.

Layer 5: Technical and economic appraisal of ANM

A profile based analysis of the 30MW DG connection at bus 1107 was performed for an annual period. A profile of the demand at bus 1107 was also required to determine the power flow at M1. When the capacity of either circuit from bus 1107 is breached the DG unit has its output trimmed (reduced) to remove the overload. The impact on the annual energy production of the DG unit is presented in table 2.

Table 2. Annual energy production of actively managed DG unit

Size/ Nature	Annual energy production (MWh)	Annual energy curtailed (MWh)	Capacity factor without curtailment	Capacity factor with curtailment
30 MW Wind Farm	106,546	3,497	0.4175	0.4043

The DG unit generates 106,546MWh under the application of ANM. The total annual curtailment due to thermal constraints on the network is 3,497MWh. The impact of this curtailment is to reduce the capacity factor of the wind farm from 0.4175 to 0.4043.

The performance data presented above must now be assessed in terms of the impact on the DG business. Additional factors that require consideration are:

- Avoided network reinforcement costs
- DG connection costs plus other capital costs
- Additional costs for connection to ANM scheme
- Revenue due to energy sales and renewables incentives (i.e. ROCs in the UK)
- Revenue lost due to curtailment
- Internal rate of return required by developer

The DNO must also assess the DG connection and ANM deployment, considering such factors as:

- Interactive DG applications
- Long term capital and operational expenditure
- Planned network upgrades
- Network performance and associated incentives and penalties
- Further DG connection opportunities
- Integration of ANM with existing infrastructure and practice (including maintenance and safety concerns)

CONCLUSIONS

This paper has presented a high-level framework to facilitate the modelling of active networks. The new challenges associated with ANM and the impacts on the traditional DG connection process have been identified. The framework allows the full implications of ANM deployment to be studied. A case study has been presented to show the application of the framework presented.

ANM holds potential for enabling the near-term connection of DG and could play a significant role in meeting renewable energy targets. DNOs and DG developers will need to fully understand the framework presented to ensure the correct investment decisions are made.

A more detailed presentation of the framework and the technical and economic appraisal of ANM will be given in future work.

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