INTEGRATING VOLTAGE CONTROL AND POWER FLOW MANAGEMENT IN AURA-NMS

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ABSTRACT

AuRA-NMS is an autonomous regional active network management system currently being developed in the UK through a partnership between several UK universities, EDF Energy, ScottishPower and ABB. The scope of control to be undertaken by AuRA-NMS includes: automatic restoration, voltage control, power flow management and implementation of network performance optimisation strategies. Through the adoption of a novel active network management system architecture based on multi-agent system (MAS) technology, AuRA-NMS aims provide a flexible and extensible means of developing solutions for a range of different types of network. This paper introduces the AuRA-NMS concept, gives details of the hardware platform it will be implemented on, discusses the potential voltage control and power flow management techniques the system may employ and the use of MAS technology as a means of integrating those approaches.

INTRODUCTION

The proliferation of distributed generation is changing the way distribution networks in the UK are designed and operated. While the renewable obligation certificate (ROC) scheme has provided the incentive for generators to connect to the distribution networks, the burden of any requisite network reinforcement can be prohibitive. As a result utilities are looking to active network management solutions [1] which allow generators to connect to existing networks under a range of connection agreements, while avoiding, or at least reducing or deferring, the costs associated with network reinforcement.

The register of active management pilots, trials, research, development, and demonstration activities [2] details over 100 distinct activities in the UK and beyond, with the most mature activities in areas of distributed coordinated voltage control and active power flow management.

Under the current regulatory framework in the UK, utilities are motivated to minimize the capital expenditure required to meet their license obligations. Active network management can be one means of doing so. There may be ancillary benefits of levels of automation if, as well as increasing DG access, it can improve network performance, i.e. reduce customer minutes lost (CML), customer interruptions (CI) and minimize losses, through automated restoration or automated network control which takes action to minimize losses.

This paper introduces AuRA-NMS, an autonomous regional active network management system, currently being developed by a partnership of several UK universities, two distribution network operators (DNOs), and ABB. AuRA-NMS is a distributable system and the scope of automation and control it is currently being developed to undertake includes: automatic restoration, voltage control, power flow management, and the implementation of network optimization strategies, such as the reduction of losses.

While the development of AuRA-NMS is being driven in part by the current needs of the partner DNOs, it is also being developed to be both flexible and extensible. Flexibility connotes the ability to easily reconfigure the control system in the face of:

- Changes to network topology and plant ratings;
- The connection/ removal of generation or energy storage;
- Changes to protection and control equipment;
- The installation/removal of measurement and monitoring equipment; and
- Changes to the commercial and regulatory framework in which the DNOs and generators operate.

Extensibility, on the other hand, connotes the ability to easily:

- Add additional network control and management functionality in the future; and
- Replace existing functionality when improved network control and management techniques or algorithms are developed.

Flexibility and extensibility are key attributes that utilities require in future active network management systems if they are to be manageable over the longer term. In this paper the authors discuss some the potential voltage control and power flow management techniques that could be employed by AuRA-NMS. The following control actions are being considered for AuRA-NMS:

- DG output and power factor control
- On load tap changers;
- Energy Storage System (ESS) regulation;
- Network reconfiguration and Load shedding

HARDWARE PLATFORM

Aura-NMS can be viewed as distributed network management and control software running on a distributed hardware platform. For the initial trials of AuRA-NMS that hardware platform will be provided by ABB's COM 600 series substation computer, existing inter and intra substation communication infrastructure and additional communication links where deemed appropriated.

ABB's COM 600 series substation automation product is a Windows XP Embedded industrial computer designed for robustness which has no moving parts. The full specification of the functionality of the COM 600 series can be found on ABB's website [3].The COM 600 has been designed to act in part as a substation gateway which translates between various master and slave protocols using IEC 61850 as a common data model and OPC technologies [3]. It currently supports a number of local and remote substation communication protocols including: DNP3, MODBUS and IEC 61850. As a result, the COM 600 comes with a readymade software interface to existing protection, control and monitoring systems as well as existing communication networks.

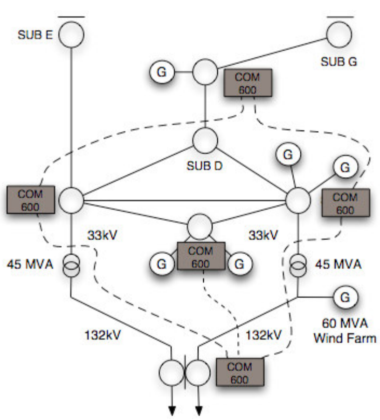

Fig 1: Networked set of COM600 units

Networked using either the existing communications infrastructure or, if cost effective, additionally installed communication channels, a network of COM 600s across several substations can provide a distributed hardware platform on which power system management and control software such as those discussed in the following sections can be deployed (Fig. 1).

POWER FLOW MANAGEMENT TECHNIQUES

The AuRA-NMS system seeks to automatically detect and offer solutions to thermal overloads.

The available control actions that can be taken for thermal overload alleviation are various and will differ from network to network. AuRA-NMS must recognise these differences and offer a solution that is plausible for the given networks and location of any thermal breach.

There are a number of candidate techniques being investigated by the authors for the responsive management of network power flows within AURA-NMS. These include:

- A current tracing approach to power flow management;
- Power flow management cast as a finite discrete domain constraint satisfaction problem (CSP);
- Power flow management cast as an AI planning problem; and
- Power flow management cast as an optimisation problem.

Current tracing has been used in transmission system usage and evaluation of the contributions from generators to loads [4]. A combination of this approach with sensitivity analysis for proportional curtailment of controllable generation to an overloaded circuit could be a strong candidate. Offering the attributes of minimal load flow calculations and being a distributable solution fits well with the AuRA-NMS requirements.

CSP [5] consist of:

- a set of variables, in this case controllable plant;
- a set of discrete and finite domains which define the values that the variables can hold, i.e. control actions;
- a set of constraints, i.e. flows must be within thermal limits plus any contractual constraints on permissible control actions e.g. curtailing of generation.

A CSP solver can be used in tandem with a load flow engine to find the preferred set of values that the variables can be assigned whilst meeting the constraints (Fig. 2).

The authors have also earmarked AI planning as potential approach [5]. Similarly power flow management could possibly be recast as an optimal power flow problem; however, studies would be required to demonstrate that it is feasible to find solutions in the required timescales on the target hardware platform. As a result, the authors are currently assessing the performance of all four of these techniques on the hardware platform in order to evaluate the feasibility of their use in AuRA-NMS.

Initial results for the use of CSP and current tracing look promising. Evaluation of the CSP approach based on experiments on the COM600 has shown that 'DG Regulation' solutions can be derived in under 10 seconds for the test, meshed and radial, networks provided by the utilities. The simulations used a first-on, last-off generator constraint and an operation within thermal limits constraint with checks made using a load flow engine. AI planning and OPF for power flow management have yet to be tested on the hardware platform.

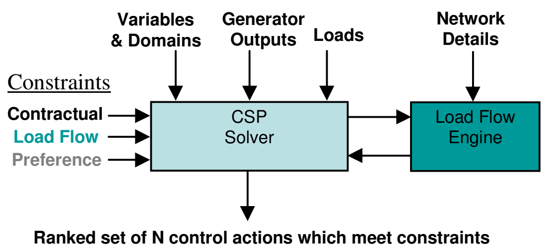

Fig 2: CSP solver inputs and load flow engine interaction

VOLTAGE CONTROL TECHNIQUES

The AuRA-NMS system seeks to control network voltages in a way that maximises DG energy yield without compromising security of customer supplies.

By using one or a combination of control measures, the voltage can be kept within statutory limits or DNO specific limits under normal and abnormal conditions proactively and responsively on radial and meshed distribution networks. Herein, proactive control refers to anticipating the location, period and possibility of a potential voltage excursion and taking action to avoid this voltage excursion over a period of time, from 30 minutes to 3 hours ahead. Responsive control governs the actions taking to restore voltages back to within limits on a time scale of approximately 5 to 30 minutes.

Case based reasoning (CBR) [6] is being investigated as the strategy for identifying possible voltage control solutions within AuRA-NMS. CBR is an artificial intelligence technique which aims to solve a problem by retrieving the matched cases in the case base library. The retrieved cases are used to suggest a solution which is reused and tested for success (Fig. 3).

A well designed case base library is crucial for a CBR system. For AuRA-NMS, various offline simulations are conducted under different network scenarios, the key features, such as, the location of the voltage excursion, the network topology information and tap changer position are recorded in a database.

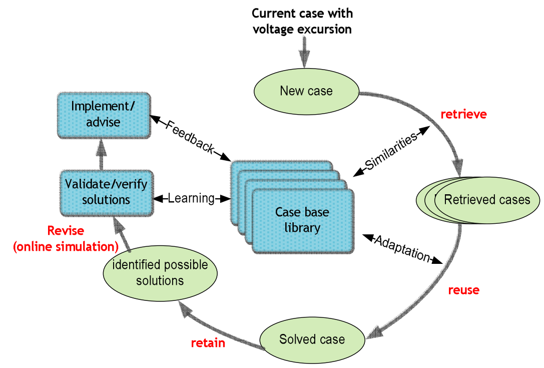

Fig. 3 A proposed voltage control approach using CBR

When a new voltage excursion case occurs on the network, CBR will quickly search the case library database by case features. For each numeric feature, a similarity will be calculated as described in [6].

Within AuRA-NMS, a number of candidate solutions to any voltage control issue would be provided by CBR along with their corresponding overall similarities. The most closely matched control solutions (with highest overall similarities) will be validated/ verified.

An online simulation tool would then be used to identify the effectiveness of all available credible control solutions in response to voltage excursions. In order to validate/verify the solutions chosen by CBR, their effectiveness would be measured against criteria, such as acceptable voltages, losses and network safety. If any of the candidate solutions are deemed unsuitable, they will be modified in pursuit of improved performance. The modified solutions will be recognised as a new solution; therefore the case base library will be updated. The control solutions which have been successfully implemented will be noted and the case base library will be updated according to the feedback from implementation. The case base library will be updated such that successfully applied solutions are assigned a higher weighting than similar currently unproven solutions.

INTEGRATING CONTROL FUNCTIONALITY

The preceding sections have shown that a number of different options exist for performing both voltage control and power flow management. Not only do these techniques need to exhibit the flexibility and extensibility required for AuRA-NMS, the system architecture in which they reside also needs to display the same flexibility and extensibility: control functionality needs to be distributed as required and removed, replaced or even extended. The authors are currently investigating the use of Multi-agent Systems (MAS) technology to provide such as "plug and play" software architecture for AuRA-NMS.

MAS technology as a means of integration

MAS technology can be used as a flexible and extensible way of both integrating and distributing the software across the AuRA-NMS hardware platform. To achieve this, the appropriate power system control decision-making software, e.g. the CSP power flow management technique and the CBR voltage control technique described above, can be wrapped as autonomous intelligent agents [7] and by augmenting **them** with the functionality required to display the properties associated with agents.

The use of Foundation for Intelligent Physical Agents (FIPA) compliant multi-agent systems to provide open, flexible, and extensible software solutions has been reported previously and the arguments for how MAS provides flexibility and extensibility can be found in [7]. Within AuRA-NMS FIPA standards are being combined with existing power engineering standards such as IEC 61850 and the Common Information Model (CIM) to provide a flexible and extensible active network management system software architecture.

However, while MAS provide a means of software integration, in terms of interoperability, while providing flexibility and extensibility, MAS do not necessarily lead to seamless integration of control functions: the problem of arbitration still needs to be overcome.

Arbitration

The approach of using a number of disparate control techniques taken in AuRA-NMS creates a challenging problem: the problem of arbitration. In certain situations problems may arise when agents responsible for voltage control, power flow management, restoration or some other yet undefined service, wish to carry out conflicting actions in order to achieve their goal: some method of arbitration is required.

Fig. 4 shows an arbitration agent receiving proposed actions for a number of other agents. In order to arbitrate between the goals of the different agents, the arbitration agent needs to be able to detect conflict and have some knowledge of the DNO's priorities.

The authors are currently investigating a MAS technique called reflection which may have a role to play in this type of situation. Reflection is the ability of an agent to reflect on the knowledge, abilities and goals of other agents. Reflection has already been applied successfully in the COMMAS system [8] and employs probabilistic methods based on Bayesian belief networks for enhancing the evaluation of competing classifications of partial discharge data.

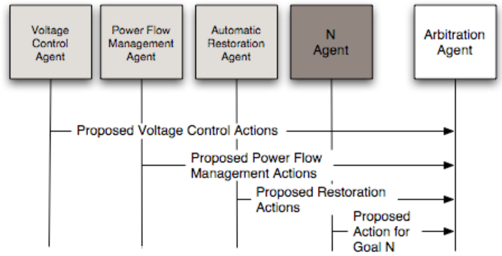

Fig. 4. Role of Arbitration Agent

CONCLUSIONS

This paper presented the AuRA-NMS approach to the control of distribution networks. This approach is underpinned by the desire to provide a flexible and extensible solution. It is clear that voltage control and power flow management can be tackled in a number of ways and that the ability to employ different methods within the AuRA-NMS system is desirable. MAS are being investigated as a way of providing this flexibility however the issue of arbitration between potentially conflicting control requirements must be resolved. Reflection is being considered as a means of addressing this issue.

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