AN ARCHITECTURE FOR FLEXIBLE AND AUTONOMOUS NETWORK MANAGEMENT SYSTEMS

Euan M. DAVIDSON
University of Strathclyde – UK
edavidson@eee.strath.ac.uk

Stephen D.J. MCARTHUR
University of Strathclyde – UK
s.mcarthur@eee.strath.ac.uk

James R. MCDONALD
University of Strathclyde - UK
j.mcdonald@eee.strath.ac.uk

Philip TAYLOR
Durham University – UK
p.c.taylor@durham.ac.uk

ABSTRACT
This paper presents the architecture of AuRA-NMS, an autonomous regional active network management system currently being developed in the UK through a partnership between several UK universities, two distribution network operators (DNO) and ABB. The AuRA-NMS architecture has two central facets: a number of software elements which provide the data gathering and novel decision-making functionality within AuRA-NMS; and the hardware platform, comprising: off-the-shelf substation computing and automation equipment; and an existing, possibly augmented, communication infrastructure, on which that software is deployed. In this paper the authors describe the design philosophy which determines where both software and hardware is located on a distribution network based on the utilities’ existing communications infrastructure and their active network management needs. Case studies illustrating the architectural philosophy applied to two different networks operated by different DNOs with differing requirements are presented. The evaluation and testing of the current implementations of AuRA-NMS, based on this architecture, as well as the challenges still outstanding will also be discussed.

INTRODUCTION
While in the US the development of active network management systems is being driven by the need for congestion management, in the UK and Europe the development of active network management systems is being driven by the need to provide network access to small scale generators to traditionally passive distribution networks that cannot support firm connections. In the UK the renewable obligation certificate (ROC) scheme has provided the incentive for generators to connect to distribution networks but in some cases the burden of any required network reinforcement can be prohibitive. In addition to the cost of the reinforcement works, the time required for seeing any network reinforcement through the appropriate planning processes can also be a disincentive. As a result utilities in the UK are looking to active network management solutions 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 network management pilots, trials, research, development and demonstration activities details over 100 such activities both in the UK and beyond. One of these activities is the autonomous regional active network management system (AuRA-NMS) programme, a research, development and demonstration initiative which aims to develop a flexible and extensible active network management system that can be deployed on a variety of different networks.

AURA-NMS: THE CONCEPT
AuRA-NMS represents a move from bespoke single issue active network management solutions to more generic solutions that can quickly be applied to a variety of networks, deal with multiple issues, e.g. power flow management, steady state voltage control, restoration, and minimisation of losses, and offer an increased degree of flexibility and extensibility once in place. Flexibility is the ability to easily reconfigure the active network management system in the face of: changes to network topology and plant ratings; the connection or removal of new generation or energy storage; changes to the installed protection and control equipment; the installation or removal of measurement and monitoring equipment; and changes to the regulatory framework in which DNOs operate and the markets in which generators connected to the network participate. Extensibility is the ability to easily: add additional network management and control functionality in the future; and replace existing functionality when improved network management and control techniques are developed.

In addition to offering flexibility and extensibility, AuRA-NMS is being developed to be safe, secure, tolerant to failure, and to possess the ability to exhibit graceful degradation in performance during adverse or unanticipated network conditions.

A key part of the AuRA-NMS concept is the notion of an active network management system that integrates a number of disparate approaches to a number of different power system management and control tasks. A description of the control techniques themselves are out of the scope of this paper, however [3][4] present results on the development and testing of novel approaches to
voltage control using case-based reasoning (CBR) and power flow management using constraint programming and current tracing. To date the AuRA-NMS consortium has developed standalone software libraries which implement different approaches to: automatic restoration; power flow management; and steady state voltage control.

These approaches have been designed to be network agnostic, allowing them to be applied to a range of networks regardless of topology. Moreover, several approaches to the same control and management task are being developed in order to compare the performance of different approaches, e.g. in [4] initial results of comparative testing of a constraint programming based approach and a current tracing approach to power flow management is presented.

A novel aspect of AuRA-NMS is the integration of these differing approaches to different power systems control and management tasks within a single flexible and extensible architecture. This paper discusses the development of that architecture and the rationale behind the adoption of certain standards and technologies.

AURA-NMS: THE ARCHITECTURE

AuRA-NMS can be viewed as disparate distributable power systems management and control software running on a distributed hardware platform.

The hardware platform and architecture

The hardware platform comprises substation computing equipment on which the control software with the network management and control functionality is installed, IEDs, potentially PLCs and PACs used for measurement gathering and simple control functionality, and the communications infrastructure linking this hardware in different locations. The substation computing equipment on which the AuRA-NMS software will initially be deployed is ABB’s COM600 series substation automation product which is a Windows XP Embedded industrial computer that, designed for robustness, has no moving parts. Full details of functionality and specification of the COM600 series can be found on ABB’s website [5].

The COM600 has been designed to act in part as a substation gateway which translates between various master and slave protocols using IEC 61850 as a standard data model using a collection of OPC clients and servers with interfaces to legacy intra and inter substation communication protocols including: DNP3; MODBUS; PROFIBUS; and IEC 61850 using OPC and MMS [5]. As a result, the COM600 provides AuRA-NMS software with ready-made software interface to existing monitoring, protection and control equipment as well as existing communications networks that use the protocols the COM600 supports. Moreover, it provides a powerful substation computing platform on which power system management and control software can run.

While COM600 units, IED, PLCs, PACs and existing possibly augmented communications infrastructure provide the hardware building blocks of AuRA-NMS, AuRA-NMS offers a software architecture, running on one or across several COM600 units.

The Software Architecture

Via its OPC servers [5], the COM600 provides a ready-made software interface to external IEDs, PLCs and PACs that support the communication protocols (fig 1).

While the use of multi-agent system (MAS) technology for distribution automation has been mooted by several authors, AuRA-NMS is different in that it does not map an agent architecture onto the existing topology of the power system, i.e. in AuRA-NMS agents do not represent specific generators, circuit breakers, feeders or busbars. AuRA-NMS exploits multi-agent systems technology as a means of providing a flexible, extensible and distributable software integration framework. The use of MAS technology to this end can be found in [6]. Details of the use of MAS for AuRA-NMS and the rationale for its use in AuRA-NMS can be found in [7].

In order to design the appropriate agent architecture, a detailed specification process was undertaken. In collaboration with the industrial partners, a requirements specification, functional specification and set of design specifications were generated. These drove the architecture design, and prevented assumptions being made about the distribution and deployment of hardware and software.

A key component of the AuRA-NMS architecture is the use of the Foundation for Intelligent Physical Agents
(FIPA) standards (IEEE Computer Society). The interested reader can find out more on the use of FIPA standards within AuRA-NMS in [7]. These standards, in part, help provide the software architecture with the flexibility and extensibility required for AuRA-NMS. The agent platform, highlighted in figure 1, is part of the FIPA standards. In order for AuRA-NMS agents to seamlessly integrate with IEC 61850 then AuRA-NMS agents use an agent ontology, the vocabulary of the agent's communication language based on the IEC 61850 data model and the common information model (CIM).

Distribution State Estimation is integrated into the architecture by exploiting the ability of the COM600 to manage virtual IEDs [5] via a virtual IED OPC server. System voltage, currents and loads estimated by the DSE can be written to these virtual IEDs and then used by the AuRA-NMS agents which can connect to OPC servers which support the IEC 61850 data model.

Arbitration

The approach taken in AuRA-NMS is the integration of a number of disparate control techniques rather than designing a single controller capable of carrying out all required power system management and control tasks. This leads to the need for arbitration between potentially conflicting sets of control actions suggested by restoration, power flow management and voltage control agents.

The concept of arbitration between control systems in power systems can be found in the literature relating to special protection systems (SPS). The approach used in SPS is to use arbitration logic based on a set of control signals [8]. Such an approach may be applicable with AuRA-NMS but whether it would afford the extensibility required by DNOs is arguable; arbitration logic may have to be re-implemented as the DNO's goals change, therefore agents providing the power system management and control decision making functionality for different tasks are replaced with alternative agents employing different approaches to power flow management, restoration, voltage control or minimisation of losses.

A MAS technique known as reflection may have a role to play in this situation. Reflection is the ability of an agent to reflect on the ability, knowledge and goals of other agents during its decision-making. Probabilistic reflection methods have already been successfully applied within a condition monitoring application [9] however it is questionable if the use of weightings or some other measure of preference for discriminating between competing sets of control actions would be appropriate within AuRA-NMS: such methods do not provide a rationale for the selection of one set of control actions over another. Hence, symbolic forms of reflection or a hybrid approach may be required in order to capture rationale and provide an appropriate level of explanation for arbitration decisions.

At the time of writing the authors are investigating a number of different approaches to arbitration. A strength of the use of MAS technology is that different approaches to arbitration can be tested within the same architecture. At any point the arbitration agent can simply be replaced by another arbitration agent using different methods.

DISTRIBUTING ACTIVE NETWORK MANAGEMENT FUNCTIONALITY

What functionality is required to meet the DNO's active network management requirements can differ depending on a number of factors. Part of the AuRA-NMS programme is the development of a deployment methodology that, based on DNO's needs and existing communications infrastructure, determines where COM600 should be placed on a network, any augmentation of the DNO's communications networks and how AuRA-NMS agents should be distributed within the AuRA-NMS software architecture. Below two different networks are briefly discussed.

Case study 1: 11kv radial network

Case study network 1 (fig. 4) represents a fairly standard radial network with limited measurements in place.
Distribution state estimation is required in this case as it is unlikely that it would be economic for the DNO to instrument the network to provide all measurement required by the restoration and voltage control techniques. Given that the DNO wishes to exploit the existing communications infrastructure, not shown here for the sake of brevity, the COM600 unit would be placed in the primary substation. Agent-based software for restoration, power flow management, voltage control and arbitration would be deployed with the software architecture.

Operated by a different DNO, case study network 2 (fig. 5) presents a different set of challenges. The topology of the network is such that automatic restoration is not a key requirement of the DNO but voltage excursion problems and thermal constraints require active network management solutions. In the case of this network, existing network measurement points mean only a handful of additional measurements would be required in order to use the power flow management techniques and voltage control techniques in [3][4]. No state estimator would be required as all points are measured directly. The existing communications infrastructure means that all relevant measurements and control signals can be sent and received from substation A. Hence, the COM600 unit would be installed in SUB A (fig. 4).

Case study 2: Interconnected 33kV network.

Figure 4: Test network 2

TESTING

AuRA-NMS is being tested using a real time simulation environment developed and managed by Imperial College London. At the time of writing, testing was focused on unit testing of the different control and management approaches to the restoration, power flow management and voltage control tasks. However, initial tests of the MAS platform running on several COM600 units located at 3 different universities over a secure VPN, have indicated that MAS technology runs robustly on such hardware. Performance of the MAS degrades gracefully should communications links between the COM600 units be lost. Once unit testing of the control approaches is complete, these will be integrated with the AuRA-NMS architecture and the performance of different approaches to arbitration can be evaluated.

CONCLUSIONS

This paper has presented the proposed AuRA-NMS architecture. The role of existing standards such as IEC61850, OPC, and the FIPA standards for MAS within that architecture has been discussed. Case studies have illustrated how the approach described could be applied to two different case study networks. It has also highlighted the research questions relating to arbitration that still need to be addressed.

Acknowledgements

The authors would like to acknowledge the input of their academic partners at Imperial College, the University of Cardiff, the University of Edinburgh and the University of Loughborough.

REFERENCES

[5] ABB COM 600 Product Website: http://www.abb.com/Product/seitp328/3cc7d0b2a99f2f40c1257188002facd2.aspx?productLanguage=us&country=00