CASE BASED REASONING FOR DISTRIBUTED VOLTAGE CONTROL

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ABSTRACT

Distribution networks were not designed with significant levels of Distributed Generation (DG) in mind, therefore the proliferation of DG results in a number of technical challenges. Controlling network voltages, while also providing adequate DG access, represents one of the most important challenges. This paper presents research being carried out, as part of the UK AuRA-NMS research project, to address this challenge through the novel application of novel case based reasoning.

INTRODUCTION

The proliferation of distributed generation (DG) on electricity distribution networks can result in a number of adverse impacts, including voltage variation, degraded protection, altered transient stability, bi-directional power flow and increased fault level. Controlling network voltages, while also providing adequate DG access, represents one of the most important challenges [1]. As a result utilities are looking to adopt active network management solutions which allow significant levels of DG to connect to existing networks while ensuring statutory voltage limits are not exceeded.

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. Aura-NMS can be viewed as distributed network management and control software running on a distributed hardware platform (Fig. 1). 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.

This paper introduces an intelligent voltage control approach which makes use of a case base reasoning (CBR) technique. Results from real-time simulation based testing of the CBR based voltage control approach are also presented in this paper.

VOLTAGE CONTROL TECHNIQUES ON DISTRIBUTION NETWORKS

In comparison to transmission lines, the typical X/R ratio of a distribution network is relatively low; therefore any significant power output of DG or heavy load conditions will result in voltage variations on the distribution network. Severe voltage variations could occur under the following situations:

- DGs operating at maximum output during minimum load periods;
- DGs operating at low or zero output during peak load periods.

To avoid any severe voltage problems on distribution networks, distribution network operators (DNOs) may employ one of the following control measures:

- On load tap changer control;
- DG power output and power factor control;
- Energy Storage System (ESS) regulation;
- Network reconfiguration;
- Demand side management (DSM);
- Reactive power compensation.

Due to the complexity of existing electricity distribution networks, a single control measure strategy is often insufficient in solving voltage problems. Therefore, hybrid and cooperative methodologies are likely to produce the best results.
AuRA-NMS 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, therefore the following control actions are being considered:

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

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.

CASE BASED REASONING

Case based reasoning (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. CBR has created numerous applications in a wide range of domains, including: diagnosis, planning, customer support, assessment, decision making and legal reasoning. In electrical power systems, only a few applications have been investigated so far.

Long et. al [2] proposed a CBR system for controlling generators during emergency conditions. The CBR needs to determine the amount of generation increase/decrease required from the value of area control error. System topologies at the time of the disturbance and the generators available for dispatch are important parameters. The amount of generating capacity remaining for these generators must also be determined. Once these states are known, the CBR will begin to retrieve the problem from the database. The set points for each of the generators are then sent out by the CBR system to the automatic generator controller.

A hierarchical CBR (HCBR) methodology is proposed for power system restoration decision making in [3]. HCBR includes two types of cases:

- abstract cases with solutions that correspond to high-level plans for particular problems;
- concrete cases with detailed solutions that correspond to particular problems.

When a problem occurs, the HCBR will make an enquiry to the abstract cases, high-level descriptions of the target solution will be returned. This high-level solution is further refined by retrieving and adapting more specific cases, each solving some sub-problems of the target. Eventually, concrete cases are selected and an actual solution can be proposed.

A SQL-based approach to similarity assessment is presented in [4]. This novel approach is proposed where the retrieval of the case information and the calculation of the similarity values are performed in one action. This algorithm was successfully applied to the design of protection schemes for transmission networks. A web-based design decision support system called DEKAS (Design Engineering Knowledge Application System) was developed which utilises CBR to provide support to the various activities within protection scheme design.

CBR for AuRA-NMS voltage control

CBR is being investigated as the strategy for identifying possible voltage control solutions within AuRA-NMS. A modified CBR system for the AuRA-NMS voltage control function is illustrated in Fig. 2, the software design is shown in Fig. 3.

Typically, a CBR system comprises the following sub functions [5]:

- Retrieve the most closely matching (highest similarities) cases with their corresponding solutions from the case base library.
- Reuse the cases to attempt to solve the current problem case, adaptation maybe included.
- Revise the proposed solution if necessary.
- Retain the new solution as a new case.

In the schematic cycle of the CBR system, a well designed case base library is crucial. 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. The database can be populated manually or potentially through the use of an optimal power flow (OPF) technique. The database was designed in a non network specific structure; therefore it could be used for various networks under different situations.

When a new voltage excursion case occurs on the network, the CBR engine searches the case library database by case features. For each numeric feature, a similarity measure is
Fig. 3 CBR prototype software design calculated as described in [4]. Within AuRA-NMS, a number of candidate solutions to any voltage control problem can be provided by CBR along with their corresponding overall similarities. The most closely matched control solutions (with highest overall similarities) are then validated/verified. An online verification tool is 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 the current implementation of the online verification tool uses a load flow engine to check that all voltages are within limits.

If any of the candidate solutions are deemed unsuitable, they will be modified in pursuit of improved performance. The modified solutions will be recognized 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 feedback from implementation.

SIMULATION

Test network
A CBR system was tested on a simplified UK distribution network, the network IPSA+ model is shown in Fig. 4. The test network is a 42 bus 11kV radial network with 2 DGs and 3 transformers. In the simulation, voltage constraints on busbars are set at ±3% which is stricter than the normal DNO’s operating limits. This tighter limit is used such that voltage control problems are experienced even at modest levels of DG, which therefore facilitates comprehensive testing of the CBR system. More details of the DGs, loads and transformers are described in Table 1.

Real time Simulator
The role of the real-time (RT) power network simulator is to re-create network conditions suitable for testing the control algorithms. This is done by feeding the algorithms with RT measurements from the network and also by applying to the

<table>
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<tr>
<th>Operating range</th>
<th>Details</th>
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<tr>
<td>DG1 [0, 2] MW 0 [0, 0.4] MVAr</td>
<td>Landfill gas</td>
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<tr>
<td>DG2 [0, 3] MW 0 [0, 0.6] MVAr</td>
<td></td>
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<tr>
<td>Loads [30% 100%] of maximum load values</td>
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<tr>
<td>Transformer 1, 2 &amp; 3 [1-10, 10] Tap step=1</td>
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pre-defined load and generator profiles and feeds the data to the COM600 servers. Also, it reacts to any change of the control data and applies the change to the simulated network.

The RT simulator is implemented in C++ and uses the embedded Python interface to IPSA+ for the power-flow engine and the manipulation of the network parameters.

**Simulation results**
The results of CBR based voltage control prototype software are displayed in a graphical user interface (GUI). The GUI shows the following:

- Details of identified voltage excursions;
- The 5 most similar cases retrieved by the CBR;
- The results of online verification tool for the proposed solutions to those 5 cases.

During the simulation, a pre-defined DG and load profile were employed to create a voltage excursion (over limit) on the test network. The software checked the voltage level of each monitored busbar continuously, once an excursion was detected, the location and severity of the excursion, as well as the current network status, such as transformer tap position, are presented on the GUI. The 5 most similar cases were retrieved from the case base library within 0.1 second; corresponding solutions were identified for verification. Then the solutions were evaluated by the online verification tool, all the solutions which passed the online verification check were shown in GREEN in the GUI, otherwise the solutions were shown in RED (Fig. 6).

**CONCLUSION**
This paper has presented the first version of the AuRA-NMS voltage control approach utilising CBR. The test results demonstrated that CBR provides an effective approach to solving voltage variation problems on radial distribution networks by employing OLTCs, DG power and power factor control techniques. Further research in this particular area will continue to investigate more advanced features, such as closed loop testing, applications to meshed networks, automatic database generation using OPF and more voltage control techniques, such as ESS and network reconfiguration.

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**REFERENCES**


