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Active Management of MV and LV Distribution Networks

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Abstract

The proliferation of distributed generation (DG) is expected to lead to a change in philosophy in the manner that distribution networks are managed and operated. It is envisaged that distribution networks will be transformed from passive to active entities in order to accommodate the connection of DG. This paper presents current research at Durham University relating to the active management of distribution networks at MV and LV levels. A dynamic thermal rating system has been proposed for the control of DG at the MV level. Furthermore, a multi-agent system-based distributed control approach has been presented for the coordinated control of micro-generators, energy storage units and controllable loads at the LV level.

Keywords: Distributed Generation, Micro-generation, Distribution Networks, Active Network Management, Active Distribution Automation.

1. Introduction

Distributed generation (DG) includes all electricity generation plants connected to distribution networks. These may employ a number of different technologies and fuels using synchronous or non-synchronous electrical generators. Most distributed generators are powered either by renewable energy sources such as wind, solar and hydro, or by combined heat and power (CHP) units using conventional fuels with higher overall energy efficiency than electricity only cycles. These generating plants are often connected to passive distribution networks at 33kV and below. Furthermore, in addition to the DG embedded in Medium Voltage (MV) distribution networks, micro-generators installed at end users at Low Voltage (LV) levels are gaining significant momentum, due to potential advantages regarding reliability, energy efficiency and power quality.

For the United Kingdom (UK), Governmental targets for renewable and CHP generation by 2010 are: (i) to produce 10% of the UK's energy needs from renewable energy sources; and (ii) to reach a total of 10GW of CHP generating capacity [1]. At the same time, installed micro-generation capacity could grow to as much as 8GW by 2015 according to a major recent study [2], while a second study has suggested that micro-generation technologies could supply between 30 to 40 per cent of the UK's electricity demands by 2050 [3].

This anticipated growth in DG will entail the introduction of large numbers of generators of different types and sizes at various locations and voltage levels of the electricity distribution network. However, these have often been designed and operated based on planned centralized generation, and on the assumption that the current always flows from the substations to the ends of feeders. Hence, a key challenge facing the electricity industry is to accommodate the anticipated growth of DG onto existing distribution networks without compromising security of supply, while at the same time minimizing costs incurred to customers and maximizing the potential benefits gained from these units. There is a consensus within industry and academia that the most appropriate way of achieving this is by active control techniques [4]. In response to this, the European Commission have developed the concept of SmartGrids [5], which aims to formulate and promote a vision for the development of European electricity networks looking towards 2020 and beyond.

This paper presents research currently carried out at Durham University for the development and evaluation of active network management techniques at the MV and LV levels of distribution networks with high levels of DG and micro-generation. The first project describes the development of an active thermal controller for distribution networks at an MV level. The research is being conducted

by a consortium including Parsons Brinckerhoff, Durham University, Scottish Power Energy Networks (SPEN), AREVA T&D and Imass, part-sponsored by the UK Government's Technology Strategy Board (TSB). The architecture of the controller is outlined that will provide DG set points to the network operator, informed by the real time dynamic thermal rating (DTR) of network components. This moves beyond current operational regimes that, at times, assume a fixed set of worst-case meteorological conditions, to create capacity headroom that could allow greater DG access to the network.

Regarding the research and development of DTR control systems, relevant work is described in [6] and [7], considering overhead lines, underground cables and power transformers. Research, pertaining to the dynamic rating of overhead lines, has been carried out by different network operators, such as Iberdrola in [8], NIE Energy in [9] and by Central Networks, E.ON-UK in [10]. The possible advantages of a DTR system implementation are described in [11] and [12].

The second project is based on work funded by Engineering and Physical Sciences Research Council (EPSRC) and E.ON-UK Power Technologies. The project investigates the development and evaluation of a distributed control approach, based on Multi Agent Systems (MAS) technology, for MicroGrids. MicroGrids are public low voltage feeders containing a mixture of several micro-sources, distributed energy storage units (ESUs) and controllable loads, and appear to the upstream distribution network as a controllable entity [13]. Through intelligent co-ordination of micro-generators and ESUs, coupled with demand side management techniques, MicroGrids have the potential to offer significant improvements in the commercial value and environmental impact of the installed micro-generation. Moreover, it is possible that MicroGrids could be used to provide ancillary services to Distribution Network Operators (DNOs) such as local voltage control and spinning reserve.

A number of demonstration projects have been commissioned internationally with regards to MicroGrids, in particular in Europe, USA and Japan [14-15]. However, development of these projects has mostly been undertaken independently and significant differences exist in network topology, the rating and mixture of micro-generation, as well as on their operational aims and their specific controller implementations. One such project is currently under development in Durham University with three main aims: (i) to assess the impact of micro-generation on existing passive low voltage distribution networks, (ii) to validate distribution network models that have already been developed [16-17], and (iii) to implement, test and refine control algorithms for future active distribution networks. Results from a practical implementation of an agent-based control system on the Experimental MicroGrid at Durham University are presented and discussed in [18-19].

2. Active Control of DG based on a DTR system at an MV level

This section describes the development of an active controller for DG based on a DTR system at MV level. A service-oriented architecture (SOA) has been adopted that will be implemented using web services (as shown in Figure 1). Aspects of the system are connected together using a service bus approach that allows all services to communicate with each other using industrial standard protocols. This approach gives complete flexibility for deployment of services over a distributed network, even through in practice the core services for the thermal controller are likely to be implemented on a single hardware platform.

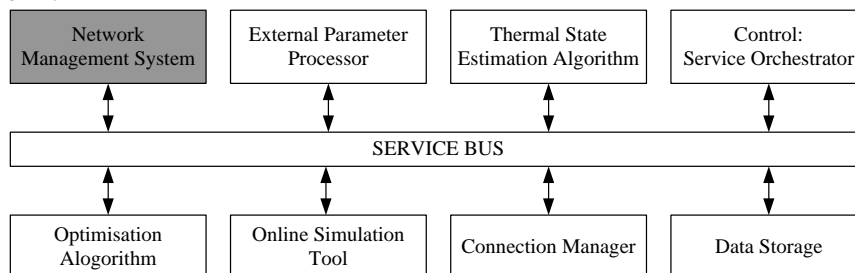


Figure 1: Service-oriented architecture to be adopted for the thermal controller

Control and Data Storage Service: The control service will be responsible for orchestrating the other services in order to meet the overall objectives of the Thermal Controller. The data storage service will store current and historical input signals (e.g. external thermal measurements and NMS signals), controller calculation results and network model information to be used by the other services.

External Parameter Processor (EPP): The EPP will calculate the values of external parameters such as wind speed, wind direction, air and soil temperature and solar radiation around the distribution network, based on signals from a small number of meteorological measurement units. It is important to note that the EPP is being designed to allow for the addition of new modules and external inputs such as weather forecasts.

Thermal State Estimation (TSE): Thermal State Estimation is a fundamental part of the active thermal control system that this project aims to realise. The role of the TSE service is to manage the EPP results and the component thermal models to improve the estimation precision and to increase the controller's reliability. The method is described graphically in Figure 2. Starting with a probability distribution for each meteorological measurement, a corresponding probability distribution is calculated for each external parameter value and each component thermal rating.

These estimates act as an input to the DTR algorithms and are used to calculate the rating and associated probability for each of the relevant network components.

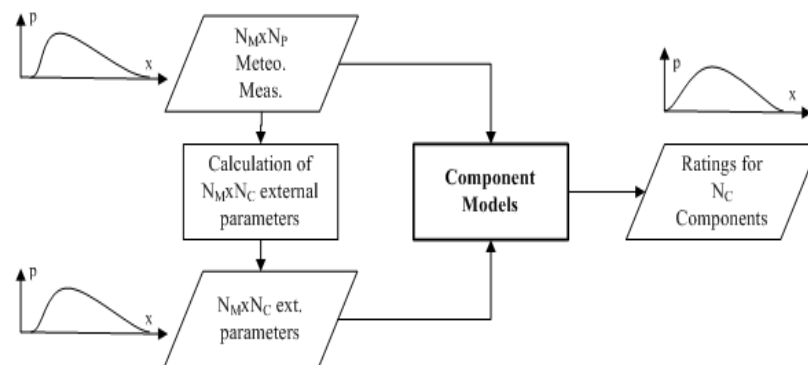


Figure 2: Thermal State Estimation process

Network Management System (NMS): It is expected that electrical inputs for the thermal controller will be provided by the NMS. From the status of circuit breakers and switches in the network, faults and network reconfiguration events can be detected. A number of predetermined network operating states will be incorporated into the control system to allow network reconfigurations to be accommodated. Other electrical measurements such as generator outputs, network loads and voltages will allow an electrical network model to be populated in order to fully simulate the present network state.

Optimisation: Using the NMS component power flows and building in any measurement uncertainty, the DTR and actual power flow will be compared for each component. The optimisation algorithms will aim to minimise the constraints placed on the generating schemes based on generation energy yield and economic considerations such as contractual obligations within operational constraints.

Online Simulation Tool: Inputs from the NMS will be used in the online simulation tool to validate the generation set point(s) proposed by the optimisation service and ensure that the power flows across the network are managed effectively. The main purpose of the online simulation service is to ensure that a solution to a thermal event on the network will not result in the violation of operational voltage limits.

Connection Manager: The final stage of the active thermal control system response is to dispatch a set of suggested P and Q set points to the various generation schemes within the jurisdiction of the thermal control system. This will be done by either closed-loop automatic active generation control or by advising controllers in the DNO control rooms.

3. Active management of LV distribution networks

The use of a distributed control approach for MicroGrids has been proposed in [21]. This approach is realised through the development of a Multi Agent System (MAS) based control system. The proposed MAS-based control system is based on the idea of using agents to distribute the management and control tasks of the MicroGrid. Each agent makes control decisions autonomously and pro-actively in order to accomplish its design goals, but can also interact and cooperate with other agents.

Three types of agents have been identified in order to satisfy the specific control requirements of a MicroGrid and adhere to the specifications developed by the Foundation of Intelligent Physical Agents (FIPA): (i) direct control agents, (ii) indirect control agents and (iii) utility agents.

- 1. Direct control agents (Generator Agent; Consumer Demand Agent; and Energy Storage Agent) use local measurements to directly control a power system entity (micro-generator, energy storage unit or demand) within the MicroGrid
- 2. Indirect control agents (Operational Goals Agent; Unbalance Agent; Voltage Regulation Agent; and Thermal Limits Agent) use global measurements to indirectly control one or more power system entities within the MicroGrid
- 3. Utility agents (Agent Management System; and Directory Facilitator) perform administrative duties and are in alignment with FIPA specifications.

3.1 Software Implementation

A software implementation of a MAS-based control system containing all system agents that have been identified in Section 4 is currently under development at Durham University. The MAS is written in JADE (Java Agent Development Framework), which is middleware implemented in Java for the development of fully FIPA-compliant MAS. The MAS is coupled with a relational database management system developed in MySQL. This is then linked to the power system simulation package PSCAD/EMTDC™ in order to evaluate the MAS based on its suitability to satisfy the specific control requirements of MicroGrids. Three different LV distribution networks will be considered as a MicroGrid: one urban generic UK LV distribution network described in [16-17], one sub-urban generic European LV distribution network and one existing public UK LV distribution network operated by Central Networks.

System agents have two functions: (i) reasoning and (ii) communications. They are responsible for interpreting the measurement data and deciding on the active (P) and reactive power (Q) set points of micro-generators, ESUs and controllable loads within the MicroGrid. Control decisions taken by the agents are stored in the MAS Outputs Database, which is also accessed through JDBC, and are then passed to the PSCAD™ simulation models. This allows control decisions taken by the JADE-based MAS to be evaluated on a power systems simulation package.

Based on general power system operation theory [21], three operating states for system agents are implemented inside the functionality of the MicroGrid controller: (i) normal, (ii) alert and (iii) emergency state.

- 1. Normal State: If all system agents are operating in their normal state, all measured parameters (voltages, currents, power flows) are located within their desired operating limits. The aim of the controller is to maximise the total active power output of connected micro-generators and also to minimise system losses in the MicroGrid branches and the MV/LV windings of the distribution transformer supplying the MicroGrid. Loads and ESUs are not controlled during the normal state, because their operation is only considered for cases where they can contribute to secure system operation, or in order to meet an operational goal.
- 2. Alert State: If one or more of the measured system parameters exceeds their desired operating limits, the system enters an alert state where the goal is to restore all system agents back to their normal state. This is achieved either through energy storage and demand side management, or through reactive power support. This is done in order to avoid real power output curtailment of the connected micro-generators.

- 3. Emergency State: The MicroGrid is said to be operating under an emergency state if one or more of the measured system parameters have exceeded their maximum or minimum permissible operating limits, according to either statutory regulations or equipment ratings. In this case, active power curtailment of the connected micro-generators is required in order to ensure secure system operation.

The controller will be evaluated based on its suitability to satisfy the specific control requirements of MicroGrids, namely: (i) to overcome the LV distribution network constraints under investigation in the event of system disturbances; and (ii) to meet the MicroGrid's identified operational goals [20]. Results will be described in a forthcoming paper.

3.2 Laboratory-based Implementation

A laboratory based experimental MicroGrid is currently under development at Durham University [18-19]. The experimental MicroGrid consists of one load emulator, one wind turbine generator emulator, one PV generation emulator, one dCHP emulator, one ESU emulator and one network connection emulator, as illustrated in Figure 3.



Figure 3: View of the experimental MicroGrid at Durham University

Monitoring and control systems have been developed using the LabVIEW™ visual programming environment. This system enables the flexible, real-time measurement of system parameters (voltage, current, frequency etc) and also enables repeatable, controlled testing to be carried out. In addition, the LabVIEW™ based control system allows control of the individual micro-source emulators and ESU inverter interfaces in order to regulate active power flow. Reactive power flow absorbed and produced by the energy storage system may also be controlled. The experimental MicroGrid is therefore an enabler for the development and evaluation of centralised and distributed active network management techniques for low voltage distribution networks. Initial results of first-stage agent-based control systems developed in the LabVIEW™ visual programming environment are presented in [18-19].

4. Conclusions

Interest in DG has increased greatly in recent years as fears over global warming, high oil prices, the decline of indigenous energy supplies and increasing government support are expected to lead to a continuous increase in electricity generated by renewable energy sources. This anticipated growth in DG is likely to present a number of technical, economic and regulatory challenges, as well as a number of potential economic, technical and environmental benefits. A key challenge facing the electricity industry is to accommodate the anticipated growth of DG onto existing distribution networks without compromising security of supply, while at the same time minimizing costs incurred

to customers and maximizing the potential benefits gained from these units. There is a consensus within industry and academia that the most appropriate way of achieving this is by active control techniques.

This paper has presented current research at Durham University relating to the active management of distribution networks at MV and LV levels. A DTR system-based approach has been proposed for the control of DG at the MV level. Furthermore, a MAS-based distributed control approach has been presented for the coordinated control of micro-generators, energy storage units and controllable loads.

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