University of Kurdistan
Faculty of Engineering
Department of Electrical and Computer Engineering

Title:
Automatic Generation Control using Multi-agent System

By:
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Supervisor:
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A Thesis
Submitted in Partial Fulfillment of the Requirements for the Degree of
M.Sc. in Computer Engineering

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Best Regards,

Fatemeh Daneshfar

August 25, 2009
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The above thesis was evaluated and approved by the following members of the thesis committee with mark 20 and excellent quality

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Dedication

To my beloved husband

for letting me pursue my dream

for so long

&

To my dear supervisor

for giving me

new dreams to pursue
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I would like to thank my supervisor, Dr. Hassan Bevrani, for supporting me over the months, and for giving me so much freedom to explore and discover new areas of artificial intelligence applications in automatic generation control and deserve thanks for not only guiding me with a steady hand, but also leaving me the freedom to pursue my own research interests. He has generously given me invaluable suggestions on my research. He guides me to conduct scientific research as well as theoretical studies. Without his directing and support, I would not have finished my thesis research. I thank you for your patience and encouragement. You opened up a whole new world for me.

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Abstract

The load-frequency control (LFC) problem has been one of the major subjects in power system especially in interconnected networks using wind power turbines. In practice, LFC systems use proportional-integral (PI) controllers. However since these controllers are designed using a linear model, the nonlinearities of the system are not accounted for and they are incapable to gain good dynamical performance for a wide range of operating conditions in a multi-area power system. Also the wind power fluctuation negatively contributes to the power imbalance and frequency deviation and cause more difficulty in LFC with PI controllers. These significant interconnection frequency deviations can cause under/over frequency relaying and disconnect some loads and generations. Under unfavorable conditions, this may result in a cascading failure and system collapse.

A strategy for solving this problem due to the distributed nature of a multi-area power system, is using the intelligent agent based approaches. These methods do not depend on any knowledge of the system and they admit considerable flexibility in defining the control objective. Moreover using multi-agent systems (MASs), realized parallel computation and leading to a high degree of scalability.

This thesis presents three intelligent control methods to LFC: multi-agent reinforcement learning (MARL) control, multi-agent Bayesian networks (BNs) based control and multiobjective (MO) optimization based on genetic algorithm (GA) for tuning the PI controller parameters. To demonstrate and analyses the capability of the proposed control structures two systems are used: a three-area power system example with two scenarios and a nonlinear time-domain simulations on a 39-bus test power system.

Keywords: Automatic generation control (AGC), intelligent control, wind power generation, multi-agent systems, multi-agent reinforcement learning, Bayesian networks, multiobjective optimization, genetic algorithms
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Chapter 1

Introduction

Nowadays MAS technology is being used for a wide range of control applications including scheduling and planning [1],[2], diagnostics [3], condition monitoring [4]-[6], distributed control [5]-[7], hybrid control [8], congestion control [9],[10], system restoration [11], market simulation [12],[13], network control [13],[14], and automation [15]. Moreover, the technology is growing to the point where the first multi-agent systems are now being emigrated from the laboratory to the utility, allowing industry to gain experience in the use of MAS and also to evaluate their effectiveness [1]. Nevertheless, despite a growing awareness of the technology, some primary questions often arise from other researchers and, in particular, industrial partners when discussing multi-agent systems and their role in control engineering. These are: what benefits are offered by multi-agent systems? What differentiates them from the existing systems and approaches? To which kind of problems can they be applied? If and when MAS technology is supposed appropriate for a particular control engineering application, then other questions naturally follow: how should multi-agent systems is designed? How should multi-agent systems be implemented? Are there any special considerations for the application of MAS in control engineering?

As MAS are a new technology, a number of technical challenges need to be overcome if they are to be used effectively. Then identifying details of those challenges and providing technical leadership in terms of recommendation and guidance on the appropriate use of the standards, design methodologies, and implementation approaches which are currently available, is necessary too.

This chapter begins by describing concepts and approaches related to multi-agent systems and presents a background on intelligent solutions that have been used with MAS technology in this thesis to load-frequency control. Finally the basic concepts related to the
LFC in presence of wind turbines and without it, are explained.

1.1 Backgrounds

1.1.1 Multi-agent Systems

In order to find benefits of MAS to automatic generation control, the basic concepts and definitions related to multi-agent systems need to be understood.

1.1.1.1 What is an agent?

The computer science community has produced various definitions for an agent [16]–[20]. A comparison between these definitions and their relative merits and weaknesses, from a computer science view, can be found in [21]. However all the definitions referenced above are different, they all share a basic set of concepts: the notion of an agent, its environment, and autonomy. According to Wooldridge definition [20], an agent is “a software (or hardware) entity that is situated in some environment and is able to autonomously react to changes in that environment”. The environment is everything external to the agent. The environment may be physical (e.g., the control system), or it may be the computing environment (e.g., data sources, computing resources, and other agents). An agent can alter the environment by taking some action. The separation of agents from environment means that agents are inherently distributable. Under Wooldridge definition [20], an entity situated in an environment is an agent if it can act autonomously in response to environmental changes. The definition of autonomy says that an agent “exercises control over its own actions” [21], meaning that it can initiate or schedule certain actions for execution.

Wooldridge and Jennings [22] identified three different classes of agents:
• Agents that execute straightforward tasks based on pre-specified rules and assumptions,

• Agents that execute a well-defined task at a user’s request,

• Agents that volunteer information or services to a user whenever it is deemed appropriate, without being explicitly asked to do so,

From an engineering view, this classification has some problems: it does not clearly separate agents from a number of existing systems. According to above definition, some existing systems could be agents. For example, a thermostat device could be considered as an agent. It is situated in its environment. It reacts to temperature changes of environment. It also exhibits a degree of autonomy. Therefore there is a need to know how agents and multi-agent systems differ from existing systems and system engineering approaches.

1.1.1.2 Intelligent Agents

Wooldridge [20] extends the above definitions of an agent to an intelligent agent by extending the definition of autonomy to flexible autonomy. An agent which displays flexible autonomy, i.e., an intelligent agent, has the following three characteristics:

• Reactivity: an intelligent agent reacts to changes in its environment in a timely manner,

• Pro-activeness: intelligent agents have goal-directed behavior. Goal-directed behavior supposes that an agent will dynamically change its behavior in order to achieve its goals. Wooldridge [20] describes this as an agent’s ability to “take the initiative”.

• Social ability: intelligent agents are able to interact with other intelligent agents,

Social ability connotes more than the simple passing of data between different software and hardware entities. It connotes the ability to negotiate and interact in a cooperative manner. That ability is normally created by an agent communication language (ACL), which allows agents to converse rather than simply pass data.

Not only the characteristics of reactivity, pro-activeness, and social ability help us to distinguish agents from traditional hardware and software systems, it is from these characteristics, that many of another benefits (discussed in this thesis) are derived.
1.1.1.3 Multi-agent Systems

A multi-agent system is a system comprising two or more agents or intelligent agents [23]. It is important to know that there is no overall system goal; however each separate agent has local goals [23]. Depending on the definition of agency mentioned above, agents in a multi-agent system may or may not have the ability to communicate with each other directly. However, under Wooldridge’s definitions [20], intelligent agents must have social ability and therefore must be capable of communication with each other. For the sake of this thesis, the author has focused on MAS where this communication is supported. This differentiates the type of MAS discussed in this thesis from other types of systems.

1.1.1.4 MAS in Control Engineering Applications

To know how (and why) MAS is applied in control applications requires an understanding of how MAS can be used. Nowadays, MAS is exploited in two ways [24],[25]: as an approach for building flexible and extensible hardware/software systems, and as a modeling approach.

Using MAS to Construct Robust, Flexible, and Extensible Systems

There are many control engineering applications that flexible and extensible solutions are useful for them. Flexibility is the ability to respond to dynamic situations (environment), correctly. It is very similar to autonomy, and therefore intelligent agents should be flexible, automatically. But if autonomy is the ability of an agent to plan its own actions, flexibility is to select the most proper actions from a set of actions [20]. Some examples of flexible behavior would be like the ability to construct a new plan if a particular control action fails. Extensibility implies the ability to easily add new functionality to a system, or upgrading any existing functionality [25]. For example, in distribution networks, a distributed network control responsible for voltage control may be extended to responsible for frequency control. Across many applications in control engineering, there is also a requirement for fault tolerance and graceful degradation: if any parts of the system fail for whatever reason,
the system should still be able to meet its design objective [26]. A MAS can provide a way for building such systems. However, the way in which a MAS provides flexibility, extensibility, and fault tolerance needs to be understood. The properties of agents that produce these qualities are examined below.

**Autonomy**

An agent encapsulates a set of functionality, (like modular or object-oriented programming [27]). It means that the benefits of standard interfaces and information-hiding are also available in agent programming through the use of messaging with a standard agent communication language, but there is also the additional capability of autonomous action [28]. In an object programming, external objects can call and execute other object’s functions [27]. However in the agent oriented programming, external agents can only send requesting messages to the action of a special agent: the autonomous agent can decide whether to fulfill the request and its priority [28]. This can be useful in situations when an agent is receiving many requests and cannot accomplish them within a reasonable time. The autonomy of each agent and the messaging interface are useful in most of flexible and extensible systems. Because agents are not directly linked to others, then it is easy to take one out of operation or add a new one while the others are running [29]. If one agent is stopped, any agents interacting with it can use the standard service location (agent management system and directory facilitator [30]) facilities to locate another agent that performs the same task, and by this mechanism, new agents can be added within the system too. The agent framework provides the functionality for messaging and service location, it means that new agent integration and communications are handled without effort from the system designer [30]. This create extensible systems: extra functionality can be added by deploying new agents in system, which use service location to find others to communicate with; and some parts of systems can be upgraded by deploying a replacement agent and removing the old one. Flexibility also considers the appropriate mixture of agents that can be deployed to qualify the individual situations or conditions, and flexible handling of messages between agents that allows the system to self-configure.
Open MAS Architectures

An open agent architecture places no restrictions on the programming language of the system, and allows flexible communication between all agents. This is achievable because of messaging standards [30]. The separation of an agent from its environment means that the messaging language that an agent understands is important for inter-agent communication, rather than the programming language it was implemented with. A set of standards for an open architecture is defined by the foundation for intelligent physical agents (FIPA) [30],[31]. The FIPA agent management reference model includes the “framework in which FIPA agents exist”, defining standards for creating, locating, removing, and communicating with agents. This is generally called the agent platform, and is one part of an agent’s environment. One requirement of an open agent architecture is that the platform places no restrictions on the creation and messaging of agents, while a second is that some mechanism must be available for locating particular agents or agents offering particular services within the platform. Under the FIPA model, this is achieved through a separate agent called the directory facilitator. It is an agent that manages a list of services offered by other agents within the platform [30]. A closed architecture removes the possibility of an extensible or flexible system, severely limiting the benefits of using agents.

Platform for Distributed Systems

An agent is separate from its environment, it means that it can be placed in different environments and still has the same goals and abilities (as the agent autonomously schedules action in the response to sensor inputs and messages). For this reason, an agent is distributable; does not have any fixed ties to its environment. In practice, distribution of agents through a network is supported by the agent platform. The platform can be deployed on every computer and the agents are deployed within the platform as usual [30]. On a platform, there is no difference between agents on the same computer and agents on a different computer. This means that the same set of agents can be deployed on one computer, and alternatively on multiple networked computers, without modifying or changing the agent code [30].
Fault Tolerance

Building redundancy into systems is one of the standard engineering approaches to gaining fault tolerance. Building redundancy in MAS involves providing more than one agent with a given set of abilities. If an agent needs the services of a second agent to accomplish its goals, and the second agent fails, the agent can seek an alternative agent (perhaps using the directory facilitator) to provide the services it requires [30]. This redundancy may be provided by simple duplication of each agent, and with distribution of duplicates across different computers. Also the flexibility offered by an open architecture of agents with social ability will provide a tolerance to physical faults, such as the loss of a network connection, or damage to a computer.

Multi-agent Systems as a Modeling Approach

Multi-agent systems are more than a systems integration method; they also provide a modeling approach. An agent system can represent a real-world with entities’ interaction. Natural representation of the world has been given as an advantage of object-oriented (OO) systems design [27], where entities in a system are modeled as objects. The main benefit of the object programming is data-encapsulation. Agent-based design adds another level of abstraction to this: not only the internal data structures, but also the “methods” (actions) which an agent can do are hidden [29]. However, many control engineering applications can apply this way of viewing the world, such as power systems operation and control. Such an application would be using agents for both their modeling properties and also as a way of building a flexible, extensible system.

1.1.2 Intelligent Approaches

This section presents a brief background on the intelligent approaches that have been used by MASs to automatic generation control in this thesis. They are reinforcement learning (RL), Bayesian networks and multiobjective optimization respectively.
1.1.2.1 Reinforcement Learning

First, the single-agent reinforcement learning is defined and its solution is described. Then, the multi-agent task is defined. The discussion is restricted to finite state and action spaces, as the major part of MARL results are given for finite spaces [32].

Single-agent Reinforcement Learning

RL is learning what to do—how to map situations to actions—so as to maximize a numerical reward signal [33]. In fact the learner will discover which action should be taken by interacting with the system and trying the different actions which may lead to the highest reward. Reinforcement learning will evaluate the actions taken and gives the learner a feedback of how good the action taken was and whether it should repeat this action in the same situation or not. In another word, RL methods learn to solve a problem by interacting with a system. The learner is called the agent and the system it interacts with, is known as the environment. During the learning process, the agent interacts with the environment and takes an action $a_t$ from a set of actions, at time $t$. These actions will affect the system and will take it to a new state $x_{t+1}$. Therefore, the agent is provided with the corresponding reward signal ($r_{t+1}$). This agent-environment interaction is repeated until the desired goal is achieved. In this text what is meant by the state is the required information for making a decision, therefore what we would like, ideally, is a state signal that summarizes past perceptions in a way that all relevant information is retained. A state signal that succeeds in retaining all relevant information is said to be Markov, or to have the Markov property [33] and a reinforcement learning task that satisfies this property is called a finite Markov Decision Process (MDP). If an environment has the Markov property, then its dynamics enable us to predict the next state and expected next reward given the current state and action. In the remaining of the text it is assumed that the environment has the Markov property, therefore a Markov Decision Process problem is solved. In each MDP the objective is to maximize sum of returned rewards over time, then the expected sum of discounted rewards defined by the following equation: