COMPUTATIONAL INTELLIGENCE AND SMART GRID

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Contents

Summary

Smart grid integrates advanced sensing technologies, control methodologies, and communication technologies into current electricity grid at transmission and distribution levels in order to supply electricity in a smart, user friendly way. Smart grid encourages integration of renewable energy sources, distributed generation, and plug-in hybrid and electric vehicles in distributed power systems, which adds complexity and challenges to various controllers at all levels of power grids. Therefore, new control and management paradigms, and advanced computational methodologies are required for planning, optimization and control of modern power systems.

This chapter presents applications of computational intelligence techniques for planning, optimization, and operation of smart grid. In this chapter, an approach for implementing decentralized distributed control and management of smart grid using intelligent Multi-Agent System (MAS) is proposed, and developed. Decision making modules of agents in the multi-agent system were developed using mathematical and computational intelligence techniques. For examples, the decision making module of demand side management agent was developed with a flexible Evolutionary Algorithm (EA), and that of scheduling agent was developed with a hybrid algorithm that combines Lagrangian Relaxation (LR) with Evolutionary Algorithm (EA) (LREA). In addition, power ratings of Distributed Energy Resources (DER) in the smart grid were optimally sized out using Evolutionary Strategy (ES).

Simulation studies were carried out on an integrated microgrid in the context of distributed smart grid. Integrated microgrid is an innovative control and management architecture at power distribution network level, which helps to operate distributed power systems effectively by implementing smart grid techniques at distribution level. Simulation outcomes demonstrate the effectiveness of multi-agent platform for control and management of integrated microgrids throughout implementing smart grid techniques. Furthermore, some of the applications of computational intelligence techniques for smart grid development are also demonstrated.

1. Introduction

Smart grid represents a vision of future power systems. According to the United States Department of Energy's modern grid initiative report, the main characteristics of a smart grid are consumer friendliness, hack proof self-healing, attack resistant, ability to accommodate all types of generation and storage options, enabling electricity markets, high power quality, optimizing operations, and operational efficiency. This intelligent grid is made possible by applying sensing, measurement and control devices with two-way communication between electricity production, transmission, distribution and consumption entities. Some of the key characteristics of a smart grid such as penetration of distributed power generation, demand side management and market based operation have already been implemented in many distributed power systems, and the other characteristics of smart grid are expected to be implemented very soon.

The traditional way of control and management of power systems is carried out by Energy Management System (EMS) which consists of three components, Supervisory Control And Data Acquisition (SCADA) system, State Estimator (SE) and Contingency Analyzer (CA). SCADA system serves as both data gathering system as well as device control system. Data is collected from generation plants and substations through field Remote Terminal Units (RTUs), and fed into master stations integrated in the control room of each control area. SE is used in the control room to improve the accuracy of the raw sampled data by mathematically processing to make it consistent with the electrical system model. The resulting information for equipment voltages and loadings is used in software tools such as CA to simulate various conditions and outages to evaluate the reliability of the power system.

Motivation of smart grid and integration of power systems with other technologies and industries add complexity and challenges to various controllers at all levels of power systems. Therefore, new control and management paradigms and advanced computational methodologies are required for control and management of modern power systems. Computational Intelligence (CI) techniques which have been applied to several power system problems like market operation, monitoring, diagnosis, restoration and protection.

This technology has great potential to solve problems in control and management of modern power systems and implementing smart grid concepts. In order to validate and evaluate the effectiveness of the computational intelligence techniques for the development of smart grid, it is necessary to carry out several simulation studies on the control and management of modern power systems.

In this chapter, a decentralized multi-agent system has been proposed to develop smart grid techniques for control and management of an integrated microgrid in the context of distributed smart grid. The multi-agent system was developed based on IEEE FIPA (Foundation for Intelligent Physical Agents) standards. Furthermore, in this research, optimization of control and management of smart grid has been done at three levels.

At the first level, power ratings of distributed energy resources in the integrated microgrid is optimally sized using evolutionary strategy for a long-term planning of the system. The other two levels are at demand side management and generation scheduling, which are functions of energy management of smart grid. A demand side management technique is proposed and developed with a flexible evolutionary algorithm, and generation scheduling is proposed and developed with a hybrid algorithm which combines Lagrangian relaxation with evolutionary algorithm. Some simulation studies were carried out on the developed multi-agent system for control and management of an integrated microgrid.

The rest of this chapter is organized as follows. Section 2 provides background information about microgrids and integrated microgrids. Section 3 provides details about optimization problems and proposes methodologies based on computational intelligence techniques for solving the optimization problems. Section 4 proposes a multi-agent system for the control and management of a smart grid and shows details about its development. Section 5 simulates the operation of an integrated microgrid in context of a distributed smart grid. Section 6 provides simulation results and discussions. Section 7 concludes the chapter.

2. Microgrids and Integrated Microgrids

The modern power systems are become more distributed mainly due to the massive development of Distributed Generation (DG). Distributed generation encompasses any small-scale electricity generation technology that provides power at a sit close to customers. The size of distributed generation varies from few kilowatts to few megawatts. Today, there is growing interest in distributed generation, particularly as on-site generation for business and homeowners, which provides better power quality, high reliability and fewer environment problems. In general distributed generation can make use of energy derived from wind, solar, geothermal, bio-power or fossil fuels.

Typically, distributed generation technologies available include wind turbines, photovoltaic panels, fuel cells, combustion turbines and combustion engines. Several of these technologies offer clean, efficient and cost-effective electric energy. Distributed generation technology is often lumped with distributed storage and their combination is referred to as Distributed Energy Resource (DER) that represents modular electrical generation or storage installed at customer site. Distributed generation is operated in parallel with a utility system or as an islanded system.

Technological advances in distributed generation have resulted in small scale generation that is cost-competitive with large power plants. Compared with traditional large scale generation stations, distributed generation is less expensive, flexible and environmentally friendly power source. These features enhance its position in market competition.

In general, distributed generation can make use of energy derived from wind, solar, geothermal, bio-power and fossil fuels. Typically, available distributed generation technologies include wind turbines, photovoltaic panels, fuel cells, combustion turbines and combustion engines. Several of these technologies could offer clean, efficient and cost-effective electric energy. In general, economics of electrical power systems depends on capital costs, operating efficiencies, fuel costs, as well as operational and maintenance cost. Distributed generation technologies are considered compatible with other merchant power generation options, and are utilized in smart grid environment. Each technology has its own strengths and weaknesses.

These technologies can be combined with other forms of energy sources to form a hybrid system that is cost-effective and supplies a continuous source of power. Environmental friendly renewable energy technologies such as wind turbines and photovoltaic, and clean and efficient fossil-fuel technologies such as gas turbines and fuel cells are new generating technologies driving the utilization of distributed generation. These Renewable Energy Sources (RES) usually have small size, and can be easily connected to distribution grids.

As the modern power systems are become more distributed, it is necessary to come up with novel control and management architectures, operational strategies and algorithms. There are few concepts and architectures that are already existent in the industry. Microgrid and integrated microgrid are some of the novel innovative control and management architectures for distributed generation. Currently, these operational architectures are mostly used as test beds for research and development of smart grid techniques.

Microgrid is an innovative control and management architecture at power distribution network level, which helps to operate distributed power systems by implementing smart grid techniques at the distribution level. Microgrids can be defined as low voltage distributed electrical power networks comprising various distributed generators, storage systems and controllable loads, which can be operated either interconnected with the main distribution grid, or islanded from the main distribution grid.

From the grid's point of view, microgrids can be regarded as controllable entities within the electrical power system that behave as aggregated loads, sources of power and networks supporting ancillary services, depending on the abilities and status of the microgrids. From the customers' point of view, microgrids are similar to traditional low voltage distribution networks that provide electricity to the customers. Microgrids enhance local reliability of the power grid, reduce emissions, improve power quality and potentially lower the cost of energy supply. These enhancements denote the ability of microgrid architecture for implementing smart grid techniques at power distribution network level. A schematic diagram of a microgrid is shown in Figure 1.

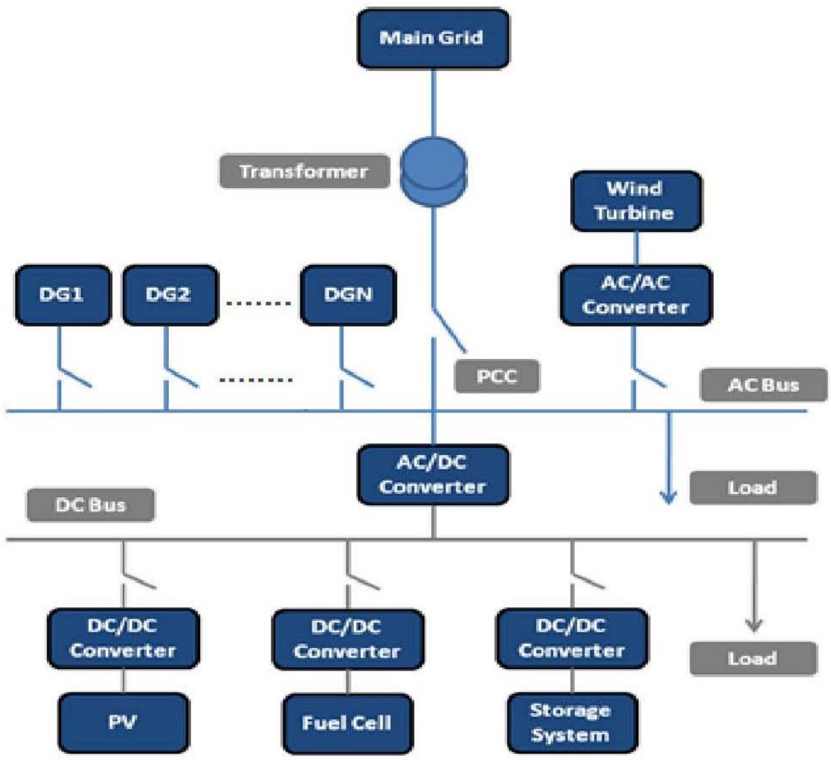

Figure 1. Schematic diagram of a microgrid

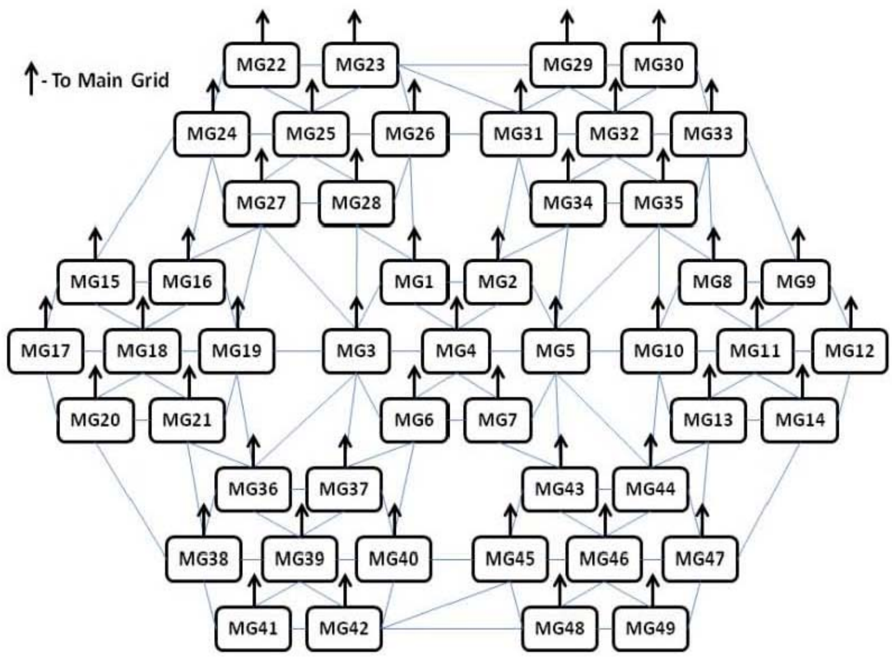

Figure 2. Schematic diagram of an integrated microgrid

Recently, interest in microgrids and renewable energy resources has increased significantly. As a result, more microgrids are being implemented in distributed power systems. An innovative control and management architecture, called integrated microgrid that provides ability to control and manage more microgrids is proposed in this chapter. A schematic diagram of an integrated microgrid is shown in Figure 2.

Integrated microgrid has several microgrids interconnected with each other. Each microgrid in the integrated microgrid could contain different types of loads and energy sources, and can be operated with different sets of rules and policies. As a result, a proper resource sharing among the microgrids leads to more benefits than that from a single microgrid. Furthermore, electric power grids are expected to guard them against man-made and natural disasters. This can be achieved by resiliency and autonomous re-configurability of the electric power system. Having more microgrids at distribution network level, electrical grid increases its resiliency and re-configurability.

3. Optimization Problems and Proposed Methodologies

This chapter presents four computational intelligence techniques for smart grid development. First, a distributed computational intelligence technique, Multi-Agent System (MAS) is proposed for development of a simulation platform for control and management of smart grid. Second, Evolutionary Strategy (ES) is proposed for optimal sizing of distributed energy resources. Third, a flexible Evolutionary Algorithm (EA) is proposed for optimizing decision making module of demand side management agent. Finally, a hybrid algorithm that combines Lagrangian Relaxation (LR) with Evolutionary Algorithm (EA) (LREA) is proposed for decision making module of generation scheduling agent. Background information about these optimization problems and mathematical formulations of them are given in the following sections.

3.1. Control and Management of Smart Grid

The current control and management approach of distributed power systems is using a central Supervisory Control And Data Acquisition (SCADA) system and several smaller distributed SCADA systems, which is no longer sufficient for various control operations of future smart grid because future distributed power systems having millions of controllable appliances will have to work efficiently on a large scale system. An approach that provides adaptable local control and intelligent decision making is therefore required. This can be achieved by distributed control, monitoring and management.

Multi-agent system approach that is one of the most suitable technologies for implementing such functionalities is proposed in this chapter for the operation of smart grid. Multi-agent system is a distributed computational intelligence technique, which can be used to model autonomous decision making entities.

Furthermore, multi-agent system can be used to implement flexible, extensible and fault tolerant control and management systems. Multi-agent system provides a common communication interface for all elements in the smart grid, and has the potential to provide autonomous distributed intelligent control and decision making. Potential of solving complex problems in distributed nature motivates the use of multi-agent system for implementing smart grid techniques. Recent literature shows that several researchers have investigated applications of multi-agent system for simulation studies on microgrids and other kinds of distributed power systems. Most of these multi-agent systems are only dealt with one or two smart gird techniques, and some of them are not implemented with any industrial standards.

3.1.1. Proposed Market

Enabling electricity markets in the operation of distributed power systems is a key characteristic of smart grid. Several electricity market models are implemented around the world. Coordination and interaction among market entities are essential in market operation. Hence, intelligent multi-agent system is an attractive approach for simulating such complex market operations. In this chapter, an energy market is proposed for the operation of a distributed smart grid. According to the proposed market policy, microgrids participate in an open market. They exchange energy with the other microgrids and the main distribution grid through the market. Each microgrid behaves as a single generator capable of relieving possible network congestions not only in the microgrid itself but also by transferring energy to nearby feeders of the distribution network.

Each microgrid manager tries to maximize the corresponding revenues of the microgrid by exchanging power with others. Objective function of each microgrid is given as follows.

$$\text{Maximize}\left\{Profit\right\} = \text{Maximize}\left\{Revenue - Expenses\right\} \quad (1)$$

According to the proposed policy, each microgrid sells power to its internal loads, and exchanges power with the main distribution grid at open market prices. If the sum of power production by microgrid sources is not enough, or expensive to cover its local loads, power $P_{\mathrm{g}}(t)$ is bought from upstream network, and sold to the consumers at the same price. Each microgrid maximizes its profit which is given as follows.

$$G(t) = \left[M_{\mathrm{P}}(t)\times P_{\mathrm{g}}(t) + M_{\mathrm{P}}(t)\times\sum_{i=1}^{N} P_i(t)\right] - \left[\sum_{i=1}^{N}\left(b(P)_i(t)\right) + M_{\mathrm{P}}(t)\times P_{\mathrm{g}}(t)\right] \quad (2)$$

where, G denotes profit, $M_{\mathrm{P}}(t)$ is the open market price, $P_i(t)$ is the power production of ith source, N is the number of sources that offer bids for power production, $\left(b(P)_i(t)\right)$ is the bid from ith source at time t.

This maximization problem is subject to the following system constraint.

$$P_{\mathrm{g}}(t) + \sum_{i=1}^{N} P_i(t) \geq P_{\mathrm{L}}(t) \quad (3)$$

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Biographical Sketches

Thillainathan Logenthiran received B.Sc. degree in electrical and electronic engineering from University of Peradeniya, Sri Lanka in 2005 and Ph.D. degree in applications of intelligent multi-agent system for control and management of distributed power systems from National University of Singapore, Singapore in 2012. He is the first prize award winner of the Siemens Smart Grid Innovation Contest in 2011. He was awarded in recognition and appreciation of his professional contribution on “Multi-Agent System for Operation of a Smart Grid” and “Autonomous Distributed Power System Restoration”. His main areas of interest are distributed power system, and applications of intelligent multi-agent system and computational intelligence techniques to power engineering problems.

Dipti Srinivasan obtained her M.Eng. and Ph.D. degrees in Electrical Engineering from the National University of Singapore (NUS) in 1991 and 1994 respectively. She worked at the University of California at Berkeley’s Computer Science Division as a postdoctoral researcher from 1994 to 1995. In June 1995, she joined the faculty of the Electrical & Computer Engineering department at the National University of Singapore, where she is an Associate Professor. From 1998-1999 she was a Visiting Faculty in the Department of Electrical & Computer Engineering at the Indian Institute of Science, Bangalore, India. Her research interest is in the development of hybrid neural network architectures, learning methods and their practical applications for large complex engineered systems, such as the electric power system and urban transportation systems. She is currently serving as an Associate Editor of IEEE Transactions of Neural Networks and IEEE Transactions on Intelligent Transportation Systems. Dipti is a senior member of IEEE, and was awarded the IEEE PES Outstanding Engineer award in 2010.