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A self-tuning load frequency control strategy for microgrids: Human brain emotional learning

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ABSTRACT

Micro-grids consist of distributed power generation systems (DGs), distributed energy storage devices (DSs), and loads. Controlling these systems is more difficult than ordinary form of power systems since, in most of them, their energy is provided by renewable energies which have uncertain and varying nature. These fluctuations in the generated power might cause some problems in the function of conventional controllers. As a result, modern power systems require increased intelligence and flexibility in the control and optimization to ensure the capability of maintaining a generation-load balance, following serious disturbances. In this issue, the emotional controller which has a self-tuning nature is used to overcome these difficulties. This controller is based on emotional learning process of the human brain and can provide an appropriate control against changes in the system structure and occurrence of uncertainties. To evaluate the performance of the proposed controller, the results are compared with those obtained by conventional PI and fuzzy controllers, which is the latest research in the problem in hand. Simulation results show the effectiveness of the emotional controller.

Introduction

One of the main outcomes of the paradigm change toward sustainable supply of electricity is the currently speeding development of renewable resources. As a result of higher penetration of intermittent renewable resources, fluctuations of power generation and mismatch in supply and demand have increased significantly [1]. Such mismatch will cause the frequency of the power grid to fluctuate. It is of utmost important to keep the frequency of the grid within an acceptable bound, because if otherwise, it will cause the grid to become instable or, even worse, it might lead to black outs. Recently, among different renewable resources, demand for wind and photovoltaic (PV) power generators has highly increased [2]. As a result, frequency stability has become of more importance in micro girds (MG). To control frequency of power systems, several approaches have been proposed. In [3], a method not dependent on real-time information, and in [4], a statistical model of a heating system of heater pump have presented which have been used in frequency control applications.

Although ordinary PI controller was previously used in frequency stabilizing applications, it has become obscure recently [5]. From then Zadeh presented fuzzy logic, this theory has become widely used in many different applications including designing controller [2,5–12]. Fuzzy logic is known to make the control system more sophisticated and also to increase the response time of the control system compared to ordinary PI controllers. Introduction of the evolutionary based algorithms in early 1970s was a prodigious attempt toward the stability of the non-linear system. As one of the pioneers of evolutionary algorithms, Genetic Algorithm (GA) was first presented by John Holland. GA is originally aimed to mimic the evolution of biologic systems; it consists of cross-over between pairs of parents' chromosomes to form a child in the next generation; GA also mimics the concept of mutation which makes random changes in the next generation of individuals. GA has been used as an optimization tool in many different non-linear applications. Recently, the researchers has applied genetic algorithm in MG as a mean to optimize the design of the controller [2,13].

As another heuristic optimization tool, Sir James Kennedy invented Particle Swarm Optimization (PSO) [14]. PSO has also been used in different frequency stabilizing applications in micro grids [2]. It has been shown that applying fuzzy logic based controllers alongside with evolutionary algorithms could enhance

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the performance of power systems [8]. As a more recent trend, researchers are working on simultaneously stabilizing the frequency and regulating the voltage of the grid [2]. The algorithm like bacteria foraging and radial basis function neural logic network are being used in controllers designed with intention of highly efficient stabilizing the frequency in a MG [2,13]. Besides, model predictive control approach has been also used frequency control applications [15].

Smart grids are known to have advanced structures with the main goal of facilitating the connection of various AC and DC generation systems. Smart grids are also assumed to include energy storage devices as well as controllable loads (AC or DC) which can be used to achieve optimized operation. Smart grids can also provide means to exploit the power of demand-side and controllable loads to balance supply and demand and also participate in frequency control [16,17].

According what was mentioned earlier, frequency control in micro-grids is arduous for the sake of highly uncertain behaviors of these systems; consequently applying an efficient control method, which can overcome these problems, is recommended. Hence, in this paper, we propose emotional controller which is a self-tuning PI controller and is inspired from human brain learning. Due to being self-tuning, the proposed controller has the ability to control frequency of micro-grids in every uncertain situations, from intensive changes of load levels to changes in the system's elements. In order to prove high performance of this control procedure, we consider a wide range of scenarios and subsequently show that this controller can act significantly better than other controllers, standard version of PI and fuzzy controller.

AC micro-grids model

AC microgrids structure

An AC microgrid is made by interconnecting domestic distributed loads and low voltage distributed energy sources, such as PVs, micro turbines, wind turbines, and storage devices. Fig. 1 shows a basic framework structure of an AC MG. The system shown is composed of a group of radial feeders as a part of a distribution system. The domestic load could be divided into sensitive/critical and non-sensitive/non-critical loads through independent feeders [2].

In the case of contingency or a serious disturbance, the non-sensitive loads may be shut down, while the sensitive load must be always kept supplied by one or more micro sources. The feeder of each unit has a circuit breaker and a power flow controller which is controlled by the central controller or energy manager. The circuit breaker is used for disconnecting the correspondent feeder (and the unit associated with it) in order to avoid the impacts of sever disturbances through the MG.

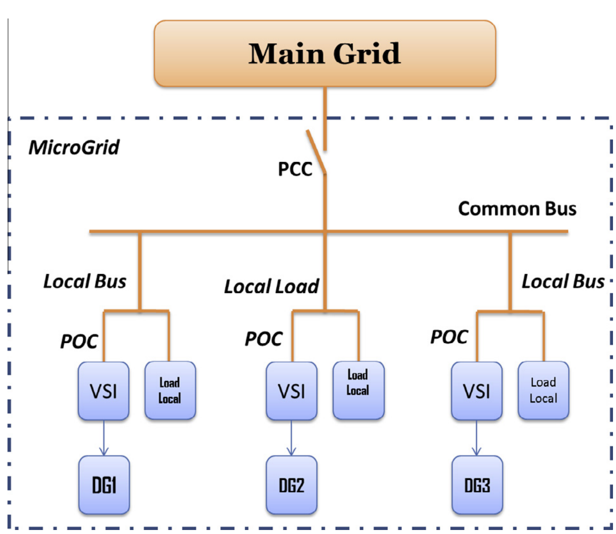

Fig. 1. A simple ac microgrid framework.

A static switch (SS) connects the AC MG to the distribution system by a point of common coupling (PCC). This switch islands the MG when a fault/contingency occurs or when maintenance becomes necessary. In order to avoid interruptions of electrical supply of the feeders with sensitive loads, local power supplies such as energy capacitor systems (ECSs) or diesel generators with enough energy saving capacity are required [2].

A high level management of the MG operation is facilitated by an MG central controller (MGCC) through technical and economical functions. Also, the micro-sources and the energy storage systems are controlled by the micro-source controllers (MCs) and finally, load controllers control (LC) the controllable loads. To connect to the ACMG, the micro-sources and storage devices use power electronic circuits.

Depending on the type of unit, the interfaces are dc/ac, ac/ac, and ac/dc/ac power electronic converters/inverters. The control of MG depends on the inverter control since the MG elements are mainly power-electronically interfaced. The MG systems need to be capable of showing proper performance in both connected and disconnected modes, in order to increase the reliability of the conventional power systems.

In connected mode of operation, the main grid controls the power systems and keeps them in desired conditions and, the MG systems are responsible for injecting active/reactive power. While in disconnected mode of operation, the MG maintains the local loads and keeps the frequency and voltage indices at specified nominal values [18,19].

Control loops in an AC microgrid

One of the key technologies for deploying an ACMG system is the control technology. The control structure of an AC MG is a hierarchical structure which has different layers. In this hierarchical structure, advanced control techniques must be used effectively at all levels. As it was mentioned before, the MGs must be capable of operating independently but also they can interact with the main grid.

In islanded mode of operation, appropriate control loops must be used by MGs in order to respond to load disturbances, to cope to the variations, and to perform active power/frequency regulation, and reactive power/voltage regulation. Also in this mode of operation, the AC MG must be operated on the basis of available standards, and in order to supply the required active and reactive powers as well as to provide voltage and frequency stability, the existing controls need to function properly. Fig. 2 shows a typical scheme for operating controls in an AC MG [2]. An MC locally controls each micro source. In order to provide capability of controlling loads, the LCs are installed at the controllable loads. As an interface between the MG and higher distribution networks (such as main grid), an MG central controller (MGCC) might be needed by each MG. Like conventional power systems, an ACMG could operate using different control loops [19]. These loops could be divided into four main control groups: local, secondary, global, and emergency controls.

The local control is responsible for initial primary control e.g. voltage and current loops that exist in the micro sources. The secondary control guarantees that after every change in load or supply, the frequency and the mean voltage of the microgridis regulated toward zero. The secondary control is also responsible for ancillary services inside. The global control makes operation of MG economically optimum. It is also responsible for organizing