A Multi-Agent System for Distributed Energy Resources Control in Microgrid

Wen-Di Zheng, Jin-Ding Cai

Abstract—**The microgrid is a potential solution for future distributed generation systems. It aggregates many distributed energy resources (DERs) and loads together as an autonomous entity. As the penetration of DERs is increasing and their characteristics are very distinct, the control of DERs in microgrid is still a complex task. In this paper, a multi-agent system (MAS) approach, as a branch of distributed artificial intelligence methods, is introduced for DERs control in microgrid. The DER units and loads are classified and three types of agents, namely, the regional agent (RA), the local agent (LA) and the service agent (SA) are also defined. Two-layer control strategies are established to achieve local autonomy and global optimization respectively, operating in both grid-connected mode and island mode. Generation/load forecasting and schedule of loads shedding are also discussed in this paper.**

Index Terms-- **Distributed generation, microgrid, multi-agent system (MAS).**

I. Introduction

MICROGRID, as a potential solution for future distributed generation systems, is widely discussed nowadays. It aggregates distributed generation (micro-turbines, wind turbines, PV, fuel cells, etc.), distributed storage (batteries and energy capacitors) and various loads together as a single autonomous entity providing both power and heat. It can operate both in grid-connected mode, and island mode if disconnected from the grid [1]. However, there are multiple distributed energy resources (DERs) with significantly different power capacities and generation characteristics in a microgrid, and the owners of DER units may have different goals; diverse control strategies exist in grid-connected mode, island mode and transient between them. In summary, how to control DERs in a microgrid efficiently and feasibly must be of prime consideration in microgrid design and operation.

In papers [1]-[3], droop characteristics are introduced to control electronically interfaced distributed generation (EI-DG) units in parallel, including power vs. frequency droop and voltage vs. reactive power droop. The load demand is shared among the EI-DG units in proportion to their capacities. It is similar to primary frequency control of conventional generators and easy to operate. However, the failure to consider frequency restoration, results in the inability of the grid to ensure frequency quality when serious disturbance arises. The cooperation with conventional generators is also not taken into consideration.

Power management strategies (PMSs) are proposed by F. Katiraei et al [4]-[5]. A frequency-droop characteristic and a frequency restoration algorithm are adopted for real power control of each EI-DG unit, and three strategies are defined for reactive power control. The linearized model of micro-grid including EI-DG units and conventional DG units is used to investigate the small-signal dynamics for choosing the parameters of controllers and analyzing the sensitivity of the system. However, the mentioned PMSs are only based on locally measured signals without any communication, thus it is difficult to achieve global optimization.

A multi-agent system is also introduced for microgrid control. In papers [6]-[9], Dimeas et al propose a three-level MAS for microgrid control. Their research focuses on microgrid market operation, using an auction algorithm to share the power among the DER units, presenting how the local intelligence and the social ability of the agents may provide solutions in the optimal and effective control. The strategy is only adapted in grid-connected mode, because the extra energy is bought or sold to the grid which is assume to offer or receive infinite energy.

This paper proposes a Multi-agent system for distributed energy resources control in microgrid. The DER units and loads are classified and three types of agents are defined. Two-layer control strategies are established to operate in both grid-connected mode and island mode. Local autonomy and global optimization are achieved simultaneously. This paper also discusses generation/load forecasting and schedule of loads shedding.

II. Multi-Agent System

A Multi-agent system (MAS) is a system composed of multiple interacting intelligent agents, which can be used to solve problems which are difficult or impossible for an individual agent. MAS technology stems from distributed artificial intelligence (DAI) research, and has been successfully applied to power system protection, operation and modeling currently [10].

What an agent is is not strictly defined, but it can be described as media which has capacities of decision-making and acting independently, and takes certain approaches to finish the tasks given according to some principles. An agent

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has several important characteristics for DERs control in microgrid:

The first characteristic is that agents have a certain level of autonomy, which means each of them can function properly and control its internal status without being manipulated by commander or other agents. Each agent has respective objectives to satisfy by using their own resources, functionality and services. To the agent controls battery unit, it can cease generating power automatically when energy storage has decreased to a certain level.

Another significant characteristic of agents is that they can interact with each other or human being to achieve certain goals. For instance, DERs agents in same district should conduct negotiations to optimize regional power dispatch.

Agents can perceive an environment and make real-time responses to its changes which then change the environment's status. A DG agent can change its set-points according to local needs and can also change the security level of the microgrid in a global view.

Finally, another characteristic is that agents have self-adaptability which means agents can adapt to change in the environment. It is usually realized by a learning mechanism online or offline. According to the changes in the global status of a microgrid, a regional agent will evaluate the behaviors of each subordinate agent, and then stimulates or punishes them by taking such actions. The subordinate agents then learn to take the actions that bring about long term benefits. The characteristic proposed can be implemented by multi-agent reinforcement learning [9].

Compared with traditional approaches for management and operation of DERs in microgrid, the MAS approach has many advantages. The autonomy enables agents to take certain actions according to their own objectives. Several adjacent DER agents of same owners can unite by communication in order to achieve local benefits. Contrary to traditional central control such as SCADA of the utility grid, large amounts of data transmission is probable not necessary in MAS structure microgrid. Thus, reliability of the control system will be increased

To summarize, dynamic coordination of DERs, and maximize their benefits can be achieved by using MAS technology.

III. Microgrid Modeling

A. Component Classification

A microgrid is composed of a number of components such as DG units, distributed storage (DS), various loads etc. The components should be classified for better control according to their characteristics.

The DER units can be divided into five categories:

1) Conventional synchronous machine-based DG (Conventional DG for short): Take a hydro turbine generation unit for example, it consists of a prime mover (hydro turbine), synchronous machine, excitation system, and governor. Due to the inertia of synchronous machines, the generated power output cannot change instantaneously. Thus, it has relatively slow responses for power control signals. However, it is able to participate in the small dynamic and steady-state power management [4].
2) Constant electronically interfaced DG (CEI-DG): Its prime mover could be a dc source like Fuel cell, or a high frequency AC source like microturbine [12], and interfaces to a microgrid via a dc-dc-ac converter or an ac-dc-ac converter. A short-term storage unit should be equipped to the dc link of the converter in order to provide short-time power flow requirements [11]. It is capable of limiting the short-circuit current by converter controller. The word constant means this category of EI-DG probably generates constant power with no dependence on weather conditions.
3) Variable electronically interfaced DG (VEI-DG): This is similar to CEI-DG, but the prime mover is dependent on weather conditions, such as PV array and wind turbines [13]. The generating power will fluctuate in the short term significantly. In this model, EI-DG units of this category could be assigned to generate maximum power, or provide reactive power support to the bus.
4) Distributed Storage (DS): This refers to long-term distributed storage (DS) just like NAS battery [14]. Compared with EI-DG, it interfaces to a microgrid via a bi-directional inverter. It can generate power to offset VEI-DG variability, and store surplus energy during lower load periods for future use.
5) Reactive power generation: This only generates reactive power including shunt capacitor, ASVC [15], STATCOM, etc. Some of them can regulate voltage dynamically and continuously, supporting local reactive power.

The loads could be divided into three categories as follows: Sensitive loads, non-sensitive load and sub-microgrid. The sub-microgrid is a smaller load, which can also be regarded as an intelligent load producing or consuming energy.

B. MAS Based DERs Control Architecture

Fig. 1 presents a typical MAS microgrid architecture. There are three types of agents in the system.

The lower level is called the local agent (LA), which controls a DER unit or an aggregation of loads directly. The local agents perceive a limited environment and only control specified components. Each of them will have different properties according to the category of component it controls proposed above in order to accommodate various control strategies. Take a sodium-sulfur (NAS) battery unit agent for example, it knows all the details of its control object in real-time, including the real/reactive power the battery is generating, how much energy the battery is storing, what temperature the battery is operating, but has no idea of other agents' statuses if the communication system is failed. Its properties qualify it to control the battery to store and release energy. LAs may be assigned certain tasks by upper level agents, and then they will accept or reject them considering their own security and benefits. LAs can also operate well without specific tasks, presenting their autonomy.

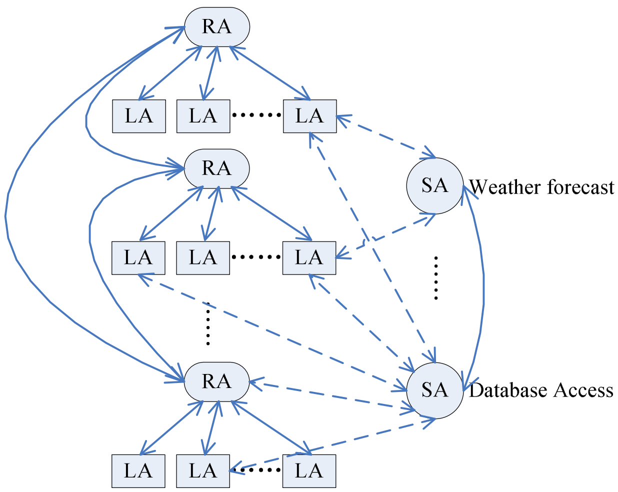

Fig. 1. The DERs control architecture based on MAS.

The upper level is called the regional agent (RA). A number of RAs will probably exist in a microgrid. It manages several LAs in a given region. The principal of division can be based on different ownership of components, optimal distribution regions, etc. For regional security, reliability or benefits, the RA will assign subordinate LAs tasks. It also receives requests from the LAs, and evaluates them, deciding whether to satisfy them or not. RA is not only a coordinator of LAs, but also a participant in a microgrid. RAs can communicate with each other and negotiate to deal with global issues or achieve global optimization.

Service agents (SAs) are not allocated to any one level, and provide RAs and LAs auxiliary services. The data exchanges are also allowable among SAs. As in Fig. 1, the auxiliary services could be weather forecasting [16], calculations, etc. All the service data is available for other agents via a specified communication interface.

The three types of agents mentioned above constitute a MAS microgrid entity.

IV. Two-Layer DER Control Strategies

Two-layer DER control strategies are established here. Primary control is focused on local control, which means to maximize the autonomy of local agents in order to ensure security and reliability even when communication fails. Secondary control is focused on regional or even global optimization, which means the upper level agents will take responsibility for coordination of LAs behaviors and pursue global benefits. Therefore, the primary control working alone can be regarded as the emergency operation, while the secondary control makes the system complete.

A. Grid-Connected Mode

In Grid-connected mode, the frequency of the microgrid is maintained by the utility grid. Therefore, the DER units could operate in (P-Q) or (P-u) mode, which means that they just control the reactive power component and the real power output is almost fixed. In primary control, voltage stability is a top priority. The reactive power demands will be shared among the DERs units based on pre-specified proportion in each region, ensuring the voltage is within a certain security margin. LAs of DS units decide whether they should absorb energy or not, considering their charge levels and current load demands. LAs of reactive power generators regulate their production as well.

In secondary control where the communication is available, RAs are responsible for regional optimization and coordination among DERs and aggregations of loads. In a sense, it can be regarded as redistribution of power. At the end of every pre-specified period after receiving load demands and generation captivities in the next period from LAs of loads and LAs of DERs respectively, each RA calculates optimal output of DG units in its region, determine operation status of DS units, and production of reactive power generators, considering generation cost and power losses, then sends the results back to modify their set-points. If an emergency arises in a period, RA will be requested to provide regulation, which is leading to a negotiation.

Fig. 2 shows a simple example of a negotiation for reactive power coordination.

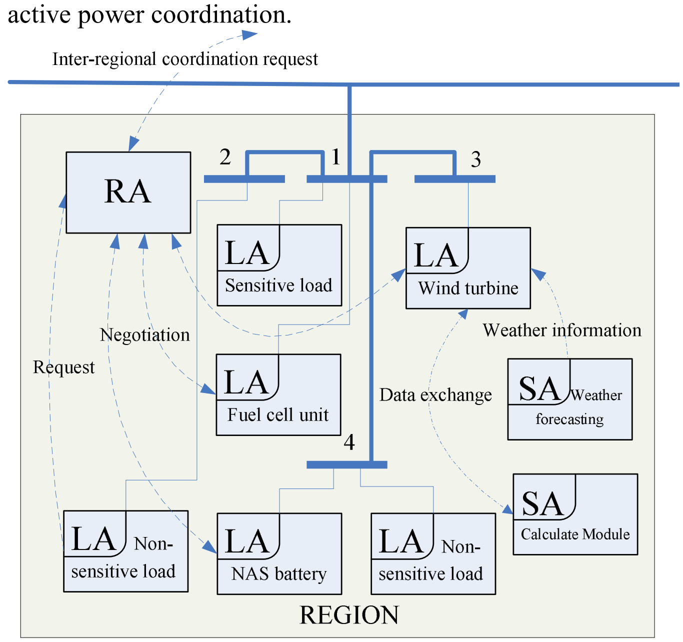

Fig. 2. Regional negotiation diagram.

Because of a sudden increase in reactive power demands on bus 2, an LA of a non-sensitive load detects that the voltage deviation exceeds the predefined range. Therefore, it requests the RA to provide voltage regulating. The RA will initiate a negotiation among adjacent LAs of DER units. Considering reactive capacities available, regulation sensitivity, voltage deviations of their own after regulating, etc, the LAs response the additional amount of reactive power and the cost. Immediately, the RA chooses an LA or LAs to support the voltage on bus 2 after estimation. If the emergency is solved, the RA will proceed to redistribute power generation among all of the DERs in the region according to the new load demands. Otherwise, RA will request adjacent RAs to provide inter-regional coordination. The figure also shows that an LA of a wind turbine receives weather information from an SA providing weather forecasting, and exchanges data with a specified SA of calculation module for generation forecast.

B. Island Mode

When a failure or other situation arises in the utility grid or upper level microgrid, the microgrid will be disconnected which means it becomes an island isolated from outside without any electrical connections. In island mode, all the load demands, both of real power and reactive power should be met by DERs in the microgrid.

In the primary control, the VEI-DG units still operate in (P-Q) or (P-u) mode, generating as much power as possible on the premise of voltage stability. In contrast, the CEI-DG units, DS units and conventional DG units in the microgrid are responsible for frequency regulation. A real power vs. frequency droop characteristic is introduced here for CEI-DG units and available storage devices control, cooperating with primary frequency regulation of conventional DG units, to share real power proportional to their capacities. The initial power generating set-point of each frequency regulating DER is obtained from database based on daily generation/load forecast in the microgrid. Due to frequency deviations caused by droop characteristic, a limited number of DERs with relatively larger capacities and faster responses are involved in frequency restoration, or called secondary frequency regulation.

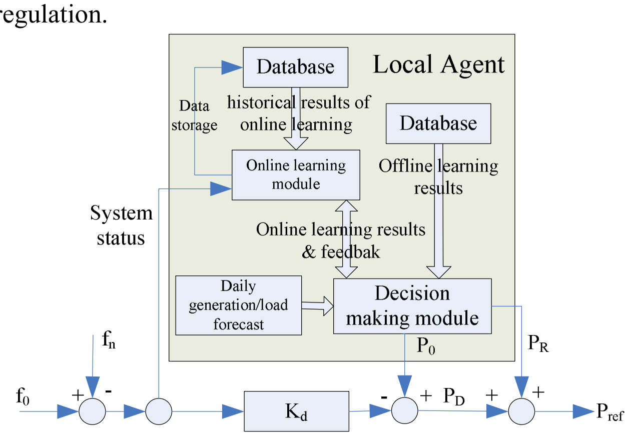

Fig. 3. Frequency regulation of primary control in island mode.

As shown in Fig. 3, the reference power is composed of two parts, where P_D is determined by the droop characteristic and forecasting, and P_R is to restore the frequency. We can also see that the LAs of DERs involved in frequency restoration have certain levels of learning capability, which means they can determine the frequency restoration setpoint according to current status of the system through offline learning and online experience.

In the secondary control, the RAs are responsible for frequency regulation. At the end of pre-specified period, each RA receives regional demands and generation capabilities. The situation is similar to that in grid-connected mode. According to shortage or surplus of energy output in the region, coordination will be established among RAs. RAs determine the initial power set-points (P_0) of LAs attached to DER units in each region based on results of supply and demand analysis. Furthermore, RAs determine the restoration power set-points (P_R) for each frequency restoration DER units on basis of the frequency deviation, with consideration of the exchange power among regions. Finally, the control signals from decision making modules in the LAs (Fig. 3) are replaced with that from RAs. The online learning database is still updated by estimating current actions (set-points) and system states.

If power supply cannot meet load demand, or decline in frequency reaches pre-specified limit, load shedding should be scheduled. As soon as the island is detected, the DERs in a sub-microgrid increase their outputs to balance supply and demand as possible, and then the sub-microgrid will be disconnected from its upper level microgrid. Non-sensitive loads can be shed any time by the order from RA or their own LAs. In contrast, sensitive load should not be shed expect that serious failure arises in the microgrid.

V. Conclusions

This paper presents a multi-agent system approach for distributed energy resources control in microgrid. The autonomy and cooperation make the agents operate spontaneously or perform simple “request and reply” conversations. Large amounts of data transmission are avoided, which reduce complex communications in the microgrid, and make the operation more efficient and feasible. The classification of DERs and load mentioned in the paper gives their local agents different properties, which make them play diverse roles in various control strategies. Two-layer control strategies are established here, both in the grid-connected mode and the island mode. In the primary control, autonomy of each agent is maximized to control the DERs without any communi-cations based on certain levels of learning process. In the secondary control, cooperation of agents is maximized, which means agents can communicate with each other in order to better distribute energy, improving stability and reliability, or reduce global cost, pursuing more benefits. It can be seen that generation/load forecasting, which is used to determine the generation set-points at the end of every pre-specified period, is very important. The schedule of loads shedding makes the sub-microgrid operate independently and reliability of sensitive loads. The detailed control algorithms and control strategies applied in transients based on MAS need further research.

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