Economic Dispatch in Microgrids Using Multi-Agent System

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***Abstract*—In traditional bulk power system, economic dispatch is usually conducted in a central controller, which has access to global system information. However, characterized as flexible and "plug and play", microgrids are often controlled in a distributed manner. This paper presents a decentralized architecture of multi-agent system for economic dispatch of distributed generators (DG) in microgrids. In this architecture, all DGs are equipped with identical agents, which can only perceive local information or obtain necessary information from their neighbors. By competing with each other, agents attempt to maximize their own profit, thereby tending to an optimal global solution. This paper first develops necessary conditions for minimal cost operation of microgrids. Then it proposes an innovative multi-agent communication algorithm to implement the minimal principle in multi-agent environment based on the consensus theorem. In the end, a five-agent system and a fifty-agent system are investigated to validate the proposed multi-agent algorithm.**

***Index Terms*—microgrid, multi-agent system, economic dispatch.**

I. Introduction

Responding to the speedy increment of economy and society, the level of demand for electricity augments ceaselessly. Limitation of conventional fuel sources and increasing concern about environment draw much attention on renewable energy in present day. A potential solution to accommodate a large proportion of renewable energy is to establish a small power system, called microgrid, with intelligent controls to integrate it to the grid.

The concept of microgrid is employed to demonstrate the localized integration of distributed energy resources, loads, storages and control devices. A microgrid can be operated as an independent system (island system) or be connected to power network as a participant. Optimal operation is usually determined by considering power system efficiency and reliability. Although microgrid introduces challenges in operation of the system, it offers remarkable benefits for both utility and customers such as enhancing power quality (voltage sag, overload, three phase imbalance, harmonic distortion) and improving system transient stability and reliability.

In the presence of high penetration of distributed participants in microgrids, centralized system becomes too complicated and low efficiency to process with a diversity of data and controls. In order to leave behind this situation, a technology, known as multi-agent system, that functions the system by making use of an automated agent technology is put forward. The objective of multi-agent system is to separate a compound operation managed at centralized level into undemanding operation implemented at component level.

A multi-agent system is merely a system consisting of two or more agents, which follow designated mission, collaborating with each other to achieve an overall goal. MAS technology offers a wide range of applications in power system such as power system monitoring [1]–[3], electricity market operation [4]–[6], optimal power flow [7], power balance control and load shedding [8]–[10], stability enhancement [11]–[13], secondary voltage control [14], protection [15], and restoration [16]–[19] rooted in the advantages of agent properties: autonomy (function without human involvement), sociality (coordinate with other agents), reactivity (observe and respond to environment) and pro-activity (display goal-directed performance via taking initiatives) [23]. Application of multi-agent system on microgrid operation has been addressed in numerous works [24]–[28]. Its performance is structured by the global goal to make the most benefits of system operations.

Traditional economic dispatch is conducted in a central computing unit, who is able to access global generation and load information. It dispatches generation according to total load demand and individual generator's cost curve. However, in microgrids, because of their flexible structures and "plug and play" characters, decentralized control is preferred. This paper proposes a completely decentralized multi-agent system, in which all equal agents only communicate with their direct neighbors to achieve a minimal generation cost while satisfying customer needs.

This paper is structured as follows. In section II, mathematical background and assumptions for economic dispatch is described and minimal principle to obtain optimal solution is deduced. In section III, decentralized multi-agent based algorithm to realize minimal solution is proposed. Section IV verified the proposed algorithm by simulating a five-agent and fifty-agent systems respectively.

II. Economic Dispatch Problem Description

Assume there are n generators in microgrids. Each generator has a cost function $F_i(P_i)$ in terms of real power output P_i. Economic dispatch problem can be stated as given total

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system load and losses, how to schedule each generator's real power output, so that the total cost of generations is minimized while satisfying generators' upper and lower output constraints and system active-power balance requirement. Mathematically, optimization of generation cost in microgrids can be modeled as follows:

Minimize:

$$F = \sum_{i=1}^{n} F_i(P_i) \tag{1}$$

Subject to:

$$P_D + P_{loss} = \sum_{i=1}^{n} P_i \tag{2}$$

$$P_i^{min} \le P_i \le P_i^{max} \tag{3}$$

where

F_i = cost function of generation unit i
P_i = real power output of generation unit i
P_D = total load in microgrid
P_{loss} = total loss in microgrid
P_i^{min} = lower limit of generation unit i
P_i^{max} = upper limit of generation unit i

The Lagrange function can be constructed as (4)

$$\begin{aligned} L = \sum_{i=i}^{n} F_i + \lambda(P_D - P_{loss} - \sum_{i=1}^{n} P_i) + \sum_{i=1}^{n} \lambda^i (P_i^{min} \\ + s_i^2 - P_i) + \sum_{i=1}^{n} \lambda_i (P_i^{max} - t_i^2 - P_i) \end{aligned} \tag{4}$$

where

$\lambda, \lambda_i, \lambda^i$= Lagrange multipliers
s_i, t_i = real variables to convert inequality constraints to equality ones

Based on the necessary condition, at the minimal point, the partial derivatives of Lagrange function should be zero. Therefore:

$$\frac{\partial L}{\partial P_i} = \frac{\partial F_i}{\partial P_i} - \lambda - \lambda^i - \lambda_i = 0 \tag{5}$$

$$\frac{\partial L}{\partial s_i} = 2\lambda^i s_i = 0 \tag{6}$$

$$\frac{\partial L}{\partial t_i} = 2\lambda_i t_i = 0 \tag{7}$$

When $P_i^{min} < P_i < P_i^{max}$, then $s_i \ne 0$, $t_i \ne 0$. Based on (5) (6) (7), it is easily to obtain

$$\lambda^i = 0, \lambda_i = 0, \frac{\partial F_i}{\partial P_i} = \lambda \tag{8}$$

Alternatively, when $P_i = P_i^{min}$ or $P_i = P_i^{min}$, according to (5) (6) (7):

$$s_i = 0, \lambda_i = 0, \frac{\partial F_i}{\partial P_i} - \lambda - \lambda^i = 0 \quad \text{when} \quad P_i = P_i^{min} \tag{9}$$

$$t_i = 0, \lambda^i = 0, \frac{\partial F_i}{\partial P_i} - \lambda - \lambda_i = 0 \quad \text{when} \quad P_i = P_i^{max} \tag{10}$$

Equation (8) (9) (10) implies that for minimized cost, individual generator in the system should be dispatched at identical incremental cost, except those that have already reached their limits while still cannot reach the global incremental cost.

III. Multi-Agent Based Optimization Implementation

Ref. [10], [26], [27] illustrate methods on multiagent based power balance; therefore this paper will not cover power balance issues within microgrid. Assume that, power balance requirement has already been met by multiagent control, each load agent has obtained an assignment for its load; however this assignment only meets power balance but is not optimal value that maximizes load benefit. Therefore:

$$\sum_{i=1}^{n} P_i(0) = P_D + P_{loss} \tag{11}$$

Where $P_i(0)$ = initial generation assignment for generation agent i.

Consensus theorem in mathmatics tell us, if we make best efforts to continue keeping local values equal, then all the values in the system will consent in the end. To meet optimal conditions (8) (9) (10), for any neighbor agents m and n, the following behaviors expressed in (12) (13) are implemented.

$$\frac{dF_m(P_m^{(k)})}{dP_m} = \frac{dF_n(P_n^{(k)})}{dP_n} \tag{12}$$

$$P_m^{(k)} + P_n^{(k)} = P_m^{(k-1)} + P_n^{(k-1)} \tag{13}$$

However, if agent m (agent n is the same case) meets its limits while still cannot meet (12), then (12) does not need to be satisfied. Agent m chooses its limit as new assignment, and agent n calculates its assignment by (14).

$$P_n^{(k)} = P_m^{(k-1)} + P_n^{(k-1)} - P_m^{(k)} \tag{14}$$

Where $P_m^{(k)} = P_m^{limit}$, the limit can be upper bound or lower bound of agent m, it depends on which one prevents agent m from having the same incremental benefit as agent n.

The procedures for decentralized agents to achieve optimal economic dispatch are as follows:

1) Any agent m selects its neighbor agent n.
2) Both agents implement behaviors (12) and (13), if one agent meets its limit, then it takes its limit as new assignment, meanwhile, the other agent implements behavior (14).
3) If all agents' assignments converge within accepted tolerance, optimization process is over. Otherwise, go to step 1.
4) Over.

Fig. 1 displays the flow chart for economic dispatch in multi-agent platform.

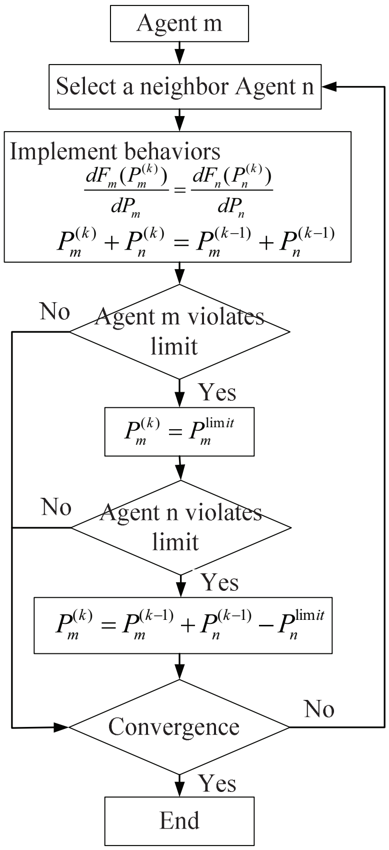

Fig. 1. Flow chart for economic dispatch

IV. Simulation Results

To validate the proposed agent-based economic dispatch algorithm, a small prototype microgrid with five DGs are studied. Assume the cost function satisfy polynomial equation expressed in (15). Other forms of cost functions also can be optimized by the proposed algorithm, as long as they are convex. The microgrid cost data are shown in Table I. Generation 4 is a renewable source, so it is operated in maximum power point. If not equipped with storage device, its output power is preferable not to be regulated. The neighbor relationships for this small microgrid is shown in Fig. 2. A line connecting two agents indicate neighbor relationship between them.

$$F = a_0 + a_1 P + a_2 P^2 \tag{15}$$

TABLE I
Generation data for microgrid

Gen. No.	P_{max}(kW)	P_{min}(kW)	a_0	a_1	a_2
1	400	200	8	0.096	0.00012
2	1000	300	12	0.072	0.00008
3	800	100	9	0.064	0.0001
4	600	600	-	-	-
5	900	150	10	0.084	0.00014

Initially, let us assume total load and line losses are 2600 kW. Initial values for Generation 1 to Generation 5 are 300 kW, 500 kW, 400 kW, 600 kW and 800 kW respectively. Fig. 3 shows the dispatched results for each generation. Only 4 iterations are needed to achieve optimal solution. It is seen in Fig. 4 that marginal costs are converged to an identical value in the end to achieve minimal operation cost except the one of the undispatchable source, Generation 4. Fig. 5 displays total cost in microgrid for the same amount of generation is reduced from \$339 to \$304.

To investigate the convergence speed of the proposed al-

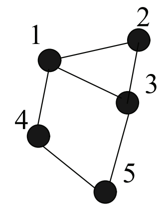

Fig. 2. Neighborhood relationship diagram

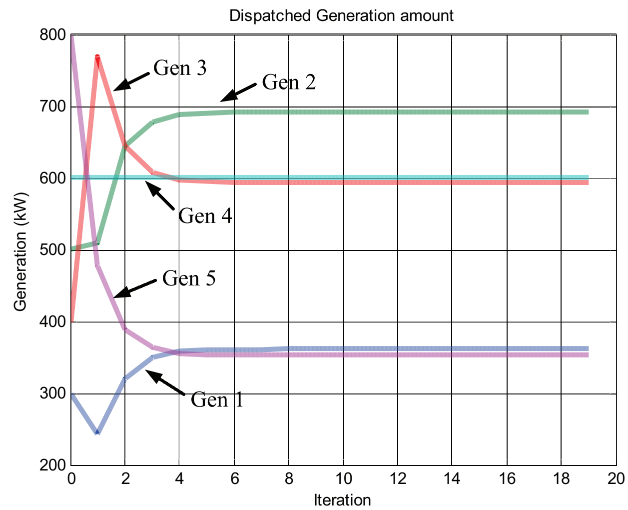

Fig. 3. Generation dispatch result for five-agent system

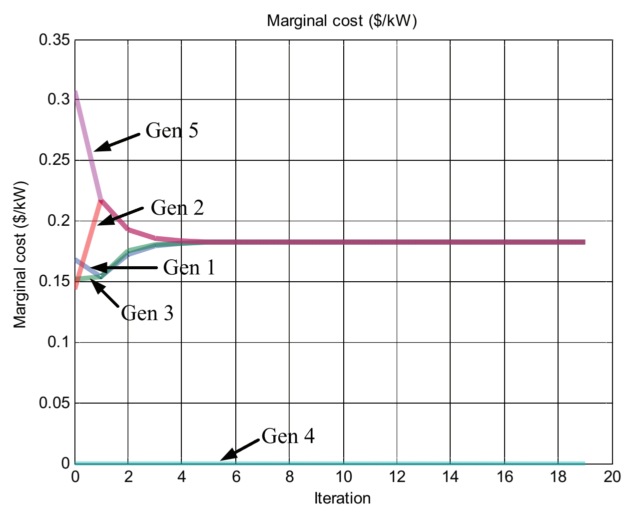

Fig. 4. Marginal cost for five-agent system

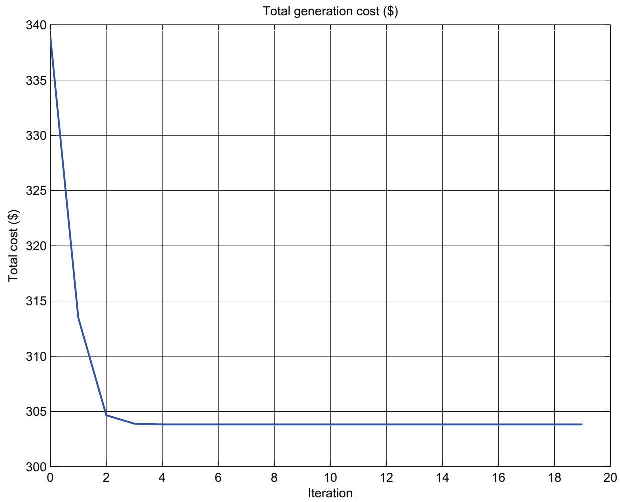

Fig. 5. Generation cost for five-agent system

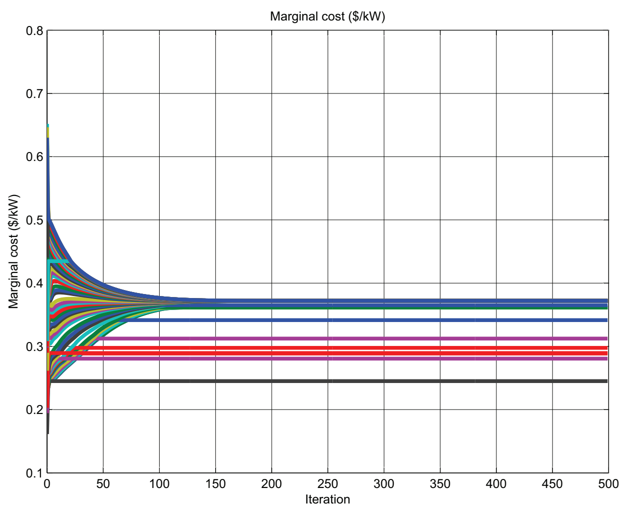

Fig. 6. Marginal cost for fifty-agent system

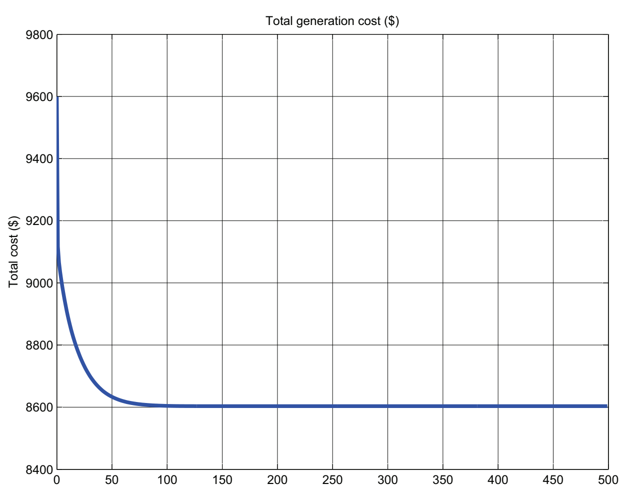

Fig. 7. Generation cost for fifty-agent system

gorithm, a complicated fifty-agent system is also studied. Assume cost functions also follow polynomial function in (15). Coefficients a_0, a_1 and a_2 are chosen randomly from 3 to 15, 0.02 to 0.1, and 0.0001 to 0.0003 respectively. All the generators have their individual power output limits, but overall, their power capacities are between 200 kW and 1500 kW. Simulation results in Fig. 6 represent that about 120 iterations are needed for the convergence. Most of the marginal costs are converged to the identical global marginal cost excluding those who have met their output limits. In Fig. 7, it is clear to see that operational cost is reduced monotonously in the proposed multi-agent system based algorithm.

V. Conclusion

This paper discusses a potential solution for distributed economic dispatch realization in a decentralized multi-agent platform. A decent communication algorithm based on the consensus theorem is proposed. In this algorithm, all agents are completely identical and autonomous. They do not have access to system global information; however, by making use of limited communications with their immediate neighbors and their local information, these agents are able to compete and corporate with each other to achieve a global minimal operational cost for microgrids. Simulations conducted in both five-agent and fifty-agent systems demonstrate the effectiveness of the proposed algorithm.

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