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# A review on multi-agent technology in micro-grid control

**Ming Ding, Xiaoqi Yin***

School of Electrical Engineering and Automation, Hefei University of Technology, No. 193 Tunxi Road, Baohe District, Hefei, 230009, Anhui, P.R. China

***Abstract:*** Micro-Grid (MG) integrates renewable generation, storage devices and controllable generations, it provides efficent utilization of clean energy while keeping stable external characteristics. Capability of continuous power supply, high scalability and flexible operation modes can satifiy the current demand of joint operation of renewable generation and Macro-Grid, and will provide a solid foundation for smart grid technology in the future. Thus, MG is an excellent integration of renewable energy utilization with a bright future, Multi-Agent System (MAS) is a new hierarchical control platform and can completely cover all the devices within a MG, its flexible control modes meet the needs of various operations of MG, and the capability of distributed computing supports intelligent functions of MG in the future. Therefore, developing premium functions for MAS in MG control will promote the development of both MG and Smart Grid technologies. This paper reviews the current applications of MAS technology for MG both in basic and advanced control demands. For basic demands concerning safe operations for MG, functions of MAS are available, but a further improvement of performance is essential for future researches to increase penetration of MAS in MG control; For advanced demands, MAS should increase calculation speed to meet the complex need of MG. In the last part, the future focuses are also depicted.

***Keywords:*** micro-grid; multi-agent system; control; review; frequency control; voltage control; economic dispatch; retailed market; nash equilibrium

## 1. Introduction

The demand for clean and reliable energy utilization is getting higher as the fast development of human society. Under this circumstance, traditional electricity consumption basing on a Macro-Grid has proven some of its defects. Macro-Grid is vulnerable to disturbance especially when encountering nature disaters, taking the blackouts in North America in 2004 and South China in 2008 as example. Moreover, Macro-Grid lacks scalability and costs much in its construction and maintainance. As a long-distance transmission is common, the power loss of a Macro-Grid is significant[1,2]. Macro-Grid is very dependent on fossil fuels, this can not meet the current needs of modern society[3–5]. Decreasing the dependence on Macro-Grid has been a crucial topic in power system research. These years researchers have developed a new technology called distributed generation (DG). DG places renewable generations near local loads and has advantages such as low pollution, low cost and high flexibility. However, DG takes solar and wind as its primary energy, this makes DG technology very unstable in real operation[6,7].


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Afterward, researchers integrate controllable generations (CGs), storage devices and local loads with renewable generations to form the original conception of Micro-Grid (MG)[8–10]. MG maximizes the utilization of renewable generation while keeping stable external characteristics due to its special structure. As loads are supplied by generations nearby, construction cost and power loss in operation are significantly lowered[11,12]. Flexibility of a MG is high since it allows devices to join or quit operation at anytime[13,14]. In ideal operation, MG runs in connecting mode with Macro-Grid to provide auxillary services[11,15]; as long as fault occurs, MG runs in islanded mode to provide uninterruptible power supply for local customers. Multiple MGs supports joint operation for different situations. Thus, MG is an excellent integration of renewable energy, it provides a good supplement for current Macro-Grid system and will lay a solid foundation for smart grid technology in the future.

Many researchers have obtained important achievements in MG technology these years. As the initiator of MG conception, Consortium for Electric Reliability Technology Solutions in the US builds a demonstrative system of MG in the state capital of Ohio. This MG system comprises batteries, turbines, normal and crucial loads and adopts a self-management for an effective control mode[16]. Recently, more than 45% of the MGs in the world are within the US, and the US has spent more than 40,000 thousand dollars to build MG systems for military bases both in its mainland and Hawaii state since 2011. In Europe, Spain, Portugal, Greece and France have built several MG systems in considerable scale. In particular, the National and Capodistrian University of Athens devotes to set a series of standards of MG cluster and its operation performance evaluation in projects named "MICROGRIDS" and "MORE-MICROGRIDS". Due to a lackage of resources, Japan values MG technology very much. In 2005, a MG consisting renewable generations 150kW in total was put into operation, and it achieved an optimal control via a combination of long and short-term plan. In China, more than 30 MGs integrating smart grid technologise have been built recently. Among those, a MG with desalination functions providing both electricity and water supply is the most notewothy.

MG is a promising technology. As its special structure, developing a superior control platform will promote fast development of MG and lay a solid foundation for smart grid in the future. Inhereted from the tranditional Marcro-Grid control, centralized control mode relies on the only control unit. The control burden is heavy and this mode is unable to satisfy various control needs of distributed devices within a MG; The newly developed distributed control mode has several completely equivalent control units, thus, none of them has a higher authority to perform an overall control to eliminate status fluctuation of the whole MG. Multi-Agent System (MAS) is a hierachicle control platform. In a MAS, every agent has a certain intelligence to perform local control independentely, several agents within the lower layer obey orders from one agent in upper layer. Thus, MAS can switch between distributed and centralized control freely when needed[12,17,18].

This paper focuses on a brief review of current MAS technology utilized in MG control. The future focuses of this technology is also predicted. The rest contents of this paper are organized as follows. Feasibility and developing mode of MAS in MG control is analysed in Section 2. Recent researches and applications of MAS in MG are evaluated in Section 3. Future development of this topic is analysed in Section 4. Finally, a conclusion basing on the content of this paper is given in Section 5

# 2. MAS feartuers

Judging from topology, MAS platform can cover each of the devices within a MG. Structure of a MG can be devided into two layers: control and device layer, which is similar to a MAS structure. A MG usually contains multiple generators, storages and loads. These devices may belong to different oweners, thus have different control objectives and various interest demands. When a MAS is utilized in MG operaion, lower agents will provide information and help upper agents control the overall status; each device within the MG is monitored by an independent, exclusive lower agent. This agent tries to satisfy all the control objectives and maximizes the benefit of this device. The relationship between MAS and MG is shown in Figure 1, when any device joins or quits MG operation, MAS platform adds or removes agent synchronously to ensure a complete coverage in topology

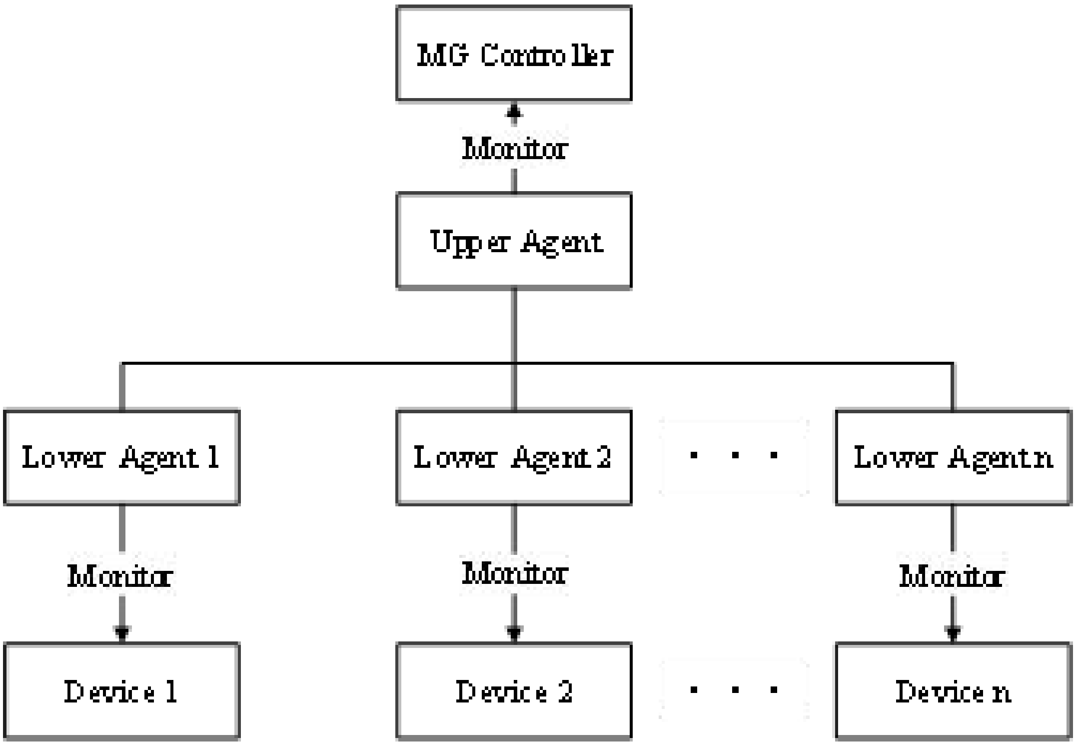

Figure 1 Common structure of MAS platform utilized in MG control

Considering the capability of control mode switching, MAS is a good choice for MG. In stable operation, upper agent allows lower agent do local control independently, this provides adequate freedom for various kinds of devices, making MG a friendly environment for integrating more devices, helping improve scalability of MG; when fluctuation or fault occurs, MG needs powerful control to retrieve stable status. In this case, upper agent performs an overall coordination, lower agents provide full support for coordination using local reasources. Thus MAS can satisfy the needs for frequent operation mode switch in MG[19].

# 3. Current applications of MAS technology in MG control

As a new control platform, recently MAS technology mainly focuses on basic and advanced control functions for MG. Basic control functions are premise of a safe operation in MG, these functions involve active and reactive balance, voltage and frequency stability within a MG; Advanced control functions improve stability, usability and efficiency of a MG and help promote the penetration of MAS platform in MG control.

## 3.1 Basic Control Functionse

As proved by references[20–27], active and reactive power imbalance cause frequency and voltage deviation from their ratings, respectively. Thus, active power coordination and frequency control are regarded the same control demand, and so are reactive power coordination and voltage control. In islanded operation mode, MG losts support from Macro-Grid, and it is quite hard for MG to stay in a stable status. Thus, recently basic functions of MAS in MG control mainly focus on inslanded modet

### 3.1.1 Active Power Coordination & Frequency Control

The traditional droop control inherited from Macro-Grid operation can be utilized for MAS platform in this control demand. Basic idea of droop control is that each inverter of distributed generations runs in active-frequency mode. Whenever a frequency deviation is detected, each inverter adjusts active power output according to its droop curve to stabilize frequency. Droop control achieves a differential regulation, and a modification of operating point is needed lately to retrive a rating frequency. A droop control of frequency basing on MAS platform with adaptability and consideration of economic operation cost of MG is presented in[26]. The frequency detected by MG Central Controller (MGCC) is taken as reference in[28], then all the CG Agents are ordered to perform droop control synchronously with an evaluation of resistant capability of communication disturbance of the system. As a MG barely comprises rotating generators, inertia of the system is low[22,29], slight imbalance of active power leads to a large deviation of frequency in the MG. When a droop control strategy is applied via MAS platform, the differential regulation leads to a stabilized frequency significantly deviated from its rating value. This decrease the usability of droop control in MG using MAS.

In contrast, a coordination of active power provides a direct solution for frequency regulation. A simple method for frequency control of MG in islanded mode is proposed in[21]. When a frequency deviation is detected, MAS orders CGs to increase active power immediately and stop output increment once a balance is achieved. Implementation of the method is easy, but it has obvious flaws. When MAS detects a power balance, it orders all CGs to stop output increment. A certain delay is inevitable between the time point MAS sends out the message and when a CG Agent takes action after receiving the message, this delay causes an opposite power imbalance leading to an opposite frequency deviation. In[30], MGCC Agent directly inquires each CG Agent its maximal active power output and judges whether the imbalance can be eliminated by CGs only, if not, MGCC Agent orders storage devices to get involved. If the total capacity of storage devices is not enough, then a part of loads will be cut. This method ignores that due to limited capacity, a storage device is not able to sustain a power output forever. When it is used up, the imbalance it fills up will appears eventually. A power coordination method for multiple MGs is introduced in[31]. First, MAS figures out outputs of renewable generations, State of Charge (SOC) of each storage device, status of CGs and the Macro-Grid. When renewable generations provide excessive power, MAS orders storage devices absorb redundant energy. If total capacity of storages is insufficient, Macro-Grid deals with the rest power; If the total power provided by renewable generations are not enough, CGs will increase outputs. Reliability of this method is high, however, considering a limited capacity of each storage, output of each renewable generation fluctuates frequently and power variation speed of a CG is low, this method shifts the instability of renewable generations to Macro-Grid rather than form a stable external MG characteristic. In fact, stability is the premise Macro-Grid allows a MG run in connected mode. A coordination method with the idea of minimal load shedding is proposed in[32]. MAS classifies loads, when a power imbalance appears and CGs have insufficient capacity, MAS sheds loads according to priority and let CGs fill up the imbalance they could. A new method with token transferring is utilized in[33]. This method is designed distributedly, corresponding agent of the device which leads to the imbalance is in charge of the coordination. This avoids single point failure. During the coordination, a selection of low generation cost is applied. Responding speed of CG is considered in[34], MAS distributes output varations of the CGs according to their responding speed to eliminate the imbalance as fast as possible. This takes the real-time performance of active power coordination using MAS platform into consideration.

Currently, MAS functions in active power coordination of MG are basically available. However, the fact that outputs of reneable generations fluctuate often leads to frequent demands for power coordination from MG, especially in a bad weather; on the other hand, small active power imbalance causes a large frequency deviation due to low inertia. Thus, MG needs coordinating method with higher performance than Macro-Grid does. The control objective is minimizing the harm the MG suffers from druing a whole coordinating process and helps it against the worst natural condition. Low control performance directly leads to an explosion to imbalance with higher value or lasting a longer period, increases possibility of system decomposition, aging of devices and circuits. This performance is considered in[34], but a further research is needed. Future development of this topic focuses on an effective improvement of real-time performance of coordination in MAS platform.

### 3.1.2 Reactive Power Coordination & Voltage Control

Being different from the global feature of frequency control, voltage control within a MG concerns local conditions. In islanded mode, due to limited resource, voltage control becomes more difficult. A detailed analysis of the functions of each agent in MAS during voltage coordination and the advantages of this control mode are given in[35].

Being similar to active power & frequency control, some researchers use droop control in voltage coordination, as is shown in[26,28]. Other solutions usually use the basic control structure shown as follows: device agent monitors voltage of its node directly. When an obvious voltage deviation is detected, corresponding agent orders local devices to help with voltage coordination. An optimal configuration of monitoring and coordinating functions of device agents in this control mode is introduced in[36]. Voltage control is regarded as a linear programming process with objective of minimizing the control cost in this reference. Each of the device agents has its own reactive power sensitivity coefficient. When a voltage deviation appears, the device agent having the largest coefficient adjusts the reactive power its corresponding device output or absorb. This control mode is distributed, monitor agent in the upper layer acts only as a communication center. As the decentralized feature of reactive power coordination, performance of this method is quite satisfactory with low brandwidth occupancy. An effective voltage control method is presented in[37]. Monitor agent calculates voltage reference of each device periodically. Once a voltage deviation is detected by an agent, it informs the monitor agent. The latter chooses a suitable device agent to adjust it reactive power. If the capability of this agent is not enough, its neighbor agents will get involoved to help achieve a complete coordination. Simulation results indicates that this method performance well in actual scenarios.

In a word, due to hierachicle control structure, recent researches provide satisfactory functions for voltage and reactive power coordination within MG basing on MAS platform.

## 3.2 Advanced Control Functions

Advanced control demands are not the premise of a normal operation. However, better advanced functions help improve efficiency and reliability of MG technology and promote its development

### 3.2.1 Economic Dispatch

If a MG belongs to a single owner, operation cost rate (cost generated in unit time) minimization becomes an important control objective. This can be described using the equations shown as follows:

$$\min\,[C_{grid} \times P_{grid} + \sum_{i=1}^{n}\sum_{j=1}^{m_i} C_j(P_i)\,] \tag{1}$$

In equation (1), objective of economic dispatch is presented. Here, n is the number of CGs within a MG, $P_i$ is the active output of number i CG, $C_j(P_i)$ is the number j cost rate function of CGi, $m_i$ is the total amount of rate functions, $P_{grid}$ and $C_{grid}$ are the power and its unit price the MG buys from Macro-Grid, respectively. As MG technology aims at maximizing the output of renewable generations, the target function of economic dispatch actually only concerns the total cost rate of all CGs. Several constraints of economic dispatch process are shown in equantions (2)–(4).

$$P_{grid} + \sum_{i=1}^{n} P_i = \sum_{a=1}^{n_{rg}} P_a^{rg} - \sum_{b=1}^{n_{load}} L_b \quad (2)$$

$$P_i^{min} \leqslant P_i \leqslant P_i^{min} \forall i = 1,2,\cdots,n \quad (3)$$

$$0 \leqslant P_{grid} \leqslant P_{grid}^{max} \quad (4)$$

Here, $n_{rg}$ and $n_{load}$ are the number of renewable generations and loads, respectively, $P_a^{rg}$ is the output of number a renewable generation, $L_b$ is the number b load. $P_i^{min}$ and $P_i^{max}$ represent upper and lower bound of output of CGi. $P_{grid}^{max}$ is the maximal power MG buys from Macro-Grid. Equation (2) indicates that in any time during economic dispatch, the grid must always keep the balance among power generations and consumptions.

MG requires an economic dispatch with higher performance than Macro-Grid does. As the frequent fluctuation of outputs of renewable generations, each time an active power coordination has been carried out, an economic dispatch is needed. For economic dispatch function of MAS, its calculating speed is as important as result quality. If it calculates slowly, output of renewable generations may change before a result is achieved, total output of CGs varies, the result becomes invalid. Besides, MG allows devices to join or quit operation at any time, the scale of MG might be large. Thus, economic dispatch function of MAS should calculate quickly for a large MG.

For this topic, recently there are many global optimization algorithms available for MAS platform. Except existing methods, the special centralized-distributed feature make MAS suitable in developing new smart algorithms.

An improvement of the model of MG ecnomic dispatch basing on MAS is introduced in[38,39], where response speeds of CGs and storages are taken into account. This model also evaluates the transient performance of switching into the status of minimal cost rate.

Many researches utilize existing alogrithms in MAS. A proportional active power distribution method is presented in[40]. When an imbalance appears, the CG having higher potential capacity increases its output by a larger amount. This method is simple, but barely achieves a global optimal. A new economic dispatch method basing on Lagrange Multiplier using MAS is proposed in[41], but the result quality is not evaluated. Authors of[42] distribute dichotomy on MAS and compare this method with particle swarm to verify its reliability. Genetic Algorithm is widely utilized in economic dispatch, such as[43] does. A Multi-Agent Genetic Algorithm is carried out in[44], emulation results indicates that this method outperforms generatl genetic algorithms in calculation quality. Detailed information and implementation of genetic algorithm can be found in[45]. Direct particle swarm is utilized in[46,47] for economic dispatch. Basing on the common model of MG economic dispatch, an practicle evaluation of the cost of optimization process is performed in[48]. In this reference, particle swarm is the core of optimization process. Mixed-Integer Linear Programming is applied in[49], simulations prove the effectiveness of this mehod. A primary prediction of the renewable generations using neural network is presented in[50], then a back propaganda mixed with particle swarm optimizes the cost rate of the whole MG. Here, back propaganda searches local optimals while particle swarm searches the global ones. Calculation results show that this mixed algorithm calculates quite fast in actual operation.

Implementation of existing method is easy, but it has several flaws. As expressed in[51–55] and the Global Optimization Toolbox in Matlab platform, advantages and disadvantages of common global optimization algorithms are shown in Table 1. Almost all the methods have flaws in actual application. Smart algorithms usually have some random searching process to improve result quality and generality of the method, thus, they usually calculate very slowly, especially in high-dimensional economic dispatch.e

Table 1. Basic Information, advantages and drawbacks of several common intelligent global optimization algorithms

| | Advantage | disadvantage |
|---|---|---|
| Genetic Algorithm | Large searching space | Slow |
| Particle Swarm Optimization | Higher possibility of | Very slow |

| | | |
|---|---|---|
| | convergence | |
| Hybrid Artificial Bee Colony | High calculation quality | Unable to deal with high-dimensional problem |
| Hybrid PSO with Stop Criteria | Fast convergence | Small searching space |
| Ant Colony | High calculation quality | Very slow in high-dimensional problem |
| Artificial Fish Swarm Optimization | Fast convergence | Many constraints |
| Hybrid Simulated Annealing | High calculation quality | Very slow |

Except transplanting existing methods to MAS platform, improving or even designing new algorithms according to special features of MAS in economic dispatch become popular solutions. A subgradient optimization algorithm is proposed in[56]. Here, step and direction of iterations are improved. Emulation results show that this method improves calculation speed significantly. An improved method named hybrid particle swarm is introduced in[57]. A combined weight diminishing with genetic algorithm helps particles trapped in local optimals jump out of its former region. This siginificantly improves calculation quality and speed. Generally, methods basing on consensus algorithms are good choices, such as expressed in[58–61]. Basic idea of consensus algorithm is making identical partial derives of the profit functions of all CGs through adjustment. This leads the MG to a condition of minimal cost rate. In[58], cost increments of CGs and profit increments of flexible loads are taken as consensus variables for the algorithm. MAS usually runs in distributed mode when implementing consensus algorithm, as can be seen from the aforementioned references. A distributed fusion strategy basing on consensus algorithm containing gradient decending process is utilized in[62]. This improve calculating speed of the method effectively. In[63], MAS performs an economic dispatch through decentralizd priority ranking. Taking generation shortage for example, each CG Agent inquires cost rate function of its corresponding CG, and finds out the derivative value situates in current output. CG having smaller derivative achieves higer priority of active power increment. Emulation indicates that this process finds good results in optimization. However, this optimization can not be divided from the coordination process and affects the performance of real-time coordination.

Specifically, some researches develop heuristic algorithms customized exactly for MAS platform. In[64,65], the authors distributed the target function of economic dispatch to several parallel sub-functions each is handled by a corresponding agent. In [64], a new information transmitting structure named: Dynamic Programming Decentralized Optimal Dispatch is created and proves its better performance in optimal searching than traditional method does. A reinforcement learing model is presented in[66] basing on MAS platform. Each agent modifies its behavior according to previous experience acquired. This heuristic method provides quite a good solution in minimizing fuel and pollution cost in actual operation.

Currently, various MAS functions on economic dispatch in MG are proposed, especially for those distributed algorithms. The diversification indicates different direction for future researches. Considering the frequent request of economic dispatch, future MAS functions should focus on the improvement of the calculation speed while keeping a good result quality.

### 3.2.2 Calculation of NE within a Retailed MG

To break up monopoly, introduce competition and allocate resources resonablly, open electricity market has become a good choice. China started the development of electricity market in 2002 and has tried to find better solutions to reconstruction of electricity industry, effective market monitoring and rules for electricity clearing. But there is no mature systematic structure on this point[67]. Large electricy market involving several countries and regions proposed by the US and EU appears in recent year[68]. A trend of retailed electricity market is inevitable in the future[69–71].

MG technology outperforms Macro-Grid in lowering power transmission loss, thus, MG has price advantage in local market competition and provides cheaper electricity for loads than Macro-Grid does. Researches on open retailed electricity market within MAS platform are quite necessary. In this situation, each device within the MG is monitored by a corresponding agent which fights for the maximal profit of this device. MAS technology provides a good solution for implementing a completely open market in MG.

In retailed market, generations hold non-cooperative relationships with each other. Nash Equilibrium (NE) is one of the most important concept in non-cooperative gaming[72,73]. Its basic definition concerns psychology: NE is a set of strategies. When a NE status is reached, none of the players can increase its profit by change strategy unilaterally, thus each player is motivated to stay within the NE state[74,75]. NE provides a stable condition that each of the players accepts this situation and this status is considered stable by the outside world.

In retailed market, elecirity transmission and consumption are similar to those of other kinds of mechandises. Thus, a retailed electricity market is valuable. In this situation, each generation competes, the result of gaming determines the retail price and quantity of electricity power. According to the basic definition of NE, the set of all global NEs forms the results of multi-objective optimization for the profit function set of all CGs. When situates an optimal, none of the CG agents can increase profit by modifying its active power output unilaterally. The definition of multi-objective optimization is in accordance to that of NE.

In non-cooperative gaming, there might be multiple NEs globally[76,77], each of them corresponds to a different status. In retailed electricity market, it is important for MAS to pick up a certain optimal NE quickly. High calculation speed enables the MG provides stable sevice quickly, this is an essential feature for an electricity provider; Optimal NE implements the policy of the whole market environment such as promotion of renewable generation, lowering pollution and retail price, etc.

Recently most researches create a dynamic gaming environment for retailed maket. In dynamic gaming, previous bids are shown in public, former strategy of one player will affect later strategy of the others. After multiple rounds of gaming, the market might converge to a NE. In[78], a retailed market basing on MG monitored by MAS is proposed. First, all the agents initiate their strategies with an assumption that a NE is already achieved. In one round, each agent assumes that strategies of the others remain unchanged, and it calculates maximal profit of the device under this circumstance. Then all the strategies are collected and updated for the next round of optimization. After many iterations, MAS helps MG converge to a NE. The possibility of convergency is not evaluated in this reference. A Double-Sided Energy Auction in islanded mode is introduced in[79]. This method is totally distributed, each of the CG Agent modified its current strategy according to its expectation, previous bids of load agents and retail price; Then load agent modifies load demand according to the bids of all CG Agents. This process runs in iterations and finally leads the MG to a specific NE. The method in[80] is similar to that of[79], only with an optimization process implemented by particle swarm algorithm. An evaluation of calculation speed is also needed. In[81], a proofing of the existance of NE is given. In calculation, MAS platform provides 2 kinds of gaming strategies: strategy basing on retail quantity and price. CG Agent bids according its risk cost while electricity retail price evolves using an adapative algorithm. After a round of gaming, load agent changes load demand according to retail price. The process iterates until a NE is formed. Emulation results indicate the effectiveness of this method. In[82] a strategy making method similar to that in[81] is presented. 2 models basing on 2 different strategies are made: models basing on risk tolerance and minimal cost, the latter utilizes an improved Roth Erev reinforcement learning algorithm to bid. Real-time emulation proves its fast calculation speed and high stability. Differential gaming is a complex dynamic gaming in continuous time slots. Differential gaming is more competitive and can describe activities within an open market precisely. Linear Quadratic Differential Games is applied to describe market environment in[83]. By solving Riccati Equations, MAS achieves a NE.

Dynamic gaming is a good model describing market activity, it provides more freedom for CG Agent and attracts more players. However, dynamic gaming need multiples iterations to converge, proofing of the certainty of convergence is difficult and calculation speed might be slow. Besides, when a player detects a NE is going to be achieved, it may take some strategies to stop the process. Even that behavior may not succeed, it takes quite a long time for the market to reach a stable NE, and the corresponding retail price and quantity may not be satisfactory.

In order to avoid the uncertainty of dynamic gaming, several researchs design a static gaming for MG. In this situation, content of each bid and the sequence of bidding remain secret, CG Agents have no reference of previous action. They must predict a NE and bid for it. When each agent predicts the same NE, a global stable NE is formed. On the other hand, if a NE is the ultimate target of open market, regardless of gaming pattern (dynamic or static) and strategies of different CG Agents, if the result converges, it forms a NE. If MAS can calculate global NEs and select the optimal one, calculation time will be shortened significantly. In[57] the cournot model is utilized for NE calculation. Its basic idea is solving the equation set of zero deviratives of profit functions of all CGs. However, this method will miss the NEs situates in undifferentiable point. A method basing on basic NE definition is proposed in[84] to search the whole strategy space of all players to select optimal NE. This method can find all the NE globally and is suitable for MAS platform, but its calculation speed needs further evaluation. Binary Expansion Approach is utilized in [85], this process first switches the calculation of Mathematical Program with Equilibrium Constraints to Mixed interger linear programming, then uses commercial software in optimal calculation. Static gaming is not commonly used in MAS calculating NE due to that multi-objective optimization is quite difficult. However, this gaming model worthes further research. Future development should focus on the calculation speed and effectiveness of optimal NE selected by MAS platform

# 4. Future Focus

The future development of MAS technology will develop advanced functions which promotes penetration of MG in the future. MAS platform should also help standardrization of MG technology. Future focuses on this topic are not limited within the follows:

A. MAS in MG protection and service restoration. Distributed monitoring functions enable MAS to monitor complex power stream, thus, MAS is originally suitable for implementation of advanced MG protection functions. One agent can detect and cut down faults along with information provided by its neighbor agents. This is a fully distributed mode; After severe faults occurs, MG may suffer a blackout, a fast service restoration function of MAS increases the stabiligy of the whole system. Advantages of MAS in service restoration is the distributed coordination capability. Every agent can maximize resources of corresponding device and provide support orderly. The independent runtime capability of each agent can help monitor local voltage and reactive power to provide further auxiliary functions such as electricity quality control during restoration.

B. Plug and play. MAS platform supports plug and play and can implement the same function for devices within MG. This feature can help build a friendly environment integrating various kinds of devices. Traditional centralized control mode depends on the control center totally, as its calculation burden is already heavy, various and frequent costumized control needs from the device can not be satisfied. For MAS, each of the devices within the MG has a corresponding agent, thus, when a new device joins the operation, MAS only needs to add a new agent to keep the new device from harming the stable environment; when a device quits operation, its agent can cooperate with others to achieve a seamless quitting. Plug and play is a set of functions coordinated quite presicely, a good designation of these features help improve penetration of MAS platform in MG control.

C. Prediction. The hierarchical control structure of MAS supports implementation of heuristic algorithms, which can predict loads and generations. Specifically, MAS can predict renewable generation basing on previous experiences and prediction data of primary resource made by meteorologic bureau via internet. This provides an advanced prediction functions for MAS.

D. Big data and self-learning. MAS is a platform suitable for implementing and developing self-learning algorithms. By recording MG status continuously, MAS can collect big data on MG operations within a long duration. Self-learning functions can find implied features of MG within those data and provide further suggestions for MG construction, operation and optimization.

E. MAS promoting the development of smart MG. MG technology has a promising future; the operation mode of electricity industry will be a Macro-Grid integrated with many small MGs. Introducing artificial intelligents to MAS platform to enable learning, thinking and judging capability of MG can create smart MG. Thus, MG can judge whether support or absorb power from Macro-Grid, make prudent choices when the situation is not clear, make automatic decision by emulating preference of its owner and cooperate with other MAS of MG to provide local area with economic operation. Smart MG provides infinite potentials of electricity industry.

# 5. Conclusion

As the high compatibility of various generations, MG technology can relief the dependency on fossil fuel, decrease power loss, increase stability and compatibility of various kinds of generations in electricity industry; MAS platform suits control need of MG both in topology and capability of operation mode switch. Thus, a systematic research on the MAS technology in MG control is necessary and will promote the development of MG.

This paper reviews the current applications of MAS for MG both in basic and advanced control demands. For basic demands, MAS functions are available, but a further improvement of performance is essential for future researches to increase penetration of MAS in MG control; For advanced demands, MAS should increase calculation speed to meet the complex needs of MG. In the last part, the future focuses are also depicted.

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