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A Microgrid Operation based on a Power Market Environment

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Abstract

A Microgrid is a private small-scale power system composed of distributed energy resources (DERs), storage devices and loads. And it is expected that the Microgrid will come into wide use in the near future. For this, the establishment of the Microgrid operation methodology is a very important problem. Especially, the Microgrid is greatly different from existing private small-scale power systems because of the multiple participants. Therefore, the Microgrid operation considered various requirements according to multiple participants is more complicated than the operation of existing private small-scale power systems. In this paper, Microgrid operation methodology based on a market environment is suggested. Through case studies , the effectiveness of the suggested methodology is verified.

Key Words : Microgrid, Microgrid Operation, Microgrid Operation Procedure, Power Market Environment, Microgrid Operation based on Market Environment

1. Introduction

A Microgrid suggested by Prof. Lasseter in 2001[1] is a private small-scale power system composed of distributed energy resources (DERs), storage devices and loads. The Microgrid has lots of merits such as an eco-friendly energy system, supplying a good quality power, energy security and so on. Recently, the research, development and demonstration projects of Microgrids have been progressed in many countries [2-3]. And it is expected that the Microgrid will come into wide use in the near future.

The many studies about the Microgrid have been progressed in various areas such as inverter analysis and control [4-6], power quality [7-9], island mode analysis and control [10-12].

Since the Microgrid has multiple participants, there is a big difference in operation between the Microgrid and the existing private small-scale system based on a one-owner. Therefore, the Microgrid operation is more complicated than the existing private small-scale power system operated by well-known optimal methods. For this reason, the Microgrid operation methodology should be studied and developed for rapid spread of the Microgrid.

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The key point of the Microgrid operation is to maintain system frequency. The maintenance of frequency is related to a balance between power supply and power demand. For this, Microgrid trades power with a power grid when power shortage and excess in the Microgrid system occur. When the Microgrid trades power with a power grid, the buying power price from the power grid is higher than the selling power price to the power grid generally. Power production unit wants to supply power at higher price than the selling price to the power grid and the power consumers wish to buy power at lower price than the buying price from the power grid. From that circumstances, the Microgrid operation has characteristics of power market basically.

In this paper, we suggest a Microgrid operation methodology and a procedure based on a market environment. Also, for the verification of the effectiveness of the suggested methodology, the case studies are performed based on a Microgrid market rule and the proposed operation procedure. And the effectiveness is verified through the case studies.

2. Microgrid Operation

A Microgrid is a small-scale power system constituted by small DERs, storage devices and loads in included a distribution system such as Fig.1. The Microgrid can be operated by two modes such as the Grid-interconnected operation mode and the Island operation mode. In the Grid-interconnected operation, Microgrid is connected to the power grid and can trade power with the power grid for the shortage or surplus power in the Microgrid. In the Island mode, the Microgrid is disconnected to the power grid and the power demand of the Microgrid should be supplied by inner power production units and storage units. Especially, the Island mode can be occurred by specific conditions such as a fault or blackout occurrence in the power grid.

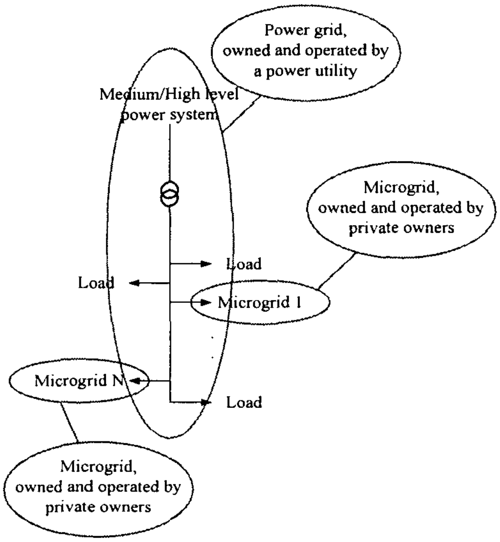

Fig. 1. A distribution system with Microgrids.

The major object of Microgrid operation is to maintain the allowable system frequency. The frequency is related to the balance between power supply and demand. When power supply is more than power demand, the frequency is increased. Inversely, when power demand is more than power supply, the frequency is decreased. In this paper, Microgrid operation is focused on the balance between power supply and demand including power trade with the power grid in the Grid-interconnected operation mode.

In the Grid-interconnected operation, the frequency is related to the balance of Eqn. (1) and Fig.2 shows the power flow in the Microgrid system interconnected a power grid. In Fig.2, Microgrid Operation & Control Center (MGOCC) plays a role in managing the operation and control in the Microgrid.

$$P_D + P_{SP} = P_S + P_{BP} \quad (1)$$

where,

P_D : power demand of power consumption and storage charging power in the Microgrid

P_S : power supply from production units and storage discharging power in the Microgrid

P_{BP} : power to be purchased from the power grid

P_{SP} : power to be sold to the power grid

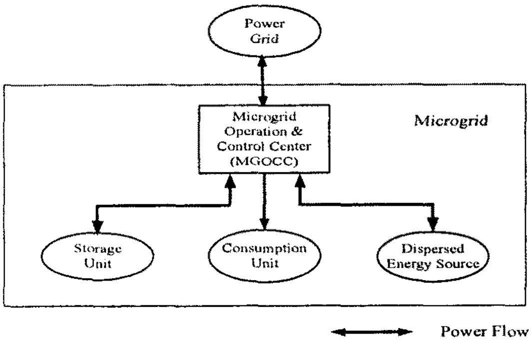

Fig. 2. Power flow in the Grid-interconneced mode.

Fig. 3 shows Microgrid operation according to the operation interval. At interval i, the operation plan for interval i+1 is established and the operation plan established at interval i-1 is implemented at the same time. Also, at the beginning of interval i, the power grid announces the selling power price to the Microgrid and the buying power price from the Microgrid to interconnected Microgrids.

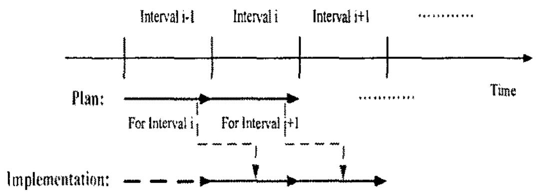

Fig. 3. Microgrid operation according to the operation intervals

Fig.4 shows the rough procedure of the Microgrid operation. In this paper, we assume that the demand of next interval can be predicted.

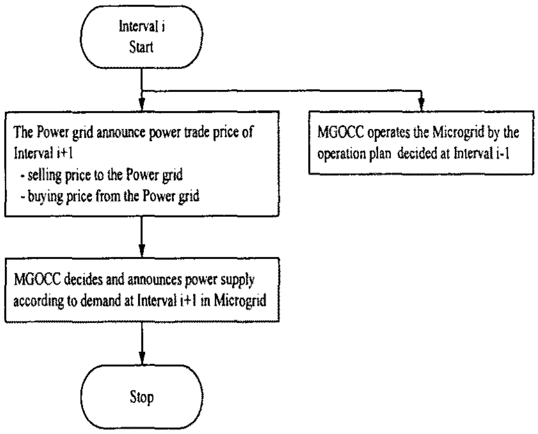

Fig. 4. Rough Microgrid operation procedure.

In general, the Microgrid has multiple participants such as the power consumption devices, power production devices and power storage devices and their requirements are dependent on their profits. For that reason, the operation of the Microgrid is more complicated than the operation of a one-owner's system such as the existing small-scale power system because of different requirements of all participants. In this paper, we suggest for Microgrid operation based on a market environment as an effective method.

3. Microgrid Operation based on Power Market Environment

The requirements of each participant in the Microgrid are as follows:

- DERs want to supply power to the Microgrid at high price within the limits of the possible;
- Storage devices want to supply power to the Microgrid at high price within the limits of the possible;
- Also, storage devices want to use power at low price within the limits of the possible;
- Consumers of power want to use power at low price within the limits of the possible.

Because of such different requirements among participants, the Microgrid operation becomes more complicated. Meanwhile, power shortage and excess of Microgrids should be traded with the power grid to maintain the system frequency in allowed ranges. In the power trade, generally the buying price from the power grid is higher than the selling price to the power grid. In this paper, we assume that the government support to DERs without fuel use such as solar power, wind power is not considered for generality and simplicity of the problem. By introducing power trade price from/to the power grid, the above-mentioned each participant requirement can be modified as follows:

- DERs and storage devices as suppliers want to supply power at a higher price than the selling price to the power grid (or at the selling price at worst);
- The consumers of power and storage devices as consumers want to buy power at a lower price than the buying price from the power grid (or at the buying price at worst).

From the above-mentioned requirements of participants, we can find a clue of an efficient methodology for the Microgrid operation from the power market environment. Although there can be many types of the market environment, this paper does not deal with which market type is most effective for the Microgrid operation. Instead, we suggest a Microgrid operation based on a market environment as an effective operation methodology.

In the operation of the Microgrid, the power price of the Microgrid (P_M) is decided such as Eqn. (2), where P_S is the selling power price to the power grid and P_B is the buying power price from the power grid.

$$P_S \le P_M \le P_B \tag{2}$$

In Eqn. (2), even though the left boundary price (P_S) is the worst price to power production units and the right boundary price (P_B) is the worst price to power consumers, we can ascertain that the requirements of power consumers and suppliers are always satisfied of the proposed operation methodology.

The bid of DERs with fuel use can be expressed by Eqn. (3), where P_{bid} is the bid price of the power production which is assumed as an acceptable price and, 0 or 1 means whether or not a power production unit bids.

$$Bid = \begin{cases} 1 & \text{if } P_{bid} \le P_B \\ 0 & otherwise \end{cases} \tag{3}$$

In case of storage devices, they can be power suppliers and consumers according to situations. Therefore, they should have capability to decide whether they supply power or consume power at each interval. In this paper, we assume storage devices have decision-making schemes for that.

In the next section, we verify the effectiveness of the suggested methodology through introducing an acceptable market rule and procedure and implementing case studies based on the rule and procedure.

4. Case Studies

4.1 Microgrid Operation Rule

To consider the effectiveness of the Microgrid operation in a market environment, the following market rule for Microgrid based on fuel cost is introduced:

① Selling power price (P_S) and buying power price (P_B) to/from the power grid for the next interval are announced from power grid at the beginning of interval and P_B is higher than P_S in general;

② MGOCC should economically manage power supply and demand in the Microgrid;

③ At the beginning of interval, MGOCC has an information of total demand including storage charge of the next interval;

④ Each production unit has acceptable production cost;

⑤ Production units without fuel use such as solar power, wind power have no production cost;

⑥ Each production unit have lower than or equal to P_B can bid its production cost and supplying amount;

⑦ Storage and production unit without cost can bid only supplying amount;

⑧ MGOCC contracts to bidders in the sequence from lower to higher bidding price until satisfied with the amount of power demand;

⑨ Inner power price is decided as an arithmetical average calculated by buying power from the power grid and inner supply power considering each price, where inner supply power price is decided by the highest bidding price;

⑩ The inner excess power produced by production cost lower than or equal to P_S is sold to the power grid;

⑪ When the award units can't fulfill the supply contact, a new contract should be prepared for the nonfulfillment.

For practical application, the market rule can be changed according to situations. The procedure of the Microgrid operation based on the above-mentioned market rule is introduced such as Fig.5.

4.2 Cases & Results

Four case studies are implemented to verify the

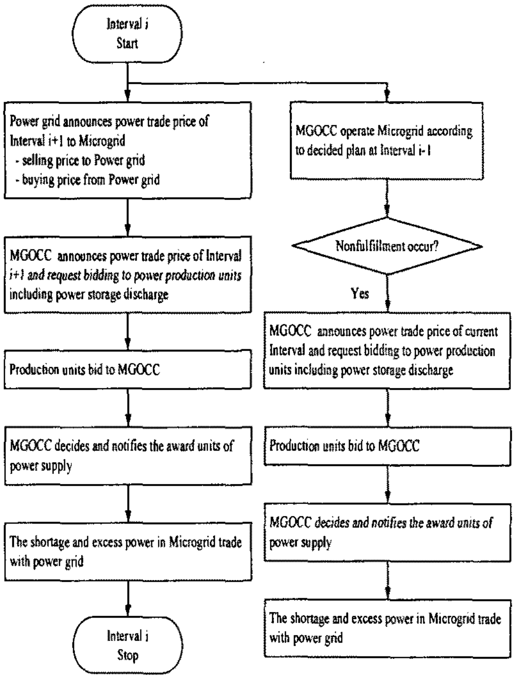

Fig. 5. Microgrid operation procedure on market environment

effectiveness of the suggested Microgrid operation based on the market environment in the test Microgrid system such as Fig. 6. The results of four case studies are focused on whether the above-mentioned requirements of each participant in the Microgrid can be satisfied by the suggested operation methodology or not. In these case studies, the storage device of Fig.6 is simply assumed as a power supplier.

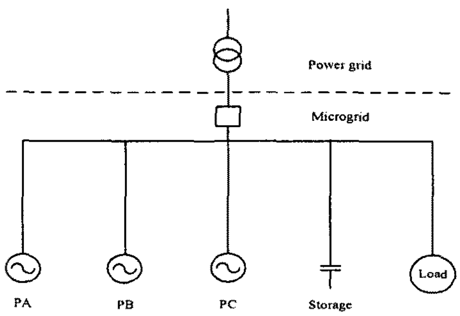

Fig. 6. Test Microgrid system

4.2.1 Case 1

The power market information is as follows:

- P_B:100[¢/kWh], P_S:50[¢/kWh] in next interval;
- Demand (D) in Microgrid: 30[kWh] in next interval;
- PA = cost: 60[¢/kWh], capability: 10[kWh];
- PB = cost: 70[¢/kWh], capability: 20[kWh];
- PC = cost: none, capability: 5-[kWh];
- S = cost: none, capability: 5[kWh].

S indicates a storage device in the above-mentioned power market information. The result of the Microgrid operation is as follows:

- D (30[kWh]) = PC (5[kWh]) + S (5[kWh]) + PA (10[kWh]) + PB (10[kWh]);
- Total demand cost = 30[kWh] · 70[¢/kWh] = 2,100¢ (70[¢/kWh]);
- Power price in the Microgrid = 70[¢/kWh];
- Power trade with the power grid = none.

The numbers in parenthesis in the Microgrid operation result refer to the amounts of power supply. The power price in the Microgrid is decided as 70[¢/kWh] by the market rule as mentioned in Section 5.1. The power price is lower than buying price from the power grid, 100[¢/kWh]. Also, PA, PB, PC, and S supply power to the Microgrid with 70[¢/kWh] which is higher than the selling price to the power grid, 50[¢/kWh]. Especially, 10[kWh] of PB as the rest capability is not generated because the selling price to the power grid is lower than the production cost of PB. From the above-mentioned Microgrid operation result, we can verify that requirements of all participants in the Microgrid are satisfied.

4.2.2 Case 2

The power market information is as follows:

- P_B:65[¢/kWh], P_S:40[¢/kWh] in next interval;
- Demand (D) in Microgrid: 30[kWh] in next interval;
- PA = cost: 60[¢/kWh], capability: 10[kWh];
- PB = cost: 70[¢/kWh], capability: 20[kWh];
- PC = cost: none, capability: 5[kWh];
- Storage (S) = cost: none, capability: 5[kWh].

The result of the Microgrid operation is as follows:

- D 30[kWh]) = PC (5[kWh]) + S (5[kWh]) + PA (10[kWh]) + Power grid(10[kWh]);
- Total demand cost = 20[kWh] · 60[¢/kWh] + 10[kWh] · 65[¢/kWh] = 1,850[¢];
- Power price in the Microgrid = 61.667[¢/kWh];
- Power trade with the power grid = buying 10[kWh] from the power grid.

PB with 70[¢/kWh] is not selected as a power supplier because its production cost, 70[¢/kWh] is higher than buying price from the power grid, 65[¢/kWh]. Therefore, 10[kWh] as the power shortage in the Microgrid is bought from the power grid. Total cost for demand in the Microgrid is 1,850[¢] and the power price in the Microgrid is decided by 61.667[¢/kWh]. The power price is lower than P_B from the power consumer point of view and it is higher than P_S from the power supplier point of view. From the Microgrid operation result, we can verify that requirements of all participants in the Microgrid are satisfied.

4.2.3 Case 3

The power market information is as follows:

- P_B: 110[¢/kWh], P_S: 70[¢/kWh] in next

interval;
- Demand (D) in Microgrid: 30[kWh] in next interval;
- PA = cost: 60[¢/kWh], capability: 10[kWh];
- PB = cost: 70[¢/kWh], capability: 20[kWh];
- PC = cost: none, capability: 5[kWh];
- S = cost: none, capability: 5[kWh].

The result of the Microgrid operation is as follows:

- D (30[kWh]) = PC (5[kWh]) + S (5[kWh]) + PA (10[kWh]) + PB (10[kWh]);
- Total demand cost = 30[kWh] · 70[¢/kWh] = 2,100[¢] (70[¢/kWh]);
- Power price in the Microgrid = 70[¢/kWh];
- Power trade with the power grid = selling 10[kWh] to the power grid.

The power price in the Microgrid is decided as 70[¢/kWh] like the power price of Case 1. But, unlike the result of Case 1, 10[kWh] of PB as the excess power is sold to the power grid at 70[¢/kWh] which is equal to P_S. That is, when the inner excess power produced by the production cost lower than or equal to P_S is sold to the power grid as mentioned market rule in Section 5.1. From the above-mentioned Microgrid operation result, we can verify that requirements of all participants in the Microgrid are satisfied.

4.2.4 Case 4

While Microgrid operation is implementing by Case 1 as the operation plan established at the previous interval, the contract nonfulfillment of 2[kWh] by PC is occurred. For the 2[kWh] of the contract nonfulfillment, a new contract is established through the market rule as follows:

- Nonfulfillment amount(2[kWh]) = PB(2[kWh]);
- Power price for the new contract = 70[¢/kWh];
- Additional Power trade with the power grid = none.

The additional 2[kWh] for the contract nonfulfillment is supplied by PB because PB has the capacity margin as 5[kWh] and the cost of PB, 70[¢/kWh] is lower than the buying power price from the power grid, 100[¢/kWh]. From the above-mentioned Microgrid operation result, we can verify that requirements of all participants in the Microgrid also are satisfied while the contract nonfulfillment is occurring.

Though case studies, there is profit difference among power suppliers. The difference will promote the development and introduction of production units with lower production cost.

5. Conclusion and Future Work

Recently, R&D and demonstration projects of Microgrids have been progressed in many countries. In the near future, Microgrids will come into wide use. For this, the preparation or establishment of effective operation methodology for Microgrids is very important. But the operation is different and complex in comparison with the existing private small-scale power system because of multiple participants and requirement related to their profits.

For those circumstances, we suggested the Microgrid operation on a market environment as an effective operation methodology. And using the case studies, we verified the effectiveness of the suggested methodology. The contributions of this paper are as follows:

- The different and complex requirements of all participants in the Microgrid were defined

concretely by introducing a market environment;
- The Microgrid operation procedure based on a market environment was established and introduced;
- The effectiveness of the suggested Microgrid operation methodology was verified through case studies.

In the near future, we will study the more suitable Multiagent system for Microgrid operation based on the suggested market environment for enhancing the effectiveness of the system. Also, we expect that effective various operation strategies and methodologies will be studied in energy economics area in the future.

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