DYNAMIC COOPERATIVE OPERATION OF DISTRIBUTED RESOURCES IN MULTIPLE MICROGRIDS

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ABSTRACT

This paper proposes dynamic cooperative operation of distributed resources for increasing resilience in multiple microgrids. In order to quantitatively represent the resilience of the distribution system, the resilience indices were proposed and verified through case studies. The proposed method significantly improves the resilience of the existing system and help to quantitatively evaluate the resilience of distribution system.

INTRODUCTION

Globally, blackouts have increased by irresistible natural disasters. In traditional centralized power supply scheme, electric power is interrupted in facilities connected main grid if transmission system is damaged by the event of a disaster. It takes a long time to recover from the blackout, and the damage will increase. In this situation, technologies of microgrid can be a solution. The microgrid performs economical operation in conjunction with the main grid in the usual way, and avoids the power outage by switching to the islanded operation mode when the main grid is out of power. In particular, while multiple microgrids are connected to each other, a microgrid having surplus power supplies to nearby microgrids, then overall reliability and resilience of the power system is expected to increase. In several papers, cooperative operation of multiple microgrids has been studied recently. [1] and [2] propose a coalitional operation model for multi-microgrid within the distribution system to achieve higher operation economy using the game theory. [3] proposes the optimal operation of MMGs by cooperative energy and reserve scheduling model, in which energy and reserve can be cooperatively utilized among MMGs. However, many papers are almost focused on economic aspects. Researches of increasing the resilience of the system through cooperative operation of multiple microgrid are at an early stage. Therefore, in this paper, a strategy of dynamic cooperative operation between microgrids is proposed. Proposed method has advantages that are increasing life time of ESS due to reduce charging/discharging cycle of battery and reducing essential capacity of battery for configuring microgrid because ESSs are shared besides the advantage of increasing reliability and resilience. To verify effectiveness of proposed strategy, quantitative evaluation is required. Traditionally, reliability indices are used for evaluating condition of distribution quantitatively. However, there is limitation to evaluate resilience by reliability indices. Because, they are calculated by numerical value considering failure rate and repair rate that cannot represent time to restore and degree of restoration. Therefore, in this paper, new resilience indices are proposed, and are used to verify effectiveness of proposed operation strategy in case studies.

MICROGRID OPERATION STRATEGY

The concept of dynamic cooperative operation of distributed resources is shown in fig.1.

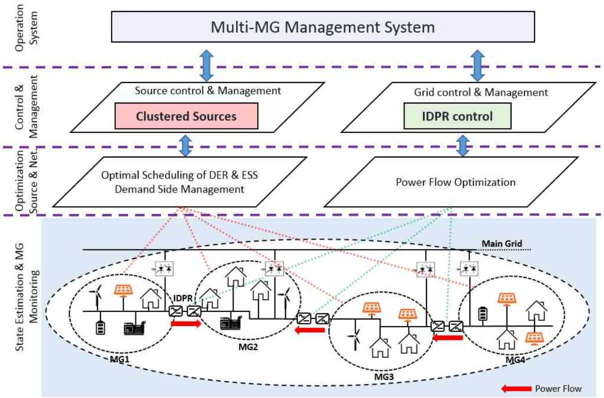


Fig. 1 Concepts of multi-MG configuration and dynamic cooperative operation

As shown in fig. 1, each microgrid sends information of available power to management system chronologically. Then, management system controls power flow between microgrids for supply and demand balance using IDPR(Intelligent Distribution Power Router). Available power to transfer nearby microgrid can be represented by (1).

$$A^{MGx}(t) = RES^{MGx}(t) + (DG^{rate} - DG^{MGx}(t)) + ESS\,(t)^{A.MGx} - L^{MGx}(t) \quad (1)$$

A, L and MGx mean available power, load and the number of microgrid, respectively. In (1), available power of RES that is uncontrollable source and DG are determined by forecasted power and it's rated capacity, respectively. In the final analysis, available power depends on output of ESS at time t. Depending on the operating target of system operator, ESSs are scheduled in a diverse strategy. In this paper, each microgrid is operated for maximizing the energy self-reliance by using controllable generators. Also, in the event of main grid fault, microgrids are immediately disconnected from the main grid for independent operation. In the case of independent operation, the final target of operation is that the microgrid will operate independently until the system failure is recovered by self-regulating available loads and power generation and supplying power to nearby microgrids. The controllable sources to achieve this goal are distributed generators and ESSs. Since, there are many DGs and ESSs in microgrid and the ESS is energy limited, it is necessary to cooperate with multiple ESSs in the multi-micro grid. For the output dispatch strategy of ESS is refer to [4] the previous study.

PROPOSED RESILIENCE INDEX

For increasing entire reliability of microgrid without supply from main grid, available power is determined by operation schedule of ESS where operation schedule is maximizing reserve capacity when microgrids are operated as islanded mode. Traditionally, reliability indices are used for evaluating condition of distribution quantitatively. However, the reliability indices of the distribution system are affected by external conditions such as disasters. So, they have limit to represent the self-robustness of the distribution system. Therefore, in this paper, new resilience indices are proposed. Resilience refers to the ability of the system to return to normal when it becomes unavailable due to an external or internal failure. For recovering microgrid from fault, the system must detect faults quickly and the detected data should be transferred to the control system or control device quickly. Finally, the generators including the ESS should response as soon as possible for the power supply. In this paper, the time from failure to restoration is defined as restoration time and expressed as (2).

$$T_{Res}^{M\,Gx} = T_{D}^{M\,Gx} + T_{C}^{M\,Gx} + T_{R}^{M\,Gx} \qquad (2)$$

$T_{D}^{M\,Gx}$, $T_{C}^{M\,Gx}$ and $T_{R}^{M\,Gx}$ are detection time, communication time and response time, respectively. Each microgrid has a probability of failing detection, communication, response if it fails, $T_{R}^{M\,Gx}$ is assumed to be equal to the repair time. System Average Restoration Time(SART) is given by (3).

$$SART = \sum\nolimits_{\forall x} \frac{L^{M\,Gx}}{L^{Tot}} \sum\nolimits_{\forall t} T_{Res}^{M\,Gx} \qquad (3)$$

The resilience index is related to the energy independence ratio. Microgrids with renewable energy sources may have less than 100% energy independence depending on weather conditions or load conditions. If the energy independence ratio is less than 100%, the independent system should be restored by reducing the load when a failure occurs. In this paper, for evaluating energy independence ratio of microgrid, the System Average Energy Independence Ratio (SARIR) considering the system load and the scheduling of the output ESS of the renewable energy source is proposed. this index is represented by (4).

$$SAER = \sum\nolimits_{\forall x} \frac{L^{M\,Gx}}{L^{Tot}} \sum\nolimits_{\forall t} \frac{A^{M\,Gx}(t)}{L^{M\,Gx}(t)} \qquad (4)$$

$$\frac{A^{M\,Gx}(t)}{L^{M\,Gx}(t)} = 1 \;\; where \;\; \frac{A^{M\,Gx}(t)}{L^{M\,Gx}(t)} > 1$$

CASE STUDY

The system used in the case study is shown in Fig. 1, assuming that four microgrids are connected to the same distribution system. For comparison, cases are divided into base system and proposed system. The base case assumes that there is no direct power exchange between the microgirds, and the proposed method controls the power flow through the IDPR between microgrids.

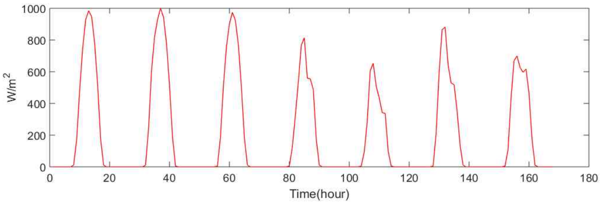
Case Data

The generator capacity and peak load of each microgrid is shown in Table 1. To simplify the case study and clarify the effect of the proposed operational strategy, it is assumed that each microgrid has the same capacity of the controllable power.

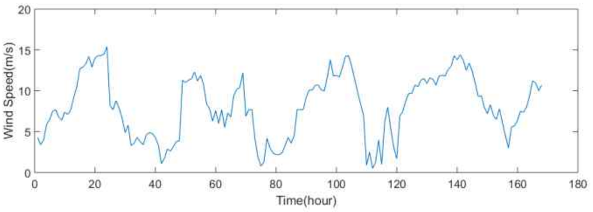
Table 1. case study data

	MG1	MG2	MG3	MG4
DG (kW)	100	100	-	-
PV (kW)	100	80	300	50
ESS (kW/kWh)	100/100	100/100	100/100	100/100
Load (kW)	107	81	120	70

Fig. 2 shows the chronological weather data used in case studies. It is assumed that the weather of each microgrid is the same because microgrids are located in a small area



Solar irradiation



Wind speed

Fig. 2 Weather Data(1 week)

Fig. 3 shows load profile of each microgrid. It is assumed that each microgrid has a different load pattern from each other.

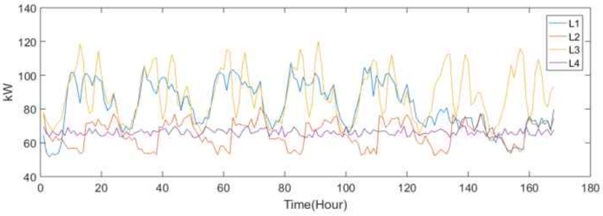


Fig. 3 Load profile(1 week)

Fig. 4 to 7 show the renewable energy output and load of each microgrid. Except for MG1, renewable energy resources are abundant, but in order to utilize surplus energy, charging and discharging of ESS should be needed.

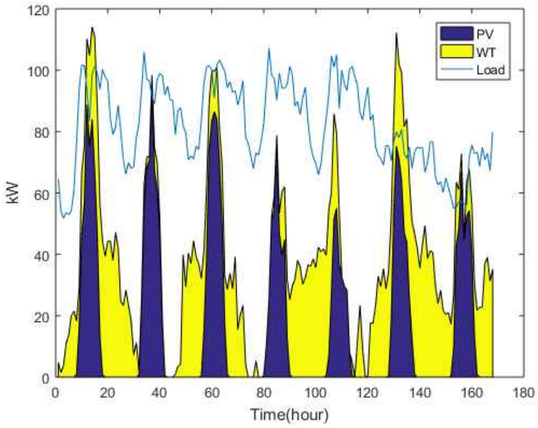


Fig. 4 Output power of MG1

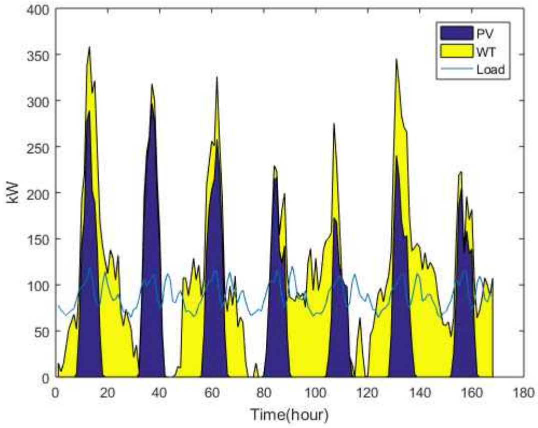


Fig. 5 Output power of MG1

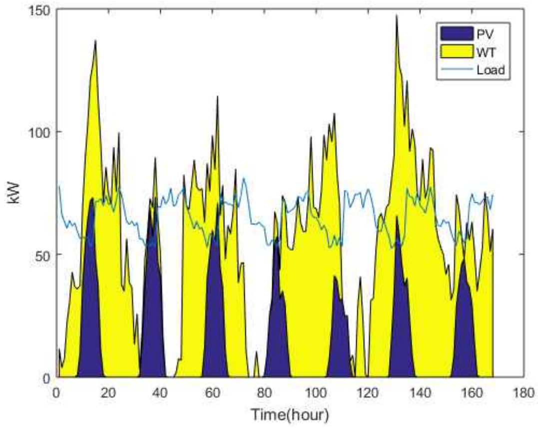


Fig. 6 Output power of MG1

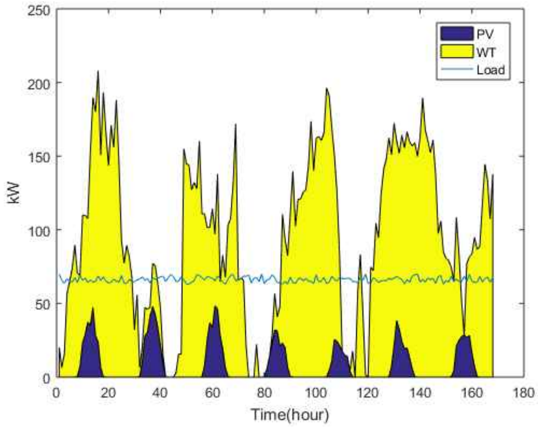


Fig. 7 Output power of MG1

Resilience Evaluation

Figure 8 and 9 show the output power of controllable sources.

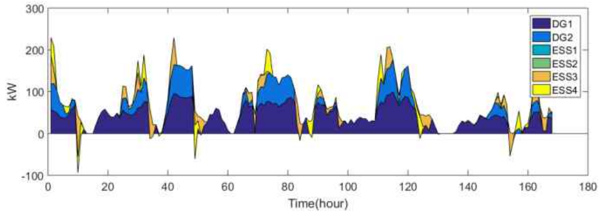


Fig. 8 Output power of case1(DG, ESS)

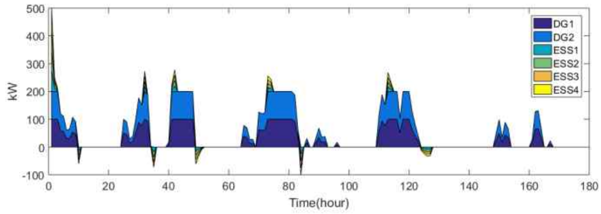


Fig. 9 Output power of case2(DG, ESS)

In the case of Case 1, it is confirmed that the ESS of MG1 and 2 hardly works. because MG1 and MG2 have a distributed generator, so the energy independence ratio is close to 100% therefore, ESS does not need to operate. On the other hand, in the case of the proposed method, the ESS of MG1 and MG2 operates to supply power to the nearby MGs. This operation is expected to increased resilience of the entire distribution system. the resilience indices of cases 1 and 2 were evaluated and are shown in Table 2.

Table 2. Resilience indices

	Case1	Case2
SAEIR	0.9240	0.9682
SART(hour)	0.8273	0.7422

Table 2 shows that the proposed method significantly increases the resilience compared to the conventional method. because the generators operate as one generator such as virtual power plant through the cooperative operation between the microgrids, so that power can be used effectively.

CONCLUSION

In this paper, dynamic cooperative operation between microgrids is proposed for improving the resilience of the system through in multiple microgrid environments. In order to quantitatively represent the resilience of the distribution system, the resilience indices were proposed and verified through case studies. The proposed method significantly improves the resilience of the existing system and help to quantitatively evaluate the resilience, thereby providing a method to evaluating the robustness of the system without any outside influence. The resilience indices are expected to be a reference index for quantitatively evaluating the robustness of the system when planning or reconfiguring microgrid based distribution systems.

ACKNOLEDGMENT

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