Optimization of Operation Plans for Multiple Points for Utilization of EV for Virtual Distribution Line of Electric Vehicles

Yoshito Nishita†, Yoshio Izui*, Daisuke Natsuume*, Hirokazu Tabata*

Abstract – In recent years, blackouts due to large scale natural disasters have frequently occurred. In order to strengthen the resilience of the electric power network, EVs equipped with large-capacity storage batteries are expected to be used as "moving storage batteries". We have conducted EV virtual distribution line demonstration experiment. Also, we have been studying the optimization of EV operation plans for EV virtual distribution line. Then, in the previous research, we proposed an optimization method using Genetic algorithm. In this research, the optimization problem is treated as multiple subproblems and the subproblems are optimized by limiting the moving area of one EV. We examined a method for optimizing the overall problem. Then, the effectiveness of the EV operation plan optimization method by the proposed method was confirmed by utilizing the empirical data.

Keywords: Renewable Energy Resources, Electric Vehicle, Virtual Distribution Line, Independent Operation, Optimization Operation Plan

1. Introduction

For the purpose of low carbon and decarbonization, the introduction of renewable energy such as solar power generation in the electric power and energy field and electric vehicles (EV) in the transportation field are expanding [1]. Also, in recent years, blackouts due to large scale natural disasters have frequently occurred. Therefore, in Japan, various items [2] are listed as issues to be examined in order to strengthen the resilience of the electric power network. For example, in response to typhoons, the power transmission and distribution networks are made stronger and smarter, no utility pole, introduction of private power generation equipment to important facilities, and the promotion of distributed grids is listed. In particular, EV is equipped with large-capacity storage battery, so they are expected to be used as "moving storage batteries" [3]. In fact, in Chiba, it has been reported that many EVs are used to patrol the area and supply power to consumers who are out of power [4].

Against this background, using the "Community mod el demonstration experiment of renewable energy best mix" [5], [6] at Kanazawa Institute of Technology (KI T), we have conducted EV virtual distribution line de monstration experiment [7]. In the previous research, th e EV operation plan was combined and defined as an optimization problem for the purpose of optimizing the EV operation plan for the EV virtual distribution line. However, as the number of combinations increased due to the increase in the number of target areas and the number of EVs, we faced the problem that a feasible solution could not be obtained.

Therefore, in this research, we propose an optimization method to solve the problems associated with the increase i n the number of EVs and target points in EV virtual distribu tion line. In the proposed method, the optimization problem is treated as multiple subproblems and the subproblems ar e optimized by limiting the moving area of one EV. After th at, we examined a method for optimizing the overall proble m. Then, the effectiveness of the EV operation plan optimiz ation method by the proposed method was confirmed by uti lizing the empirical data.

2. Overview of EV Virtual Distribution Line

Fig.1 shows the outline of the EV virtual distribution line in this research. The EV virtual distribution line consists of an area where the commercial power supply is energized (energized area) and an area where the commercial power supply is not energized (power outage area). EVs and chargers to charge them are installed in energized areas, and distributed power sources such as photovoltaic power generation (PV) and storage battery (BAT) and bidirectional chargers for supplying power from EVs are installed in power outage area. The mechanism of the virtual distribution line is to transport the electric power charged in the EV in

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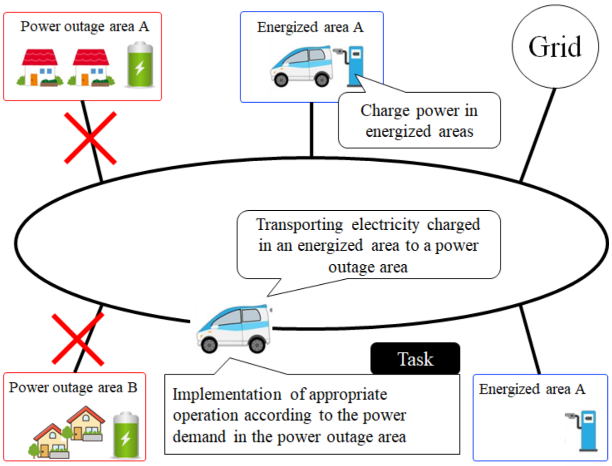

Fig. 1. Overview of EV virtual distribution line

the energized area to the power outage area and utilize the electric power of the EV to operate the electric power consumer in the power outage area independently. During self-sustaining operation, power is supplied from the BAT to meet the power demand of home appliances, and the power supplied from the EV is charged to the BAT.

KIT owns multiple campuses in Ishikawa prefecture, and in the demonstration experiment, the Ogigaoka campus and the Hakusan-roku campus are used to carry out EV virtual distribution line between these two campuses (Fig.2). In the demonstration experiment, the cottage on the Hakusan-roku campus due to a commercial system power outage will be operated independently. In addition, electricity will be transported by EV from the Ogigaoka campus, where the commercial system is not out of power and is energized. The cottage is equipped with a BAT and an EV bidirectional charging / feeding device and operates independently with only BAT. The electric power supplied from the EV is charged to the BAT and supplied as the power consumption of home appliances.

3. Operation Plan for EV Virtual Distribution Line

This chapter describes the optimization of EV operation plans in previous research [7].

3.1 Definition of Optimization Problem

First, we will describe the target problem of optimization. The purpose of the optimization target is to minimize the p ower outage duration of the power consumers in the power outage area by having the EV patrol the energized area and the power outage area to supply power to the power consu mers in the power outage area during a power outage. Next, as a prerequisite, as shown in Table 1, storage battery is set for power consumers in power outage areas, an d EVs that patrol is charged in energized areas. Finall y, the optimization content determines the EV charging

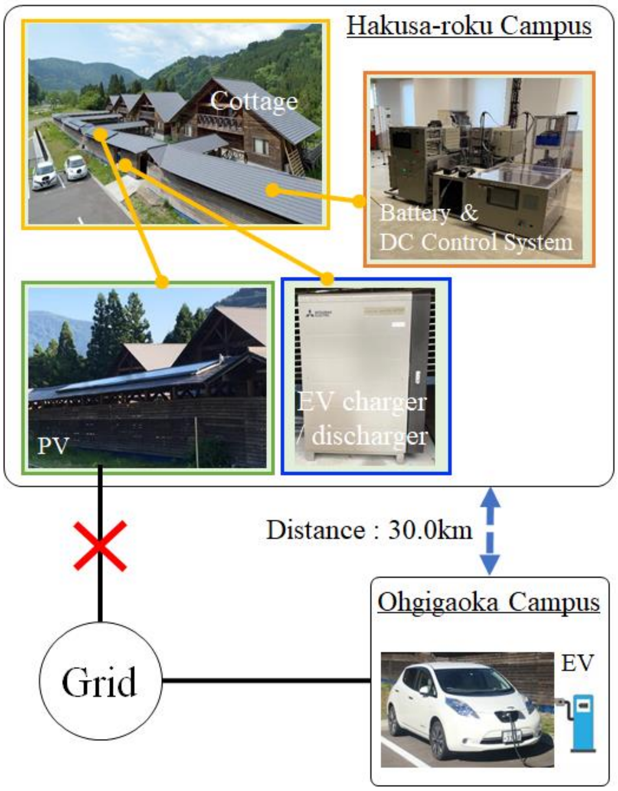

Fig. 2. Outline of demonstration experiment and equipment configuration

Table 1. Equipment conditions

Area (Point)	Equipment
Power outage area	✓ Storage battery (BAT) ✓ EV charger / discharger ✓ Load
Energized area	✓ EV ✓ EV charger

/ running / power supply time and the EV patrol route. In addition, the equipment status calculated by the op timization calculation includes the movement status of each time of EV (where it is), the amount of charge / discharge power (storage amount) at each time of EV, and the charge / discharge of each time of BAT. It is the amount of electric power (the amount of electricity stored). As shown in Table 2, the operation of each f acility differs depending on the moving state of the E V, but the BAT in the power outage area supplies pow er according to the power demand of the facility.

3.2 Operation Plan Optimization

The optimization target of this research is the state of each time of EV that patrols the energized area and the power outage area. In the previous research [7], this optimization of the operation plan was regarded as combinatorial optimization, and the optimization using the genetic

Table 2. Equipment operation

Equipment	state	Behavior
EV	Energized area	Charge with the maximum output of the charger
	Power outage area	Discharge at the maximum output of the charger / discharger
	Moving between areas	Consume power from your battery based on distance traveled and electricity costs
BAT		Supplying power to facilities according to power demand

algorithm (GA) was performed. Each item will be explained below.

3.3 Definition of operation of each equipment

We will describe the definition of the operation of each equipment. As for the state of EV, there is a stop in the energized area, a stop in the power outage area, and a stop in either the energization or the power outage after moving the point, and the operation at that time is as defined in Table 2. First, Equation 1 shows the calculation of the state of EVs stopped in the energized area.

$$\boldsymbol{EV(t) = EV(t-1) + Eff \cdot EV_{chmax}} \qquad (1)$$

EV is the amount of electricity stored in the EV storage battery at each time, Eff is the charging efficiency of the charger in the energized area, and EV_{chmax} is the rated (maximum) output of the charger in the energized area.

Next, Equation 2 shows the calculation of the state of the EV stopped in the power outage area.

$$\boldsymbol{EV(t) = EV(t-1) - \frac{1.0}{EFF_{eved}} \cdot EV_{Cmax}} \qquad (2)$$

EFF_{evcd} represents the discharge efficiency of the charger / discharger in the power outage area, and EV_{Cmax} represents the maximum output of the discharge power of the charger / discharger in the power outage area. Finally, the calculation formula differs depending on whether the vehicle is energized or has a power outage after moving to a different point. Equation 3 shows the EV state calculation when moving from a power outage area to an energized area.

$$\boldsymbol{EV(t) = EV(t-1) - Dis \cdot EV_{ec} + Eff \cdot EV_{chmax} \cdot R} \qquad (3)$$

Dis is the distance traveled between points, EV_{ec} is the electricity cost of EV, and R is the ratio to the unit time minus the time required for travel. Equation 4 shows the EV state calculation when moving from an energized area to a power outage area.

$$\boldsymbol{EV(t) = EV(t-1) - (Dis \cdot EV_{ec} + \frac{1.0}{EFF_{evcd}} \cdot EV_{Cmax} \cdot R)} \qquad (4)$$

The usable range of the EV storage battery is as shown in Equation 5, and the EV is charged and discharged within the range of the lower limit (EV_{minsoc}) or more and the upper limit (EV_{maxsoc}) or less.

$$\boldsymbol{EV_{minsoc} \le EV(t) \le EV_{maxsoc}} \qquad (5)$$

The change in the BAT status differs depending on the EV status (stopped in the energized area, stopped in the power outage area), but basically, as explained in Table 2, the BAT discharges according to the power demand. Equation 6 shows the calculation of the state of BAT while the EV is stopped in the energized area.

$$\boldsymbol{BAT(t) = BAT(t-1) - \frac{1.0}{EFF_{discharge}} \cdot DEMAND(t)} \qquad (6)$$

BAT represents the amount of electricity stored in the storage battery at each time, $EFF_{discharge}$ represents the discharge efficiency of BAT, and $DEMAND$ represents the amount of power demand for facilities in the power outage area at each time (PV power generation is considered to be negative power demand). Next, Equation 7 shows the state format of the BAT when the EV is stopped in the power outage area.

$$\boldsymbol{BAT(t) = BAT(t-1) - \frac{1.0}{EFF_{discharge}} \cdot DEMAND(t) + EFF_{charge} \cdot EV_{Cmax} \cdot R} \qquad (7)$$

The discharge from the storage battery is performed within the range of Equation 8, and the discharge of the EV outside the range is 0. The usable range of the storage battery is as shown in Equation 8, and the storage battery is charged and discharged at the lower limit value (BAT_{minsoc}) or more and the upper limit value (BAT_{maxsoc}) or less, and the lower limit value. If this happens, charging and discharging of the storage battery will stop, and the facility will lose power.

$$\boldsymbol{BAT_{minsoc} \le BAT(t) \le BAT_{maxsoc}} \qquad (8)$$

3.4 Optimization of EV Operation Plan by GA

We will describe the method to optimize operation plan by GA. First, the generation of the initial population will be described. As an individual, it is composed of the EV state at each time. Then, in the generation of the initial population, the EV state at each time is generated by a random function, and N individuals are generated (Fig.3).

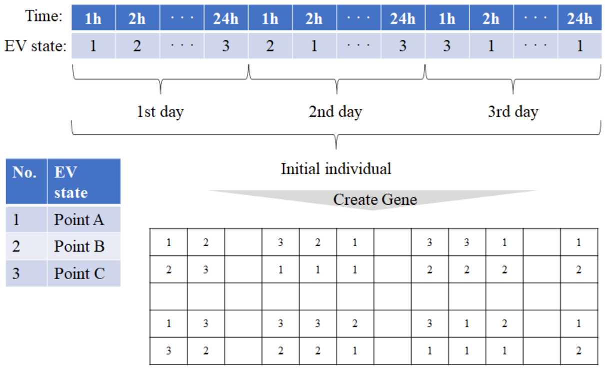

Fig. 3. Generation of initial population

Next, the calculation of the fitness of the population will be described. The fitness of the population is calculated from the state of the equipment at each point based on the state of each time of EV and the parameters of each facility at the point. The formula for calculating the fitness is shown below.

$$\boldsymbol{Fit} = \boldsymbol{w1} \cdot \boldsymbol{cnt_{batlower}} + \boldsymbol{w2} \cdot \boldsymbol{cnt_{evlower}} \quad (9)$$

Fit is Fitness, $cnt_{batlower}$ is the number of times the storage battery capacity has fallen below the lower limit, $cnt_{evlower}$ is the number of times the storage battery capacity of the moving EV has fallen below the lower limit.

Next, selection will be described. In the selection of population, the individual to be left for the next generation is selected based on the calculated fitness of each individual.

Next, crossover will be described. Crossover is performed in the selected population to generate individuals that will remain in the next generation. This time, in the individuals selected by selecting the population (selected in order from the individual with high fitness), pairs are created in order to generate individuals.

Finally, mutation will be described. For each individual generated by crossing a population, the state of the individual is changed with a certain probability. In the case of mutation, the individual with the highest fitness was left as it is in the next generation.

4. Creation of EV Operation Plan by Proposed Method

In the previous chapter, we explained the optimization of EV operation plans using GA. This chapter describes how to create an EV operation plan using the proposed method. Before that, we will explain the issues of previous research [7]. In the previous research, the operation plan is optimized using general GA. However, as shown in Fig.4, in an individual with one gene, an individual of a gene has an increasing number of individual elements as the number of EVs increases. As the size of an individual increases, the number of combinations of optimization problems increases,

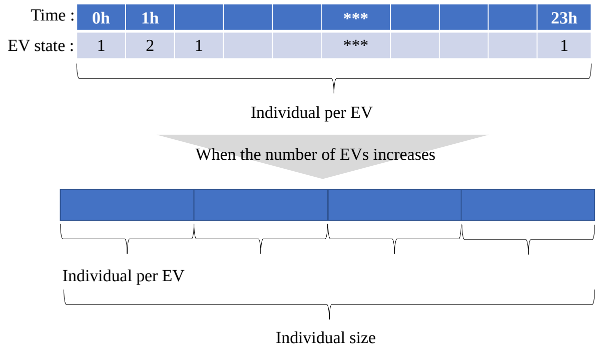

Fig. 4. Individual size as the number of EVs increase

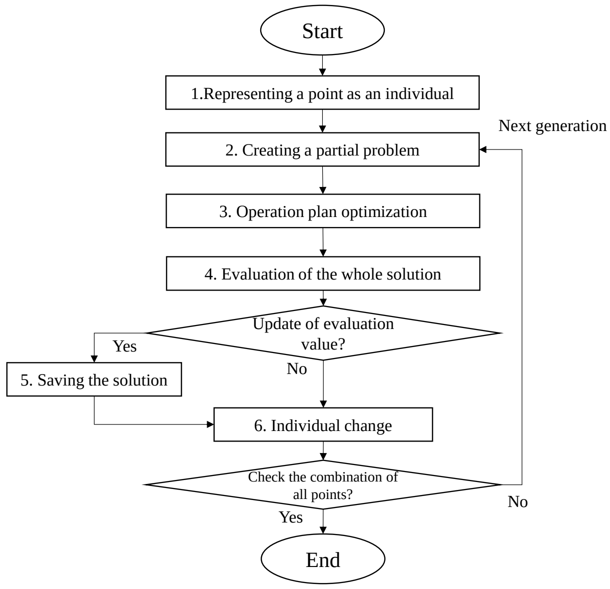

Fig. 5. The processing flow of the proposed method

which affects the convergence of solutions, and it is possible that not only optimal solutions but also feasible solutions cannot be obtained. Therefore, it is necessary to consider a method for creating an operation plan without increasing the number of combinations of optimization problems as much as possible.

Therefore, in this research, we propose a method to create an EV operation plan by improving the solution method using general GA. In the EV virtual distribution line in this research, from the viewpoint of power transportation by EV, it is not necessary for EV to make all power outage areas a candidate for movement, and there is no problem even if several points are targeted for movement. Therefore, we devised a method for optimizing by creating a partial problem that limits the EV movement target points. The processing flow of the proposed method is shown in Fig.5. Hereinafter, the details of the proposed method will be described.

4.1 Representing a Point as an Individual

In the individual representation of points, generate an individual in which all points in the energized area and the power outage area are lined up (Fig.6). In that case, the energized area must be at the top, and then the power outage area.

4.2 Creating a Partial Problem

In creating a partial problem, a target point for each EV is assigned to each generated individual, and a partial problem is created (Fig. 7).

4.3 Operation Plan Optimization

Optimize the EV operation plan for the allocated points (partial problems). To optimize the operation plan, use the GA explained in the previous chapter.

4.4 Evaluation of the Whole Solution

To evaluate the solution, integrate the optimized partial problem operation plan and calculate fitness of the entire solution.The fitness at that time is the same as in the previous chapter. Then, when the fitness becomes smaller, the operation plan is updated as a solution update.

4.5 Individual Change

As the creation of the next-generation individual, a part of the individual will be replaced and optimization will be carried out by combining all the points in each EV (Fig.8).

5. Numerical Experiments

In this chapter, in order to confirm the effectiveness of the proposed method, we conduct numerical experiments using pseudo data. In the numerical experiment, the evaluation is made by comparing the result of creating an EV operation plan by GA in the previous research [7] with the result of creating an EV operation plan by the proposed method of this research.

5.1 Experimental Conditions

Tables 3 to 5 show common information for each facility such as EV and BAT used in this experiment. Table 6 sho ws the parameters of the optimum method using GA. In add ition, information on the distance between each point is sho wn in Table 7.

5.2 Experimental Result

First, the optimization results by GA, which is the previous research, will be explained. Figure 9 and 10 shows the transition of the fitness of each generation in GA as the optimization result based on the preceding result. As shown

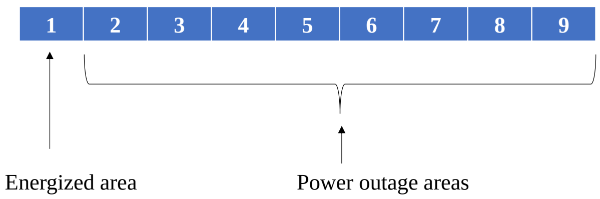

Fig. 6. Representing a point as an individual

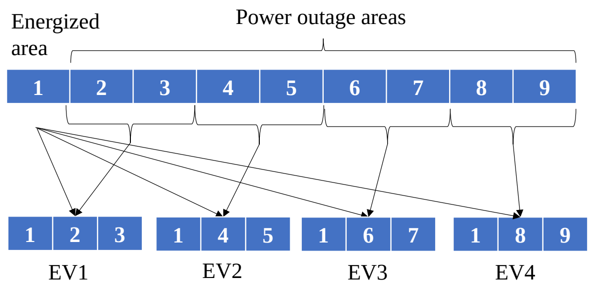

Fig. 7. Creating a partial problem

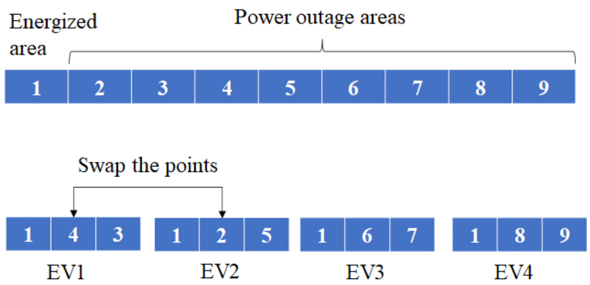

Fig. 8. Individual change

Table 3. EV equipment information

Item		Value
Battery	Capacity	40.0kWh
	SOC upper limit	1.0(100.0%)
	SOC lower limit	0.0(0.0%)
Running power rate		0.125kWh/km
Moving speed		35.0km/h

Table 4. Equipment information in power outage areas

Item		Value
Battery	Capacity 1	15.0kWh
	Capacity 2	20.0kWh
	Capacity 3	25.0kWh
	SOC upper limit	1.0 (100.0%)
	SOC lower limit	0.2 (20.0%)
	Charging efficiency	0.9 (90.0%)
	Discharge efficiency	0.8 (80.0%)
EV Charger	Maximum output	6.0kW
	Efficiency	0.8 (80.0%)
Load	Power consumption	0.3kW

Table 5. Equipment information in the energized area

Item		Value
EV Charger	Maximum output	3.0kW
	Efficiency	0.9 (90.0%)

Table 6. GA parameters

Parameter		Value
Individual size		100
Mutation rate		0.3
Population		100000
Fitness weight	w1	10
	w2	10

Table 7. Distance between points

P1	P2	Distance	P1	P2	Distance
E	PO1	20km	PO3	PO4	20km
	PO2	20km		PO5	20km
	PO3	20km		PO6	50km
	PO4	25km		PO7	40km
	PO5	25km		PO8	15km
	PO6	25km	PO4	PO5	35km
	PO7	30km		PO6	35km
	PO8	30km		PO7	20km
PO1	PO2	28km		PO8	20km
	PO3	28km	PO5	PO6	40km
	PO4	10km		PO7	10km
	PO5	40km		PO8	40km
	PO6	10km	PO6	PO7	20km
	PO7	10km		PO8	40km
	PO8	40km	PO7	PO8	40km
PO2	PO3	40km			
	PO4	50km			
	PO5	50km			
	PO6	20km			
	PO7	40km			
	PO8	40km			

*E: Energizing point, PO: Power outage point

in Fig. 9 and 10, at 3 points (1 point of energization, 2 points of power failure) with one EV, the constraint is violated (the number of times the remaining battery level of the storage battery becomes less than the lower limit, and the storage battery capacity of the moving EV becomes less than the lower limit) is 0, and a feasible solution can be calculated. On the other hand, the constraint violation is not 0 under the condition of 5 points (1 point of energization, 4 points of power failure) or more with 2 EVs. As shown in Fig.11, in the operation plan of 5 points with 2 EVs, there are places where the SOC of the EV is 0 or the SOC of the BAT is 20% or less, which is the lower limit, and it is feasible. It turns out that the solution has not been calculated.

Next, the optimization results by the proposed method ar

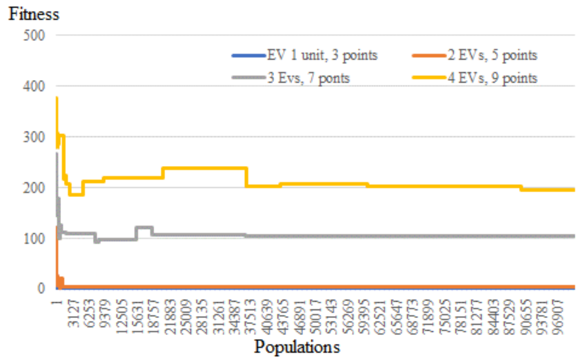

Fig. 9. Transition of fitness for each generation (elite selection and one-point crossover)

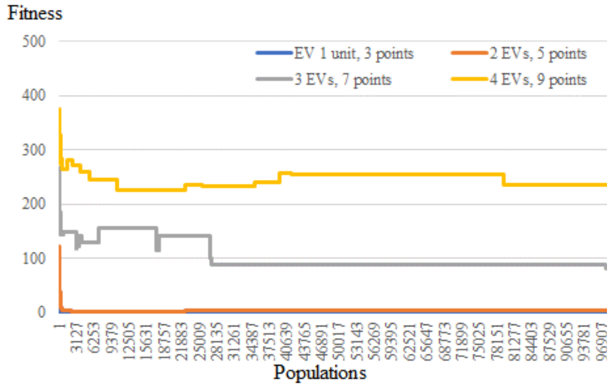

Fig. 10. Transition of fitness for each generation (roulette selection and uniform crossover)

e shown in Fig.12 to 14. Fig.12 shows an operation plan for 2 EVs at 5 points, Fig.13 shows an operation plan for 3 E Vs at 7 points, and Fig.14 shows an operation plan for 4 EV s at 9 points. As shown in Fig.12 to 14, the viable solution i s calculated because the SOC of the EV is not 0% and the S OC of the BAT is not below the lower limit of 20% under all conditions. From that, we were able t o show the effectiveness of the method by making partial pr oblems in this proposal.

6. Conclusion

In this paper, we proposed an optimization method of EV operation plan for EV virtual distribution line for the purpose of strengthening the resilience of the electric power network. In this research, in order to solve the problem that a feasible solution cannot be obtained due to the increase in the number of combinations of optimization problems, we proposed a method to obtain a feasible solution by creating a partial problem with a limited target point of EV. Then, the effectiveness of the proposed method was confirmed from the results of numerical experiments.

In this paper, the evaluation was based on numerical experiments using pseudo-set data. Therefore, in the future, we plan to create a problem assuming a real field and confirm the effectiveness of the proposed method.

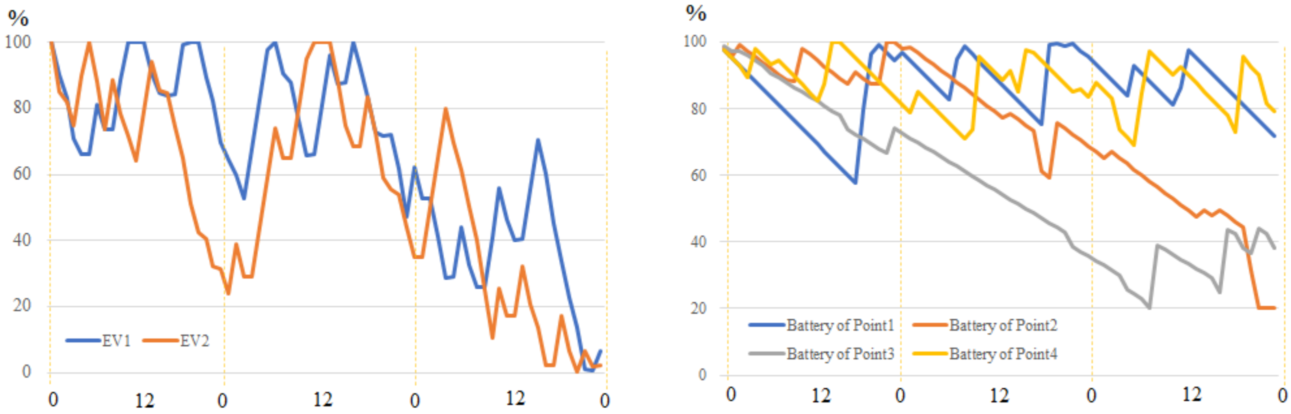

Fig. 11. Changes in the SOC of EVs and storage batteries at each location

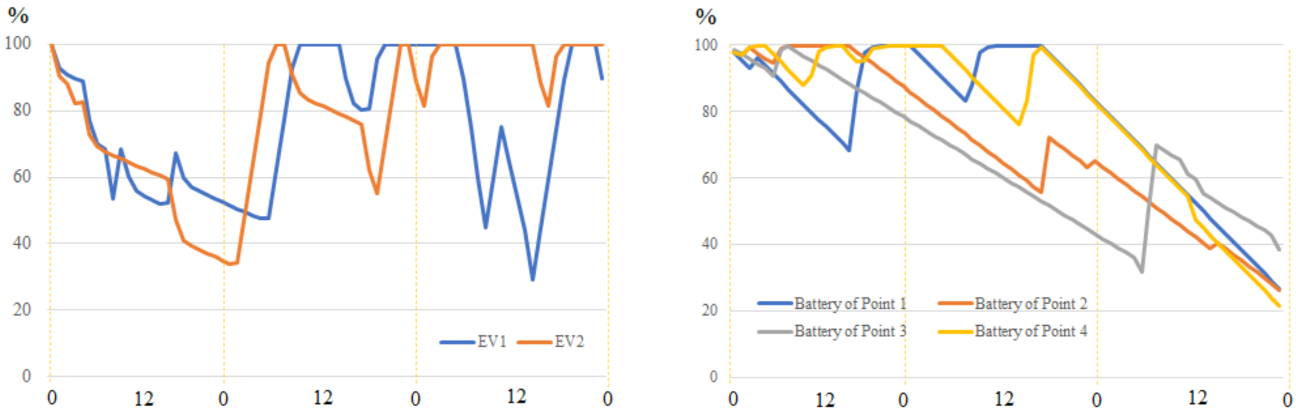

Fig. 12. Changes in the SOC of EVs and storage batteries at each location (2 EVs and 4 Points)

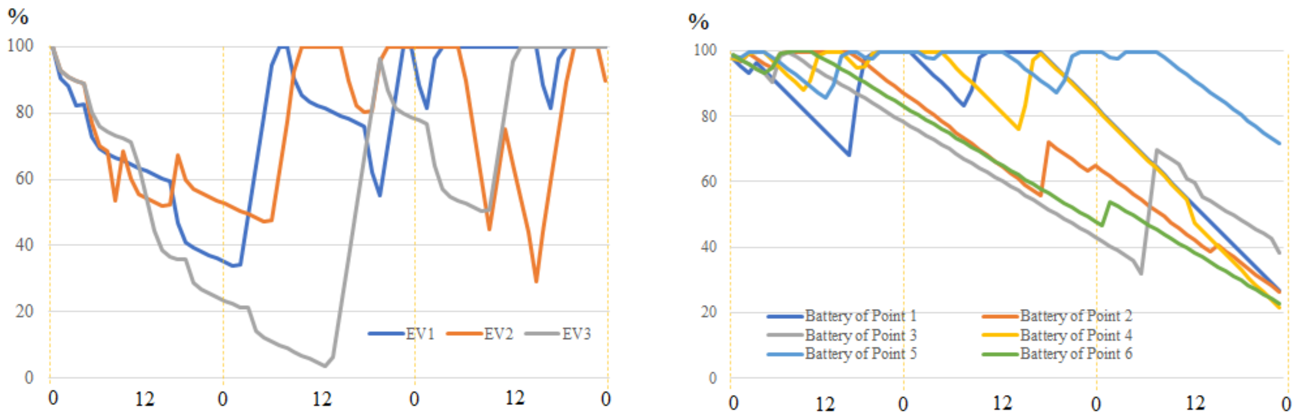

Fig. 13. Changes in the SOC of EVs and storage batteries at each location (3 EVs and 6 Points)

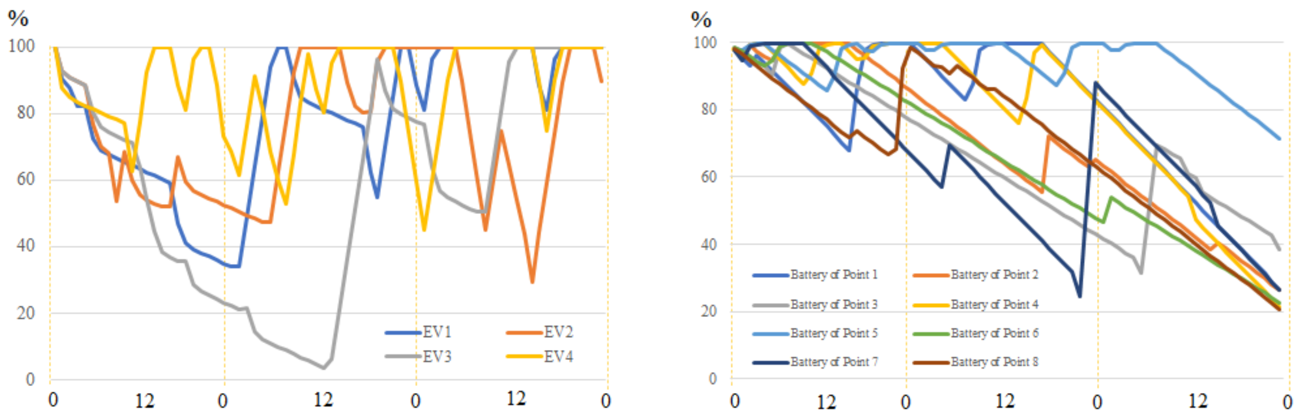

Fig. 14. Changes in the SOC of EVs and storage batteries at each location (4 EVs and 8 Points)

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