Multi-objective Optimization Using Two-stage EMO for Renewable Energy Management in Medical Facility

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Abstract- In this paper, a method of EMO to be applied for the energy management of the power system in which the renewable energy is introduced in a large-scale medical facility is proposed. The subject of the case study is a multi-objective optimization problem that seeks the optimal configuration and operation method of EG. The multiple objectives of minimizing the fuel consumption in emergency and minimizing the total power cost in normal time by means of peak cut in the power supply system combining with PV and EG are required to be simultaneously satisfied. The approach for this problem by EMO is a new attempt. It has been considered that it is difficult to obtain a highly accurate solution set by using the simple EMO alone, and it is confirmed also in our preliminary experiments. Therefore, in this paper, a two-stage EMO combining the multi-start with the local search function has been proposed. The proposed method is applied into case studies to evaluate, and the effectiveness is demonstrated.

Keywords Evolutionary multi-objective optimization, Energy management, Emergency generator, PV.

1. Introduction

With the growing global awareness of CO_2 emission reduction, the introduction of renewable energy such as photovoltaic (PV) is progressing in various large-scale facilities. In addition to obtaining a clean power, the introduction of the renewable energy has the economic purpose that lowering the electricity cost with reducing the electricity from the commercial power, as well. Moreover, it is expected to be utilized also as an emergency power supply in the event of a disaster. Such an introduction of renewable energy is also conducted in large-scale medical facilities.

Meanwhile, since large-scale medical facilities have a role to serve as a base for the relief activity in the event of a disaster, the regulation has required the installation of emergency generators (EGs) that can supply power to the facility for at least 3 days even when the commercial power loss. However, recently, it is said that the emergency power supply is necessary to be maintained for at least 1 week or more from the lessons of the Kumamoto earthquake in April 2016. Therefore, it is necessary to extend the capability of power supply at the emergency from 3 days to 7 days [1-5].

Therefore, in the power supply system of the facility, the energy management that minimize the electricity cost with utilizing the renewable energy and EGs for peak cut in addition to the commercial power supply is required in the normal time, besides that, in the case of emergency when the commercial power supply is lost, it is required to have the capability of power supply for more than seven days with utilizing the renewable energy and EGs. The energy management that satisfies both of these two objectives is required, accordingly.

As the introduction of renewable energy spreads, the importance of the methods of the energy management for the power supply system consisting of power sources of various types, such as PV, wind power, micro water turbines, geothermal power, EG, etc., will become larger and larger. In the energy management for such power systems that have various and diverse power source, it is becoming difficult to obtain an optimal operation solution by the single-objective optimization based on the only one evaluation value, therefore the multi-objective optimization by which solutions simultaneously satisfying the multiple objectives can be obtained becomes essential. In the multi-objective optimization, the method that obtain a set of solutions (a set of Pareto-optimal solutions) taking trade-off and select a preferred solution by decision making from the solutions is taken.

In recent years, artificial intelligences such as Genetic Algorithm (GA) are often used in the energy management of the renewable energy and the smart grid, since there are many cases to be required to solve optimization problems that have enormous combinations [4-14]. GA is regarded as a powerful method of the combinational optimization, and it has capability to cope with the nonlinearity, the multimodality and the constraint condition. In addition, evolutionary multi-objective optimization (EMO), in which GA has been extended to the multi-objective optimization, has an important position as a multi-objective optimization method [15-17].

NSGA-II, a representative method of EMO, has been applied in the renewable energy management, for it is said to be able to efficiently generate an approximate Pareto-optimal solution set [13],[14],[17]. Generally, in the multi-objective optimization, a set of solutions that is close to the true Pareto-optimal solutions and uniformly distributed is required. However, it has been pointed that it is difficult to obtain such a highly accurate solution set with using EMO alone, therefore hybrid EMO methods combining with Local Search (LS) such as " EMO with LS" and "EMO then LS" have been proposed [18 -21]. Actually, when performing preliminary experiments in the case study of this paper, it hasn't been experienced that such an accurate solution set can be obtained with EMO alone.

In this paper, "Global EMO then Local EMO" (GEMO then LEMO) in which EMO then LS is extended is proposed as the frame work of the two-stage EMO. In the proposed method, a global search is performed by means of EMO at the multi-start to obtain a solution set. This is defined as Global EMO (GEMO). Then areas for which a local search is to be executed are selected, in each area, EMO is performed with the initial group in which the solutions are selected by random sampling from the neighbors. This is defined as Local EMO (LEMO). A more accurate solution set can be expected by this method. Specifically, first, GEMO obtains globally diverse solution sets, and in the next step, LEMO is performed with the localized initial group of these solution sets as the seeds. In this paper, the proposed method is applied to the energy management in large-scale medical facilities using the renewable energy, and the excellent effectiveness is evaluated.

2. System Model and Formulation of Subject

2.1. System model

Figure 1 shows the block diagram of the power supply system in the subject hospital. The electric power for large hospitals is mainly supplied by the commercial power from the power companies. In the model of this study, the power supply system is configured with the PV and the EGs which are used at the normal time and the emergency in addition to commercial power.

The subject is a two-object minimization problem. The objective function 1 is the annual electric power cost at the normal time, and the objective function 2 is the fuel consumption amount in one week at the emergency. The optimization variables are contract power, configuration of EGs and the operation method of EGs (normal time, emergency). It is considered desirable to be able to run EGs for at least one week in emergencies such as disasters [5].

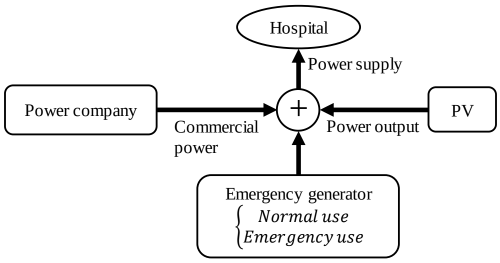

Fig. 1. System model.

The model of fuel consumption of EG can be formulated as Equation (1). Here, x is the power generation output of EG, $r_i(x)$ is fuel consumption of EG, a_i, b_i and c_i are coefficients corresponding to the type of EG, and N_{EG_Type} is the number of types of EG.

$$r_i(x) = a_i x^2 + b_i x + c_i,\ i = 0,1,\cdots,N_{EG\_Type}, \tag{1}$$

Power generation model of PV can be formulated as equation (2). Here, $p_{pv}(t)$ is PV generation power [kW] at time t, $g(t)$ is the amount of solar radiation at time [kW / m^2], RP_{PV} is the rated output of PV [kW], k is the loss factor.

$$p_{PV}(t) = g(t) \times RP_{PV} \times k, \tag{2}$$

Figure 2 shows the changes in the electricity load during a week in February and August at the hospital. The feasibility of peak cut is examined based on this data.

The contract power generally is determined at the maximum power consumed per an hour in the previous year. In this case, the contract power when the peak cut is not made is the maximum load in the summer indicated with the line of contract demand 1 is 928 kW. When deciding the basic fee based on the contract demand 1, the contract power becomes considerably larger than the peak load in the winter season, the basic fee becomes expensive more than necessary. When the contract power is determined at the contract demand 2, the basic fee is reasonable in winter. On the other hand, the load exceeds the contract demand 2 in summer, however the power shortage can be compensated sufficiently with the power from the PV generation and EG, the peak cut of commercial power can be realized. Therefore, from the economic point of view of the hospital, it is only necessary to reduce the annual cost by lowering the basic fee even if EG's fuel cost is applied.

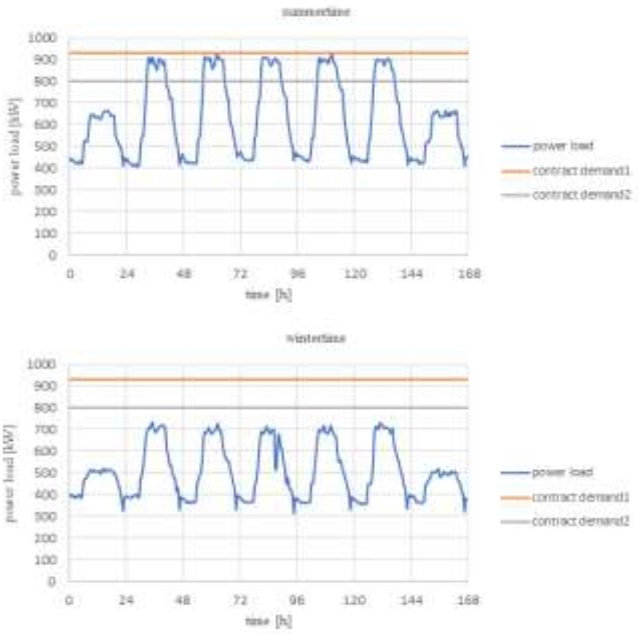

Fig. 2. Difference in one-week power load in the hospital.

2.2. Solutions in multi-objective optimization

The multi-objective combinatorial optimization problem is defined in the following expression

$$Minimize\ \ f(\boldsymbol{x})\ \ subject\ to\ \boldsymbol{x} \in S$$

where

$\boldsymbol{x} = (x_1, x_2, \cdots, x_N)^T \in \mathbb{Z}^N$ is N-dimensional variable vector (integer),

$\boldsymbol{f} = (f_1, f_2, \cdots, f_M)^T \in \mathbb{R}^N$ is M-dimensional objective function vector (real number),

$S \subset \mathbb{Z}^N$ is indicating the feasible region.

When the expression

$$\forall i \in \{1,2,\cdots,M\}, f_i(\boldsymbol{x_1}) \le f_i(\boldsymbol{x_2}) \ \wedge$$
$$\exists i \in \{1,2,\cdots,M\}, f_i(\boldsymbol{x_1}) < f_i(\boldsymbol{x_2})$$

is established for solutions $\boldsymbol{x_1}, \boldsymbol{x_2} \in S$, it is said that $\boldsymbol{x_1}$ dominates $\boldsymbol{x_2}$ and expressed as $\boldsymbol{x_1} \succ \boldsymbol{x_2}$. When there exists no solution $\boldsymbol{x}'$ which satisfy $\boldsymbol{x}' \succ \boldsymbol{x}$ and $\boldsymbol{x}' \in S$, solution $\boldsymbol{x}$ is called as a Pareto-optimal solution. In general, there are many Pareto-optimal solutions, but in multi-objective optimization, it is required to obtain a uniform solution set which is close to the Pareto-optimal solution.

2.3. Formulation of subject

Ⅰ The objective function and the constraint condition can be formulated as follows.

$$\text{Minimize Obj} \begin{cases} \sum_{m=1}^{12} NOR_{Cost}(m) \\ \sum_{t=0}^{N_t} EMA_{Fuel}(t) \end{cases}$$

Ⅱ Constraint conditions

(1) During normal operation

$$\begin{cases} ld(\mathrm{t}) - p(\mathrm{t}) < CP & \text{when } Load - output\ of\ PV < CP \\ ld(t) - p(t) - x_i(t) < CP & \text{when } Load - output\ of\ PV \ge CP \end{cases}$$

(2) During emergency operation for one week

$$\sum_{i=0}^{N_{EG}-1} x_i(t) > ld(t) - p(t)$$

III Function definition

$$NOR_{Cost}(m) = Base(m, CP) + Energy(m) + EG\_Cost(m) + Tax$$

$$EG\_Cost(m) = \sum_{i=0}^{N_{EG}-1} EG(m,i)_{COST}$$

$$EMA_{Fuel}(t) = \sum_{i=0}^{N_{EG}-1} r_i\big(x_i(t)\big)$$

where

t: time,

m: month,

i: index of EG,

$ld(t)$: load demand at t,

$p(t)$: output of PV at t,

$x_i(t)$: power output of i th EG at t,

CP: Contract Power,

$Base(m, CP)$: Base rate,

$Energy(m)$: Electric power charge,

$EG(m,i)_{cost}$: Operation cost of i th EG at m

3. Proposed Method

3.1. Design policy of algorithm

(1) Search strategy

In recent years, hybridization of evolutionary calculation and local search operation has been proposed in EMO. In the early work, "EMO with LS" that applies LS to the solution set of each generation of EMO has been mainly proposed [19-21]. Meanwhile, concerning "EMO with LS" as the combination of NSGA-II and the LS, it is pointed out that the precision of solution becomes insufficient due to the function of sharing peculiar to NSGA-II, and, "EMO then LS" has been recommended [18].

The two-step EMO, which is the proposed method, is an extended framework of "EMO then LS", that is, "GEMO then LEMO" in which LEMO extended with LS. Figure 3 shows the flow diagram of "GEMO then LEMO". A summary is given here and the details are described in the next section. First, GEMO accumulates solution sets obtained by executing multi-start EMO in the database. After completing the multi-start N_{GEMO} times, the non-dominated solutions are extracted from the solution set of the database and set as GEMO's solution set S_{GEMO}. Next, an area to be searched for from the S_{GEMO} is manually selected and set as set Q. Select N_{LEMO} individuals randomly from Q to create set S_{NRS}. In LEMO, an individual is extracted by non-restoration extraction from the set S_{NRS}, perform random sampling in the neighborhood of the individual to create N_{LPOP} local initial groups, EMO is executed, and the results are accumulated in the database. When the set S_{NRS} becomes empty, the non-dominated solutions are extracted from the solution set of the database and set as the final solution set of "GEMO then LEMO".

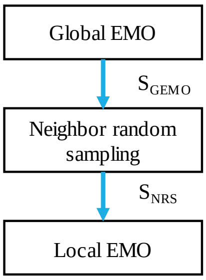

Fig. 3. GEMO then LEMO.

(2) Genetic coding

In our previous research, in order to simultaneously optimize configuration and operation, a coding method with chromosomes specifying the structure and chromosomes specifying the operation is proposed [5]. In this paper, since the operation of the normal time and the contract power are added to the previous model, the coding method has been expanded from previous one, the operative chromosome is divided into the normal time and the emergency, and the contract power is added to genes. The array defining the type of EG is $\mathrm{EG_{RP}}[i]$, $i = 0,1,\cdots,N_{EG\_Type}-1$ (EG_Type is the number of types of EG). Here, the configuration of EG is specified by referring to the index i and the array $\mathrm{EG_{RP}}[i]$. Regarding the contract power, the referring method is as well as that of EG. Figure 4 shows an example of the gene coding when three EGs are used.

The genes for "peak cut" need to be the operation chromosomes of EG that can make peak cuts as efficiently as possible, so the load of EG is divided in increments of 40 kW. Since the gene of "emergency" needs to be an operation chromosome that makes the time of EG power generation lengthen as long as possible, divide the load is divided in increments of 200 kW. This division size is determined by the preliminary experiments and can be changed according to the objects.

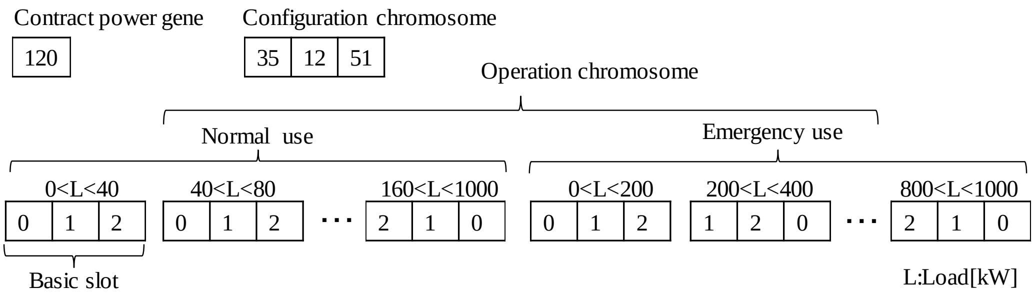

Fig. 4. Coding method.

(3) Generation alternation model

The generation alternation model consists of the reproduction selection to pick parent individuals participating in the crossover and the survival selection to choose for the next generation. In particular, the survival selection is an important design item that characterizes EMO, there are NSGA-II [17], SPEA 2 [22] etc. which selects solutions by means of ranking and sharing. The ranking is a method that defines the priority of the survival selection by ranking each solution by the superiority relationship and is thought to play a role of getting over the local Pareto-optimal solution. On the other hand, the shearing determines the method of thinning out the solutions existing in the congested region with respect to the solution set of the same rank, and is thought to play a role of widely and uniformly distributing the solution set. EMO's search scenario is to bring the solution set closer to the true Pareto-optimal solution set by repeating the alternation of generation based on the ranking and the sharing.

This paper, as mentioned above, is taking the position to bring out the capabilities of EMO through the framework of "GEMO then LEMO", therefore NSGA-II as a generational change model is used without any special improvement.

(4) Crossover and mutation

The crossover is performed at contract power gene, configuration chromosome and operation chromosome respectively. First, the crossover of contract power genes is performed by randomly sampling the contract power values between two parents, that is, between two integers. This can be said an equivalent method to a uniform crossover between two points. The crossover of configuration chromosomes is performed by randomly selecting crossover points and randomly sampling between two integers selected similarly to the crossover of contract power gene. This is a hybrid method of one point crossover and uniform crossover. The one point crossover which was effective in the previous research is used for the crossover of the operation chromosome [5].

The following method which was effective in the previous study is used for the mutation. In order to change the operation method without changing the composition of the EGs, the position of the gene is exchanged within the basic slot of the operation chromosome in the same individual [5].

3.2. Algorithm

The flow diagram of the outline of the proposed method is shown in Fig. 5, and the details of the algorithm are shown below.

[First step: GEMO]

0) n=0

1) Generation of initial population: Generate individuals randomly and calculate the fitness function of initial individuals.

2) Selection for Reproduction: $N_{Gpop}/2$ number of individuals selected randomly without replacement and $N_{Gpop}/2$ number of individuals selected randomly with replacement from the population, and generate $N_{Gpop}/2$ number of parent individual pairs.

3) Generation of child individuals: Generate multiple child individuals from each parent individual pair by crossover and mutation.

4) Calculate fitness function: Obtain the fitness value by calculating the evaluation value of the generated child individuals

5) Selection for Survival: Perform the survival selection based on NSGA-II

6) When the termination condition is satisfied, accumulate the solution set in the database DB_GEMO, make n = n + 1 and go to the next step, otherwise return to 2).

7) If n = N_{GEMO}, extract the non-dominated solutions from DB_GEMO, create the solution set S_{GEMO} and finish the procedure. If not, return to 1).

[Pre-stage for Second step]

Manually extract the region to be searched by LEMO from the solution set S_{GEMO} and make it the set Q. Randomly sample N_{LEMO} individuals from the set Q to create a seed set S_{NRS}. Extract an individual without replacement from the seed set S_{NRS}. Generate N_{Lpop} initial individuals which are randomly sampled in the vicinity of the individual. Perform this operation N_{LEMO} times and generate N_{LEMO} initial population.

[Second step: LEMO]

0) n=0

1) Initialization: Calculate the fitness function of the initial individuals.

2) Selection for Reproduction: Extract $N_{Lpop}/2$ number of individuals randomly without replacement from the population, extract $N_{Lpop}/2$ number of individuals randomly with replacement and generate $N_{Lpop}/2$ number of parent individual pairs.

3) Generation of Child individuals: Generate multiple child individuals from each parent individual pair by crossover and mutation.

4) Calculate fitness function: Obtain the fitness value by calculating the evaluation value of the generated child individuals.

5) Selection for Survival: Perform the survival selection based on NSGA-II.

6) When the termination condition is satisfied, accumulate the solution set in the database DB_LEMO, make n = n + 1 and go to the next step, otherwise return to 2).

7) If n = N_{LEMO}, extract the non-dominated solutions from the solution set which is integrated DB_GEMO with DB_LEMO, create the solution set $S_{Complete}$ and finish the procedure. If not, return to 1).

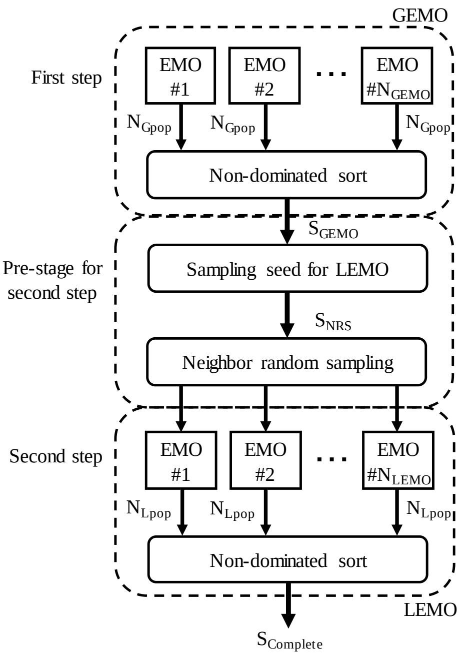

Fig. 5. Outline of flow of proposed method.

In GEMO as the first step, N_{GEMO} times multiple start EMO is executed, the obtained solution set is accumulated in the database, and finally the non-dominated solution set is obtained. At the transition from the first stage to the second stage, the areas required to be highly precise are particularly severely extracted manually to create a seed set. In the second stage LEMO, random sampling in the vicinity of each individual of the seed set is performed and EMO is executed with the sampled individuals as the initial population. In other words, it corresponds to performing a local search in the generation of the initial population, and the LEMO can be regarded as a local search type EMO where the initial group is localized.

In the generation of child individuals, multiple child individuals are generated by crossover and mutation. Figure 6 (1) shows an execution example of the crossover in the configuration chromosome, and Fig. 6 (2) shows an example of crossover in the operation chromosome, respectively. Figure 7 shows an example of the mutation execution.

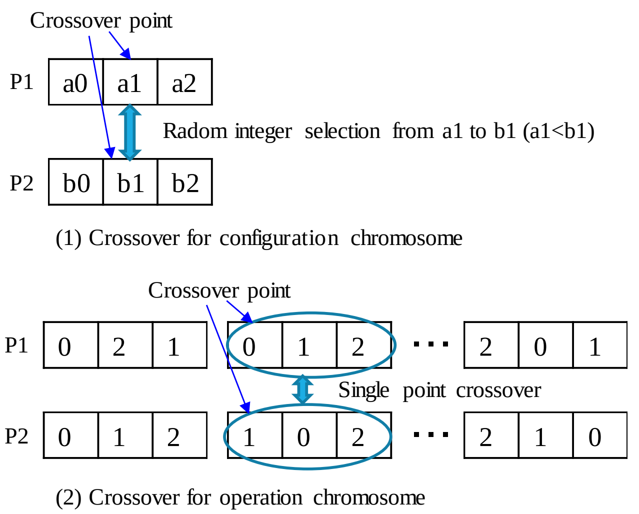

Fig. 6. Crossover.

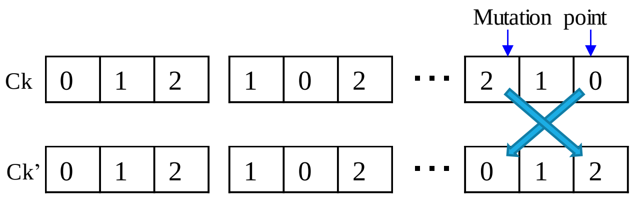

Fig. 7. Mutation.

4. Case Study

4.1. Case study scenario

The purpose of this case study is to generate an approximate Pareto-optimal solution set for the following two objectives by EMO. The first objective is to minimize the annual electricity cost by EGs and the PV, the second objective is to minimize the fuel consumption of EG's when supplying power for one week with EGs and the PV when the commercial power loss occurs. The actual data for 1 year in 2013 is used for the data of the hospital electricity load. The insolation data of every hour of Shimabara city where the target hospital is located is used, and the data is based on the insolation database (METPV-11) published by NEDO. This insolation data is the average value at every hour for 20 years from 1990 to 2009 and is considered to be suitable for estimating the generation power of PV at the planning stage like this case study. The rated capacity of PV is 200 kW and the loss factor is 0.73. The performance of EGs are based on the performance data of rated output 800 kW EG, and the fuel consumption curves are derived using the scaling corresponding to the rating of EGs. The rating of EGs used in this case study are 80 types in 10 kW steps in the range of 10 kW to 800 kW.

The conditions of the case study are shown in Table 1. The number of EGs to be used are 3 and 4, which are appropriate for the operation in the emergency

As a conventional method for comparison, a method of extracting approximate Pareto-optimal solution set from all solution sets obtained by executing NSGA-II 20 times is adopted. This method is equivalent to the proposed method GEMO, however, in order to equalize the total number of the evaluations, the size of population is set to 600 and the number of generations to 200 respectively, that is twice the proposed method GEMO. The result of comparing the conventional method and the proposed method is described in Section 4.2.

Table 1. Case study settings of proposed method.

Parameters	Contents
Number of EG	3, 4
GEMO: Number of multi-start (N_{GEMO})	20
GEMO: Size of population (N_{Gpop})	300
GEMO: Number of generation (N_{Ggen})	100
LEMO: Number of LEMO (N_{LEMO})	100
LEMO: Size of population (N_{Lpop})	100
LEMO: Number of generation (NL_{gen})	50
GEMO & LEMO: Number of child individuals (N_c)	20

4.2. Comparison with conventional method

Figure 8 shows the comparison result between the proposed method and the conventional method. In Fig. 8, EG3 represents the solutions in the case of using three EGs and EG4 is in the case of using four EGs. The horizontal axis shows the fuel consumption of EGs in one week of the emergency and the vertical axis shows the annual cost for the commercial power. Each value is expressed in the ratio with the result in the case when single EG is used, and the lower value means better result. The optimization is not performed for single EG. EG3 indicates that the proposed method has the slightly improved solution in density compared with the conventional method. EG4 indicates that the solution is dramatically improved in density with the proposed method compared with the conventional method. The number of evaluation times is 1.1×10^7 in the proposed method, and in the conventional method it is 2.4×10^7 so that the order is made equivalent. However, the size of population in the conventional method is 600, which is twice that of the proposed method. Because of this, the actual processing time for survival selection is increased. Furthermore, considering that there is superiority in EG4 where the search space is larger, it can be concluded that the proposed method has capability to realize efficient uniformity. Since the proposed GEMO as the first stage is a method which the conventional one is shrunk, it is considered that the combination with the local search by the second stage LEMO takes effect.

In the result of the proposed method, some blank spaces exist in the solution set of EG3 and EG4. This is possibly because the problem is an optimization of the discrete combination and accordingly the distribution of the evaluation values of the obtained solution set becomes discrete.

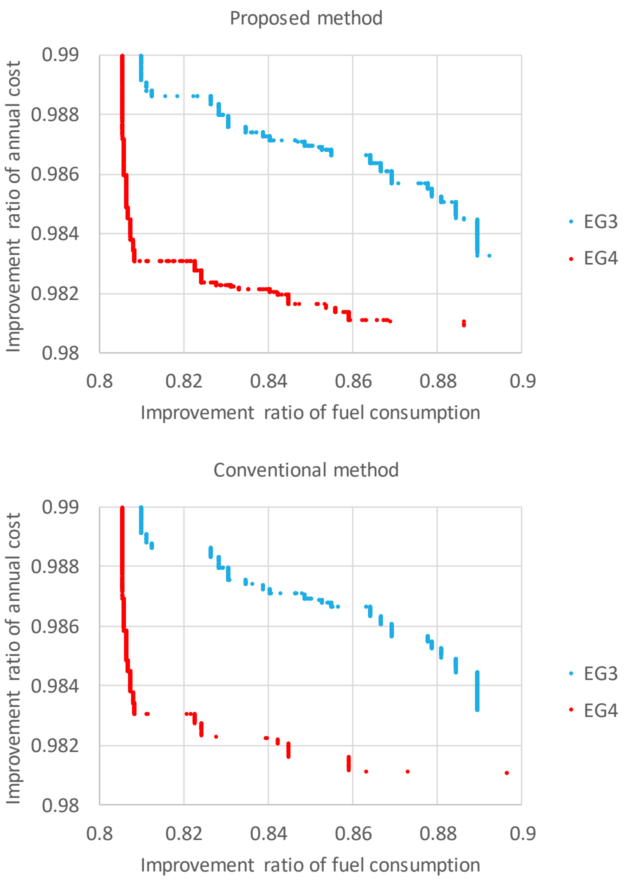

Fig. 8. Comparison between proposed method and conventional method.

4.3. Case study results

The simulation results of the proposed method are shown in Fig. 9. In Figure 9, EG1, EG3 and EG4 represent the case of using one EG, three EGs and four EGs respectively. The horizontal axis represents the fuel consumption of the EGs in one week in the emergency, and the vertical axis represents the annual cost for the commercial power. From Fig. 9, it can be seen that both EG3 and EG4 have a diversified solution set which greatly improves both the power cost and the fuel consumption compared with EG1. Furthermore, it is indicated that a solution with higher accuracy in EG4 than EG3 is obtained and the density of solution set higher.

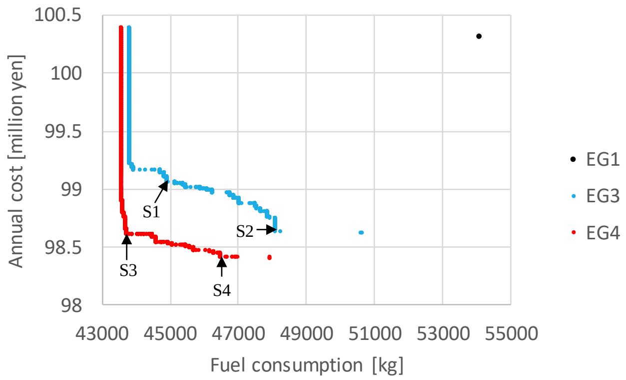

Fig. 9. Results of the proposed method.

Table 2. Comparison of preference solutions.

Label on Fig. 8	-	S1	S2	S3	S4
Contract power [kW]	867	713	709	707	680
Number of EGs	1	3	3	4	4
EG configuration [kW]	1000	12, 280, 500	4, 12, 840	40, 120, 500, 840	40, 80, 170, 590
Fuel consumption [kg]	54,073	44,898	48,080	43,701	46,462
Improvement ratio of fuel consumption	1.0	0.830	0.889	0.808	0.859
Annual cost [million yen]	100.322	99.080	98.664	98.625	98.429
Improvement ratio of annual cost	1.0	0.988	0.983	0.983	0.981

Generally in the multi-objective optimization, the decision maker selects the final solution in consideration of the trade-off from the Pareto-optimal solution set. This process is called preference selection. In Fig. 9, the case of EG1 and examples of preference selection (label S1 to S4) are shown in Table 2.

Since the annual cost of EG1 is 100.322 million yen and the annual cost in the case without EG is 100.401 million yen, it is seen that the effect by peak cut is hardly obtained in EG1. In EG3, label S1 is a well-balanced solution as the preference selection, and S2 is a solution that emphasizes the annual cost. S1 has an improvement by 17% from 54,073 kg to 44,898 kg in the fuel consumption and by 1.2% from100.322 million yen to 99.080 million yen in the annual cost compared with EG1, and the configuration of EG is well-balanced. On the other hand, S2 clearly shows that the configuration of EGs emphasizes annual cost. As a result, it can be seen that the improvement of the fuel consumption is by 11.1% from 54,073 kg to 48,080 kg, the annual cost is improved by 1.7% from 100.322 million yen to 98.664 million yen, and the annual cost is reduced at the expense of the fuel consumption.

In EG4 as like in the case of EG3, S3 is a balanced solution and S4 is a solution that emphasizes annual cost. EG4 also shows the same tendency in the configuration and the improvement result as EG3. S3 has an improvement by

19.2% from 54,073 kg to 43,701 kg in the fuel consumption and by 1.7% from100.322 million yen to 98.625 million yen in the annual cost compared with EG1. S4 has an improvement by 14.1% from 54,073 kg to 46,462 kg in the fuel consumption and by 1.9% from100.322 million yen to 98.429 million yen in the annual cost compared with EG1. It can be pointed that the degree of improvement is greater for EG4 because there is more flexibility in the combination of EGs. Regarding the contract power, it is clearly indicated that the case that emphasizes the annual cost is lowered.

As described above, when the multi-objective optimization with the proposed EMO is performed, the diversified and the highly accurate solution set can be obtained and the useful information can be expected to be acquired for the final decision making.

5. Conclusion

In this paper, it is attempted that the EMO is applied to the energy management of the power supply system which has various and diverse power sources in large scale medical facilities. The multi-objective optimization to obtain the optimal configuration and the operation method of EGs for minimizing the fuel consumption of EGs in emergencies and minimizing the power cost in the normal time by peak cut is studied as a case study. It has been pointed that a highly accurate solution set can hardly be obtained with single EMO alone. Therefore, “GEMO then LEMO” which is a framework of two-stage EMO combining multi-start EMO with Local EMO which has the local search function is proposed.

The proposed method is applied to the case study of energy management in the medical facility and the result has been evaluated. It has been confirmed that the more accurate solution set is obtained with the proposed method than that with EMO using NSGA-II alone.

When the solution balancing the objectives are selected from diverse solution sets, a reduction effect by 19.2% in the fuel consumption and a reduction effect by 1.7% in the annual cost are obtained, and when the solution emphasized on annual cost, the reduction effect by 14.1% in fuel consumption and the reduction effect by 1.9% in annual cost are obtained. In other words, it is demonstrated that the preferred selection of the optimal solution can be made for the item of which the decision maker makes much account.

Thus, it can be said that the proposed "GEMO then LEMO" is an effective method in the multi-objective optimization in the energy management for the power supply system with the renewable energy.

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