# GA Based Optimization for Configuration and Operation of Emergency Generators in Medical Facility Using Renewable Energy

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**Abstract-** In this paper, a simultaneous optimization method using GA of configuration and operation of emergency generators in medical facilities with power source of renewable energy is proposed. The simultaneous optimization of configuration and operation needs search of enormous combinations, which is generally considered to be a difficult problem. Here, PV is assumed as renewable energy, but since its output depends on the weather, fluctuation of the generated power is not small. From the viewpoint of an emergency generator, this is a factor of short-term variations in load, so there is concern that the efficiency will decline. In the proposed method, genes are divided into configuration chromosomes and operation chromosomes, and the operation chromosomes are multiplexed so that they can be switched by the time zones and the loads so as to be robust for short-term variability. The effectiveness of the proposed method is examined by a case study using amount of insolation and actual data in a hospital.

## 1. Introduction

In important facilities such as hospitals, emergency generators (EGs) are widely installed in preparation for loss of power supply from the grid due to natural disasters. Especially for medical institutions, it is obligatory to stock fuel for emergency generators for three days operation. However, in Japan's Kumamoto earthquake that occurred at 2016/4/16, a massive power outage and lifeline stoppage occurred for about a week [1]. Therefore, the conventional requirement of 3 days is not sufficient for the emergency power, and energy management that lengthens the power generation period as long as possible at least about one week is required until restoration of power supply or arrival of fuel. Therefore, in this paper, in the system configuration of

electric power supply combined with EGs and a photovoltaic (PV), to minimize fuel consumption to supply electricity for one week by EGs in the time of commercial power outage is studied as the purpose.

Generally, it can be said that the operation by multiple generators has more advantage than the single generator operation in terms of energy efficiency. This is because fuel consumption can be minimized by scheduling to operate generators at the suitable load band for each generator. However, in order to simultaneously optimize the configuration and the operation from various rated EGs, it is necessary to evaluate a huge number of combinations. In addition, fluctuations in the PV output due to weather give short-term variations in load demand of EGs. There are

multiple constraints on the operation of the equipment. Therefore, the target problem can be regarded as a constrained combination optimization problem under dynamic environment in which the evaluation function varies in the short term.

In recent years, artificial intelligence techniques such as genetic algorithm (GA) are often used for energy management of renewable energy and smart grid [2-14]. GA is regarded as a powerful method of combinatorial optimization, and it has capability to deal with nonlinearity, multimodality and constraint conditions [15]. Coping ability can be expected under the dynamic environments from the point that it is excellent in maintaining diversity by multipoint search. However, the PV output varies with weather. This leads to an increase in the variation of EG load demand. In such a case, there is concern that sufficient performance may not be obtained with Simple GA [15] which is commonly used. On the other hand, as in this paper, several studies targeting energy management in medical facilities have been made [1,16]. However, regarding the configuration and operation of EGs that combines the PV, very few attempts have been made to optimize with GA using actual data.

This paper presents a method for the simultaneous optimization of EG configuration and operation in medical facilities with power source of renewable energy using GAs. In the proposed method, algorithms are configured as combinatorial optimization using integer coding. Genes are divided into configuration chromosomes and operation chromosomes. The configuration chromosomes represent configurations of EGs, and operation chromosomes are multiplexed so that they can be switched by the time zones and the loads so as to be robust for short-term variability.

As the case study, the optimal configuration and operation plan of EGs that minimize fuel consumption for one-year operation of the power generation system is obtained by the proposed method. And effectiveness of the proposed method is demonstrated by the case study using the actual one-year data of load in the hospital, the generation power of the PV based on the actual amount of insolation and the performance data of EGs. This paper is organized as follows. The model of EG system and formulation of target system are explained in the section 2. In section 3, the proposed method is shown. Section 4 shows the case studies and simulation results. Section 5 present discussion about the simulation results. Section 6 shows conclusions and challenges of the future.

## 2. System Model and Formulation of Subject

### 2.1. System model

Figure 1 shows the EG system model at the subject hospital. The PV and *n* number of EGs are connected to the hospital ward with AC line and can supply power to all facilities of the wards such as ICU, the operating room and so on.
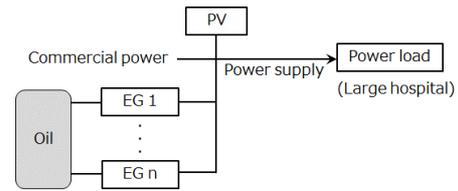


**Fig. 1.** System model.

The model of fuel consumption [kg / h] of the EG unit can be formulated as follows;

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

where $x$ is the power output of the EG, $r_i(x)$ is amount of fuel consumption, $a_i, b_i \ and \ c_i$ are coefficients corresponding to the type of the EG, $N_{EG\_Type}$ is a number of types of EGs.

The PV generation model can be formulated as follows:

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

where $p_{PV}(t)$ is the output power [kW] of the PV at time $t$, $g(t)$ is the amount of insolation [kW / m$^2$] at time $t$, $RP_{PV}$ is the rated power [kW] of the PV and $k$ is loss factor.

Figure 2 shows the variation of the load and the PV output at the same time of each day in August 2013. The upper graph is load of hospital. The middle graph is required load demand to EGs. The lower graph is the output power of the PV. Here, the load demand to EGs is obtained by subtracting the output power of the PV from the load of hospital. From Fig.2, it can be seen that the dispersion of the load demand to EGs is larger than the variation of the original load because of variations of the PV output. Therefore, it is considered that the dispersion of the output of the PV becomes a factor of the performance deterioration from the viewpoint of optimization of EGs.
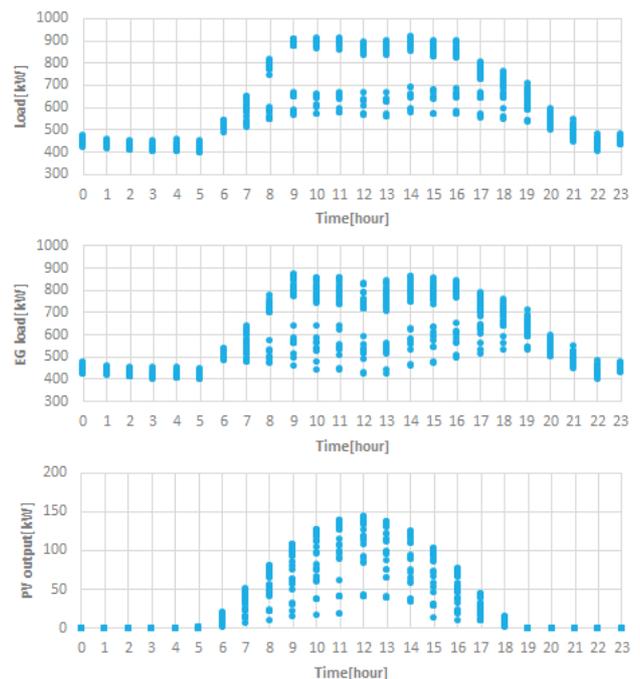
**Fig. 2.** Variation of the load and the PV output at each time.

*2.2. Formulation of subject*

The objective function and the constraint condition can be formulated as follows. As indicated by the right side of the equation (5), the load on EGs is defined as a value obtained by subtracting the output power of the PV from the total load.

Objective function:

$$\text{Minimize } \text{Obj}(\cdot) = \sum_{i=0}^{N_{EG}-1} \sum_{t=0}^{N_t-1} r_i\big(x_i(t)\big). \quad (3)$$

Constraint conditions:

$$RP(i) \times 0.3 \leq x_i(t) \leq RP(i)$$

$$\text{(Operate at 30\% output or more)}, \quad (4)$$

$$\sum_{i=0}^{N_{EG}-1} x_i(t) \geq p(t) - p_{PV}(t),$$

$$t = 0,1,\cdots,N_t - 1, \quad (5)$$

where

$i$ : index of EG,

$N_{EG}$ : number of operating EG,

$t$ : time,

$N_t$ : maximum operating time,

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

$RP(i)$ : rated output of i-th EG,

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

$p_{PV}(t)$ : output of PV

## 3. Proposed Method

In this section, its design policy to build an algorithm suitable for this subject is discussed.

*3.1. Design policy of algorithm*

Design policy of individual gene coding: Let an array in order to simultaneously optimize the configuration and operation, a chromosome specifying the configuration and a chromosome specifying the operation are provided, respectively. Let $EG_{RP}[i]$, $i = 0,1,\cdots,N_{EG\_Type} - 1$ ($N_{EG\_Type}$ is number of EG's type) be the array that defines the type of EG. Here, the configuration of EGs is specified by referring to index $i$ and $EG_{RP}[i]$. Specifically, the configuration of EGs is represented by an integer gene such as "3", "2", "0", …, "1", as shown in the configuration chromosome in Fig.3. On the other hand, operative chromosomes are categorized by time zone and load. Its contents are pointers to indexes of configuration chromosome, and they are represented by vector genes such as "2, 0, ..., 1". The operation schedule is decided as follows. The load to be allocated to each EG is preferentially allocated in the order of the EG specified by the index in the configuration chromosome indicated by the pointer.
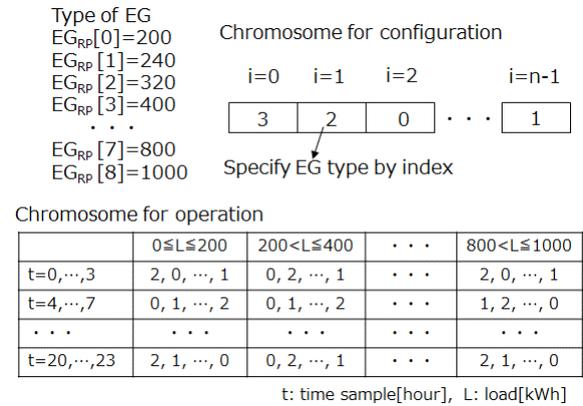


**Fig. 3.** Coding method

Design policy of generational change model: Adopt MGG (Minimal generation gap) [17] model that has a reputation for maintaining diversity. Figure 4 shows the scheme of MGG. In reproduction, two individuals are randomly extracted from a population without restoration. In survival selection, randomness is given by combining elite preservation with roulette selection. In the elite preservation, the individual with the highest fitness takes precedence. These features maintain diversity.
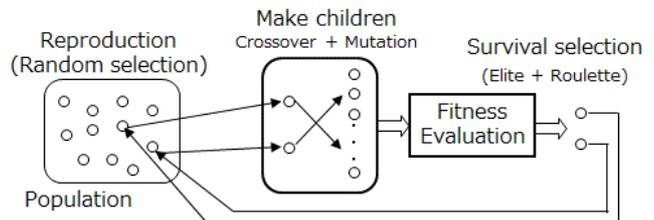


**Fig. 4.** Generation alternation model MGG.

Crossover and mutation design policy: As a crossover, single point crossover is used to minimize the change of the evaluation value and prevent initial convergence. One integer gene is exchanged in the configuration chromosome, and one vector gene is exchanged in the operation chromosome. As a mutation, it is used to change the operation method without changing the configuration of EGs. That is, the position of the vector component is exchanged in the vector gene of the operation chromosome in the same individual. After the two types of crossing execution, the mutation is executed.

*3.2. Algorithm*

The algorithm of the proposed method is shown below.

1) Initial group generation: Random generation of individuals and the calculation of fitness function of initial individuals

2) Reproduction selection: random selection of 2 individuals

3) Child individual generation: Multiple child individuals are generated by the crossover and the mutation

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

5) Survival selection: Put the individuals selected by the elite preservation and the roulette selection into a group

Repeat steps 2) to 5) shown above until the termination condition is satisfied.

The initial population is randomly generated for both configuration chromosomes and operation chromosomes. In the reproduction selection, two individuals are randomly selected based on the generational change model MGG. In the child individual generation, multiple child individuals are generated by crossover and mutation. Figure 5(1) shows an example of crossover in the configuration chromosome, and Fig.5(2) shows an example of performing crossover in the operation chromosome. Figure 6 shows an example of mutation execution.
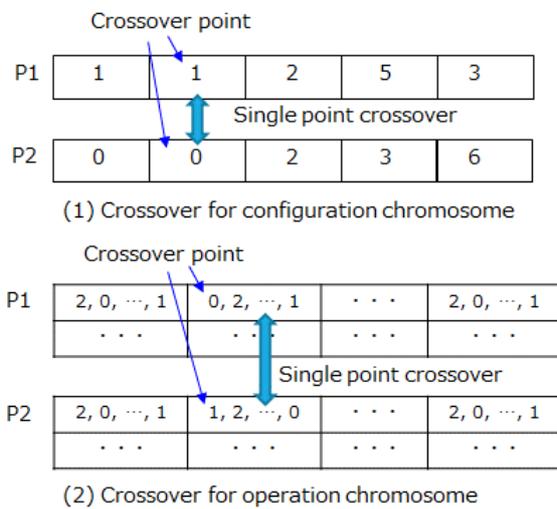


**Fig. 5.** Crossover.
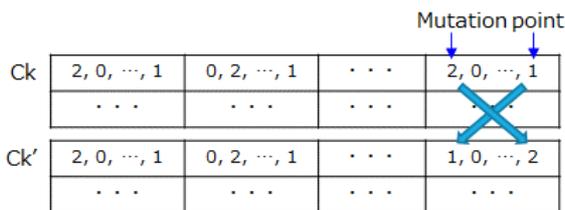


**Fig. 6.** Mutation.

In the calculation of fitness function, firstly the power output of i-th EG $x_i(t)$. A pointer to configuration chromosome is got from the vector gene of the operation chromosome corresponding to the time $t$ and the load $p(t)$ at the time $t$ and the priority order of i-th EG is obtained. Then, the power output $x_i(t)$ is allocated according to the priority order. Here, in order to satisfy equation (4) as the constraint condition, the power output of each EG is set to be 30% or more. When the power output $x_i(t)$ is determined, *Evaluation* (evaluation value) is calculated using the equation (3). The value $Sum\_eg\_rp$ is incorporated into the calculation of fitness function as a cost control term so that the total rating of EGs $Sum\_eg\_rp$ does not become too large. Fitness is sum of *Evaluation* and $Sum\_eg\_rp$ those

are linearly normalized and weighted on each. In the survival selection, two individuals are selected from the generated parent individuals and the child individuals based on the elite preservation strategy and the roulette selection. Then, these two individuals are replaced with two parent individuals selected by reproduction selection.

## 4. Case Study

### 4.1. Simulation scenario

Figure 7 shows a certain actual daily power load pattern in a hospital. At the Kyushu earthquake of 16 April.2016, the lifeline stopped for about a week [1]. Therefore, in the case that grid power loss occurs and the emergency power system which consists of EGs and the PV supply power to the hospital for one week, minimizing the fuel consumption of EGs is the target of this case study. The actual data for one year in 2013 is used as hospital electric load data. For insolation data, the data of each time of Shimabara-city where the target hospital is located is adopted from the hourly insolation database (METPV-11) published yearly by NEDO. This insolation data is average data for 20 years from 1990 to 2009, and it can be considered to be suitable for estimating the power generation amount of the PV at the planning stage like this simulation. The rated power of the PV is 200 kW and the loss factor is 0.8.
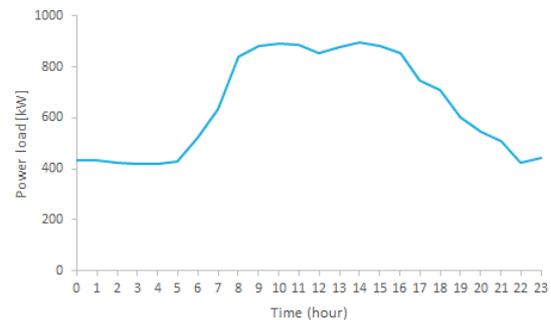


**Fig. 7.** Load pattern in one day in the hospital.

This time, optimization and evaluation are performed using data for one year (Proposed method I). Considering the purpose of the emergency generator and the fact that the occurrence of grid power loss is stochastically uniform, we aim at total optimization by using data for one year. On the other hand, optimization and evaluation are also carried out even in the case of using data for one week with the highest electricity load for comparison (Proposed method II). A comparison of these results is discussed in the section 5. Table 1 shows the parameter settings of the simulation. The weight ratio of the fitness function is *Evaluation*: $Sum\_eg\_rp$ = 95:5.

**Table 1.** Simulation setting.

| Parameters | Value |
|---|---|
| Number of EG $N_{EG}$ | 2, 3, 4 |
| Size of group | 250 |
| Number of evaluations | 100,000 |

### 4.2. Preliminary experiment

Operation chromosomes are divided and categorized according to time zones and loads, and the number of divisions is determined from the results of preliminary experiments. Let $N_{TZ}$ be the number of divisions by time zone and $N_{LD}$ be the number of divisions by load. For the time zone, $N_{TZ}=1$ (no dividing), 2, 3, 4, 6, 8, 12, and 24 are candidates. For load, $N_{LD}=4$, 5, 8, 10, and 20 are candidates. From those combinations of candidates, those with excellent results were selected. As the simulation settings, the number of EGs $N_{EG}=3$, the size of group and the number of evaluations are shown in Table 1, and the one-year data of load and the output of the PV were used. $N_{TZ}=1$ and $N_{LD}=10$ were selected according to the results of the preliminary experiment. Consideration about preliminary experiment is shown in section 5.

### 4.3. Simulation result

Table 2 shows the results obtained by searching the solutions for the fuel consumption for one week with the highest load and the fuel consumption for one year while changing $N_{EG}$ in the proposed method I. Here, the fuel consumption for one year corresponds to the average fuel consumption of the year. The result shows that fuel consumption can be reduced by operating multiple EGs than operating single EG. Comparing with the single 1000kW EG operation, it is shown that the fuel consumption for one week with highest load can be reduced about 16.4% when operating with 2 EGs, about 19.6% when operating with 3 EGs and about 21% when operating with 4 EGs, respectively. And throughout the year, it can be seen that the fuel consumption for one week can be reduced 25.5% with 2 EGs, 29% with 3 EGGs and 29.5% with 4 EGs, respectively. Therefore, it can be said that the proposed method is effective in expanding the operation time of the emergency generator.

Table 3 shows a comparison between the proposed method I and the conventional method. In Table 3, the effect is shown by the improvement ratio compared with the case of operating with one EG of 1000 kW. Here, the method in which the chromosome is extended to the dual chromosome for low load and high load in a simple GA in order to correspond to environmental change is regarded as a conventional method. By the proposed method I, it is shown that 1.5 to 1.9% improvement is achieved at the peak load and 2.6 to 3.2% on average in comparison with the conventional method.

**Table 2.** Results when changing $N_{EG}$.

|  | $N_{EG}=1$ | $N_{EG}=2$ | $N_{EG}=3$ | $N_{EG}=4$ |
|---|---|---|---|---|
| EG configuration results | 1000kW | 500kW 800kW | 200kW 320kW 400kW | 200kW 200kW 320kW 400kW |
| Total fuel 1week (kg) | 60931.5 | 50932.3 | 48960.9 | 48145.0 |
| Improvement ratio | 1.0 | 0.836 | 0.804 | 0.790 |
| Total fuel 1year (kg) | 2989122.3 | 2227423.0 | 2121921.9 | 2107783.8 |
| Improvement ratio | 1.0 | 0.745 | 0.710 | 0.705 |

**Table 3.** Comparison with conventional method (upper row: proposed method, lower row: conventional method).

|  | $N_{EG}=1$ | $N_{EG}=2$ | $N_{EG}=3$ | $N_{EG}=4$ |
|---|---|---|---|---|
| Total fuel 1week | 1.0 | 0.836 | 0.804 | 0.790 |
| Improvement ratio |  | 0.852 | 0.819 | 0.809 |
| Total fuel 1year | 1.0 | 0.745 | 0.710 | 0.705 |
| Improvement ratio |  | 0.777 | 0.741 | 0.731 |

The details of the result in the case of $N_{EG}=3$ are shown in Fig.8, respectively. In Fig.8, the load, the PV output, the load to the EGs and the output of each EG are shown from the top. In the graph of output of each EG, it can be seen that an operation schedule avoiding low output is obtained for each EG. This can be said to be reasonable as a strategy to not lower efficiency.

## 5. Discussion

In the preliminary experiment in 4.2, the result shows that division by load size ($N_{LD}=10$) without dividing by time zone $(N_{TZ}=1)$ is effective. This is because the original problem is to determine the output of each EG, so it is considered that the correlation with the load is directly higher than the time zone.

Table 4 shows a comparison of Proposed Method I (optimized using data for one year) and Proposed Method II (optimized using data for one week with the highest load). In the comparison, it can be seen that 0.4% improvement has been made by the method II in the week with peak load than by method I. However, on a yearly average, the fuel consumption by Method 2 is 4.6% worse than Method 1, which is 1.5% worse than the conventional method.
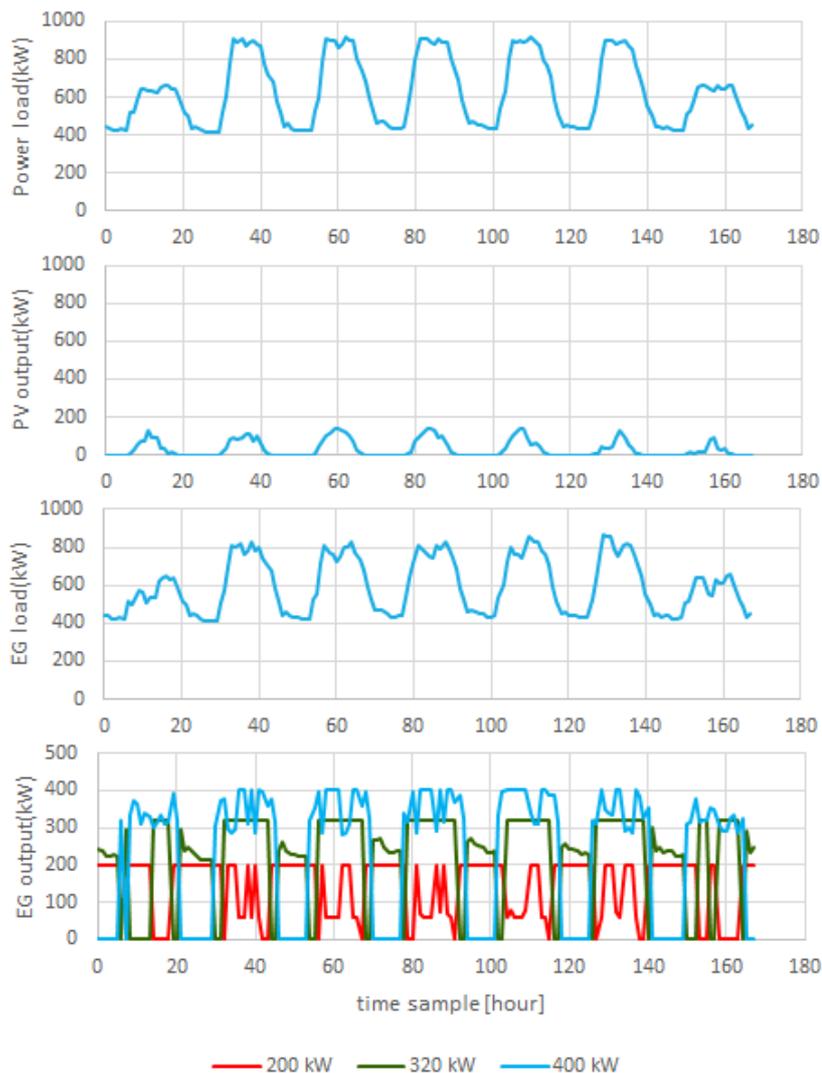
**Fig. 8.** Results of EG optimization at $N_{EG} = 3$.

**Table 4.** Comparison of proposed method I and proposed method II.

|  | $N_{EG} = 1$ | Proposed Method $N_{EG} = 3$ | Proposed Method $N_{EG} = 3$ |
|---|---|---|---|
| EG configuration results | 1000kW | 200kW 320kW 400kW | 200kW 320kW 700kW |
| Total fuel 1week (kg) | 60931.5 | 48960.9 | 48722.6 |
| Improvement ratio | 1.0 | 0.804 | 0.800 |
| Total fuel 1year (kg) | 2989122.3 | 2121921.9 | 2260897.2 |
| Improvement ratio | 1.0 | 0.710 | 0.756 |

Figure 9 shows the results of calculating the fuel consumption for each week while moving one day at a time throughout the year using the optimized solution using the proposed method I, method II, and the conventional method, respectively. It can be seen that each of them is greatly reduced in comparison with one EG of 1000 kW. However, in the comparison between the proposed method I and the proposed method II, although the latter is somewhat superior

or equal at the high load (Day number = 180 to 240), but the efficiency drops considerably at other period. On the other hand, the former is nearly equal in spite of a slightly inferior part at a high loading time compared with the latter. In other periods, there is great advantage throughout the year, and it can be said that stable performance is obtained independently of load and season. On the other hand, in comparison between the proposed method I and the conventional method,

it can be seen that the proposed method I is superior over the entire period.

From the results in Table 4 and Fig.9, when using the proposed method, more robust solution can be obtained by optimizing with comprehensive data such as one-year data than optimizing for the particular term such as peak load period. In this case study, the operative chromosome is divided only by the magnitude of the load. This point can be considered to be a success factor of realizing optimization that is robust to load change.
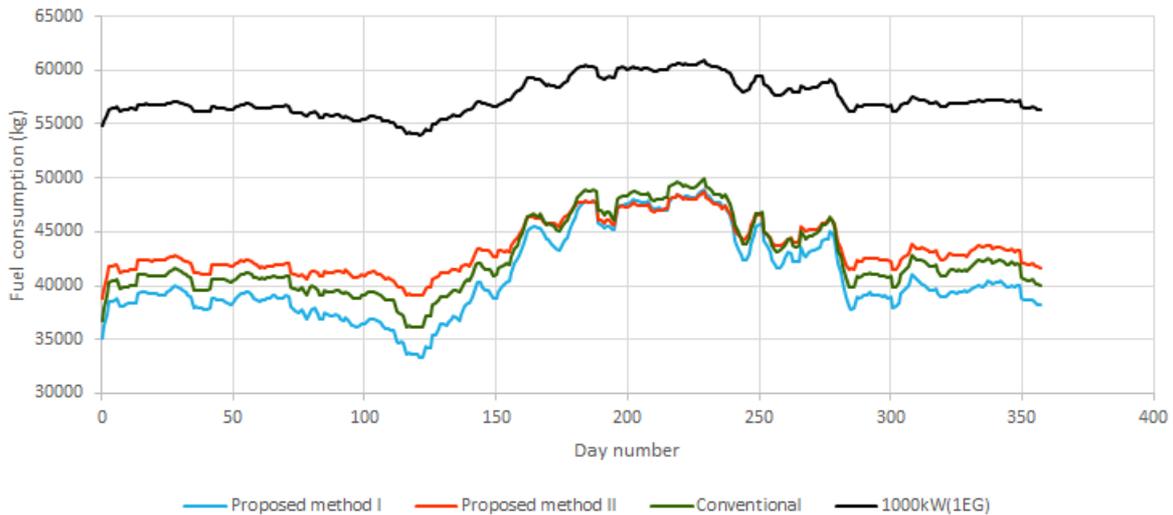


**Fig. 9.** Comparison by optimization data: Fuel consumption every week.

## 6. Conclusion

In this paper, in a large scale medical facility with power supply system consists of EGs and the PV, a simultaneous optimization method using GA for both configuration and operation schedule of EGs are proposed. In the proposed method, a simultaneous optimization for both configuration and operation is realized using two kinds of chromosomes those are configuration chromosome and operation chromosome. By means of dividing the operation chromosome by the magnitude of the load, it is demonstrated that the robust optimization can be realized under the large load variation due to the fluctuation of the PV output. In the case study using actual load data of hospital and insolation data for the PV, it is confirmed that by using the proposed method, fuel consumption can be reduced using multiple EGs. It is found that a more robust solution that does not depend on the load and the season can be obtained by optimizing with comprehensive data such as one-year data than optimizing for the particular term such as peak load period.

A study of the optimization in the case of the power supply system combining with batteries and a study of the possibility to apply EGs to peak cut will be made as the future task.

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