



HAL
open science

Integration Method of Unit Commitment Using PL-GA Binary Dispatch Algorithm for Intermittent RES in Isolated Microgrids System

Ignatius Rendroyoko, Ngapuli I. Sinisuka, Vincent Debusschere, Deddy P. Koesrindartoto

► **To cite this version:**

Ignatius Rendroyoko, Ngapuli I. Sinisuka, Vincent Debusschere, Deddy P. Koesrindartoto. Integration Method of Unit Commitment Using PL-GA Binary Dispatch Algorithm for Intermittent RES in Isolated Microgrids System. International Journal on Electrical Engineering and Informatics, 2021, 13 (2), pp.449 - 464. 10.15676/ijeei.2020.13.2.12 . hal-03636326

HAL Id: hal-03636326

<https://hal.science/hal-03636326v1>

Submitted on 9 Apr 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Integration Method for Intermittent Renewable Energy Source in Isolated Microgrids System

Ignatius Rendroyoko, *Member, IEEE*, Ngapuli I Sinisuka, Vincent Debusschere, *Senior Member, IEEE* and Deddy P Koesrindartoto

Abstract—Integrating renewable energy generators with existing electric power systems is essential in developing renewable energy generation in electric power systems in islands and remote areas. The high penetration of renewable energy sources (RES) and the possibility of working in a connected mode with the existing electricity grid are significant problems that must be overcome. With the many RES implementations, a proper integration method is needed between RES plants, which have intermittent characteristics, and existing power generation systems so that the electrical system remains stable, continuous, and reliable. One of the power plant integration schemes is unit commitment (UC), a daily scheduling method to achieve optimization goals while still meeting various operational, environmental, and technical constraints. UC method development is needed to maintain system stability, resilience, and minimize operating costs, especially for small systems for electrical development. Therefore, it is necessary to develop a new optimization method in the UC scheme for microgrid power systems.

This paper discusses the development of an optimization method to integrate power generation from intermittent renewable energy using a UC scheme in a microgrid system. The algorithm used is a combination of improved priority list techniques and genetic algorithms, where the improved priority list is run first for scheduling optimization and then a combination of the algorithm priority list and genetic algorithm for economic dispatch solutions to obtain the lowest operational costs. The generating unit's capacity to operate per capability segment is also taken into account in the operation scheduling and affects the number of iterations in the genetic algorithm's operation. This method has been simulated in the electrical system in Eastern Indonesia, which is a developing power system and has an intermittent characteristic of RES power plants.

Index Terms— Integration, intermittency, unit commitment, optimization techniques, priority list, genetic algorithm.

I. INTRODUCTION

ACCORDING to the Indonesian government's program to develop the eastern part of Indonesia, the need to provide electricity supply in Sulawesi, Moluccas, Papua, and Nusa

This work is part of doctoral research on the topic "Intelligent Electricity System for Islands," Institute Technology of Bandung, Indonesia, and is dedicated to PT. PLN (Persero).

Ignatius Rendroyoko is from the School of Electrical and Informatics Engineering, Institute Technology of Bandung, Bandung, Indonesia (e-mail: rendroyoko@students.itb.ac.id).

Ngapuli I Sinisuka is a Professor at the School of Electrical and Informatics Engineering, Institute Technology of Bandung, Bandung, Indonesia (e-mail: n.irmea@gmail.com).

Tenggara has increased significantly. For this reason, the government of the Republic of Indonesia has implemented an electricity system development program by utilizing all available resources. One of the agenda is to develop and utilize local energy potential using renewable energy sources (RES) [1]. That is needed in many regions and islands in Indonesia that require electricity at an affordable price and low carbon intensity [2, 3].

Efforts to provide electricity infrastructure in developing countries like Indonesia, especially for islands and remote areas, are generally carried out by building a microgrid system with diesel generators [4, 5]. A microgrid system consists of several generator units, electrical loads, and other supporting equipment to manage operations independently by an intelligent control system [6, 7]. Generally, most island microgrid power systems rely on diesel generators for their electricity supply. These generators are usually very flexible, with high lean capability, short start-up/shutdown times, and low minimum technicality, but their operating costs tend to be high [8, 9]. However, nowadays, along with the development of RES generation technology and the incessant reduction in fuel oil consumption programs, the use of RES has been intensified. In operation, renewable energy power plants are usually interconnected with other generating units in the existing microgrid power system.

Moreover, in some cases, the RES generator can cause instability in the power system due to its intermittency characteristics [4]. As the RES penetration of many microgrid systems increases in the future, the need to study its impact on power system operation will be increasingly needed. Therefore, a strategy is required so that the power system to be robust and flexible enough to deal with RES generators' uncertainty and fluctuating power supply [10].

One method that can be used to create operational flexibility for the power system to vary the supply of RES generators is the unit commitment (UC) method [11, 12, 13]. The UC method regulates the electric power system's operation by determining the operation and production schedule of electricity for each

Vincent Debusschere is an Assoc. Professor at the Université Grenoble Alpes, CNRS, Grenoble INP, G2Elab, France (e-mail: vincent.debusschere@grenoble-inp.fr).

Deddy P Koesrindartoto is an Assistant Professor at the School of Business and Management, Institute Technology of Bandung, Bandung, Indonesia (e-mail: deddypri@sbm-itb.ac.id)

generating unit in the electric power system, including the RES, to meet electricity load needs with minimal costs. In its operation, UC must meet several system demands, reserve requirements, and other limitations optimally and keep operating costs low. On the other side, changes in the power system load also cause variability and uncertainty, impacting UC settings. Considering the conditions of variability and uncertainty that may occur on the generation side and the load side of the power system, UC must be required to regulate and ensure the availability of continuous, and reliable generators to meet the load requirements during the operating period.

The problem of UC in microgrids systems is quite different from large electric power systems [7] [14]. Microgrids usually consist of thermal generators, diesel engines, micro-hydro, and some variable renewable sources such as wind turbines (WT) and solar photovoltaics (PV). The uncertainty of the variable RES generator's primary energy availability can cause instability in the microgrid power system. The variable RES generator characteristics are very different from conventional generators, which will complicate UC problems' resolution.

The UC scheme requires a technique to optimize the problems that arise between objective functions and constraints. The optimization technique is the process of minimizing or maximizing an objective function while still fulfilling the constraints. The main objective is to minimize total operating costs. Several optimization techniques have been developed to find a suitable solution for implementing the UC: Priority list, Dynamic programming, Lagrangian relaxation, Genetic algorithm (GA), etc [11, 15, 16]. From several previous studies on the implementation of UC, many researchers use genetic algorithms combined with other techniques to solve UC problems [17, 18]. The GA technique has been cited as the most successful evolutionary programming method, and it is suitable for optimizations with wide variations and uncertainties, such as the intermittency characteristics of RES generators. The GA technique is used because it is flexible, has the right convergence level, and is characterized by multi-search-ongoing-point.

This paper is focused on discussing the use of the UC method in the integration of the variable RE generator into the existing microgrid power system. The technique used in this UC implementation solution is a GA, which is intended to overcome the considerable variability of load changes and the uncertainty of the RES generator output fluctuation in the microgrid system. To improve GA implementation, PL techniques are used to help determine the initial population [7, 17]. Several parameters and constraints have been applied in this algorithm, allowing GA to avoid local optima traps and accelerate solution convergence. For this purpose, a microgrid system simulation model was built based on the Timor electric power system to test the new algorithm as a sample reference for the development of UC for islands microgrid power system.

This paper is structured as follows. The Concept of unit commitment is described in Section 2, including renewable energy conditioning and optimization algorithms for unit commitment. Section 3 presents the application of the unit commitment in the microgrid system. The UC procedures based

on the PL and GA algorithms are described in Section 4. The simulation studies results are described in Section 5, along with an analysis of computation time, reserve requirements, and operating costs. Conclusions are given in Section 6.

II. THE CONCEPT OF UNIT COMMITMENT (UC)

A. Unit commitment

UC is a method of scheduling power plant units' daily operation to fulfill load requirements while meeting various operational, environmental, and technical limitations [11, 13]. Optimization of the UC implementation is subject to several global constraints such as power balance, spinning reserves, and several individual constraints such as unit output limits, maximum ramp rates, and minimum up/down hours. The UC scheme in power systems with RES variable generation is shown in Fig. 1 below.

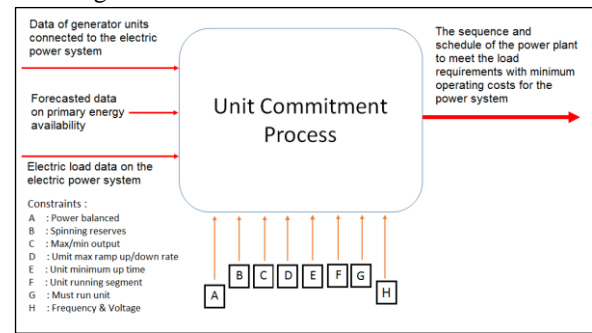


Fig. 1 Unit commitment in electric power system

In microgrid power systems, the main objective of UC implementation is to minimize the total generation cost, denoted by TOC [10].

$$TOC = \sum_t \sum_n \sum_k (\alpha_{k,n} \cdot P_{t,n,k} + \beta_{k,n} \cdot V_{t,n,k}) + \sum_t \sum_n (S_{t,n} * CS_n) \quad (1)$$

In the compilation of UC, several terms or notations are commonly used. Some of the notations used in this paper are as follows:

TOC	Total operation cost of power generation
$P_{t,n,k}$	Power output
$V_{t,n,k}$	on/off status of unit n, at time t, and at segment k
$\alpha_{k,n}$	cost coefficients of segment k of unit n
$\beta_{k,n}$	cost coefficients of segment k of unit n
$S_{t,n}$	start-up status of unit n at time t
CS_n	start-up cost of unit n
D_t	Total demand
U_n	maximum output of unit n
n	power generating units,
t, T	time, total period of time
k	segment of power generation,
U_{it}	On/off status of the i unit at time t, if the unit is on then $U_{it} = 1$, and if the unit is off then $U_{it} = 0$,
$F_{it}(P_{it})$	fuel cost function of the i-th unit, with output of P_{it} generator, at the t-time, with i-th unit start-up cost at t-hour, where a_i, b_i, c_i coefficient of unit fuel cost, P_{it} , generation output from the i-unit at t-hour,

In UC, several objectives can be formulated as follows:

Total operation cost (TOC):

$$\text{Min TOC} = \sum_{t=1}^T \sum_{i=1}^N (U_{it} \cdot F_{it}(P_{it}) + U_{it} \cdot S_{it}) \quad (2)$$

In equation (2) above, there are two functions used; first is the fuel cost per MW, which can be formulated as follows:

$$F_{it}(P_{it}) = a_i P_{it}^2 + b_i P_{it} + c_i \quad (3)$$

And the second is start up cost of generator unit :

$$S_{it} = \begin{cases} HSC_i, & \text{if } MDT_i < T_{off,i} \leq MDT_i + T_{co} \\ CSC_i, & \text{if } T_{down,i} < MDT_i + T_{cold,i} \end{cases} \quad (4)$$

In UC implementation, besides fulfilling the main objectives above, some constraints must still be fulfilled as follows:

A.1. Power balance

In this constraint, the power of generation should always keep equal to the customer's electricity load. The mathematical equation can be seen in (5).

$$\sum_n \sum_k P_{t,n,k} = D_t \quad (5)$$

A.2. Spinning reserve (SR)

The total generation must be greater than the load plus the spinning reserve needed to guarantee the stability of the power system. The total SR must be larger than 10% of demand.

$$\sum_t \sum_n (U_n \cdot V_{t,n} - P_{t,n}) \geq 10\% D_t \quad (6)$$

$$\sum_{i=1}^N (U_{it} \cdot P_{maks_i}) \geq (load_t + SR_t), 1 \leq t \leq T \quad (7)$$

A.3. Power generating limit

Active power generated has max and minimum limits:

$$\begin{aligned} L_n \cdot V_{t,n} &\leq P_{t,n} \leq U_n \cdot V_{t,n} \\ P_{min_i} &\leq P_{it} \leq P_{maks_i}, P \in R \end{aligned} \quad (8)$$

A.4. Minimum up/downtime

Before being operated, the generating unit must meet the minimum time for on/off.

$$T_{on}(i, t) \geq MUT(i), \text{ if } U(i, +1) \text{ must be off} \quad (9)$$

$$T_{off}(i, t) \geq MDT(i), \text{ if } U(i, +1) \text{ must be on} \quad (10)$$

A.5. Ramp up/downtime

This constraint is the generating unit's time limit to be ready for full operation (ramp-up) or time to go inoperative (ramp down).

$$P_{i,t} - P_{i,t-1} \leq UR_i, \text{ if power increase} \quad (11)$$

$$P_{i,t-1} - P_{i,t} \leq DR_i, \text{ if power decrease.} \quad (12)$$

A.6. Must run units

According to the forecasted output, the RES power plants are treated as a must-run unit and directly calculated into the power supply mechanism for the power system.

$$P_{RE}(t) = P_{output}(t) \quad 0 \leq t \leq 24 \quad (13)$$

A.7. System's Frequency and voltage

Limits of system frequency and voltage are :

$$V^{min} \leq V \leq V^{max} \quad (14)$$

$$F^{min} \leq F \leq F^{max} \quad (15)$$

B. UC with intermittent RES power plant

Electric power systems with renewable energy sources (RES), such as solar PV and wind power plants, the operating arrangements of each generating unit are formulated in the form of constraints as above, adjusted to its primary energy availability. The constraints are consist of generator power limit, minimum up/downtime, ramp up/downtime, and unit restriction status. Regarding the limitations and characteristics of the availability of its primary energy sources, RES power plants are classified as must-run units. Solar photovoltaic power plants are characterized by sharp temporal fluctuations, which can have considerable variability.

In preparation for the implementation of UC, the RES power plant must also be considered according to its availability. For intermittent RES, weather forecasting, historical data, and analysis are critical in preparing the generation schedule. With accurate weather forecasting, the UC of the RES generating unit can be performed with proper accuracy. In calculating the total operation cost, we will also calculate the solar PV cost according to the estimated selling price per kWh. The output of solar PV can be presented:

$$P_V = \begin{cases} 0, & G < G_i \\ \mu \cdot G, & G_{in} \ll G < G_{rate} \\ P_{rate}, & G \gg G_{rate} \end{cases} \quad (16)$$

Where P_V is the power output of solar PV, G_{in} and G_{rate} denote the minimum and rated insolation, and μ is a coefficient of the solar panel.

The output from the solar PV can be included in the net load calculation concept. The net load concept simplified the formulation of the UC problem [10].

$$\text{Net load} = \text{load} - P_V \quad (17)$$

Due to the energy sources' intermittency, it is necessary to predetermine a schedule that meets the netload. Based on the predicted values, hourly random loads and solar power are considered in each scenario.

C. Optimization Method for Unit Commitment

UC has two main interrelated parts: scheduling the order of operation of the generating unit and economic dispatch. Here, an optimization technique is needed to manage the UC in order to produce the best results. The objective function of the UC is to minimize the total operating cost while meeting the constraints: power balance, spinning reserve, power generation limit, maximum ramp rate, and minimum up/ downtime.

The optimization techniques used to solve the UC can be divided into classical, stochastic, and hybrid techniques. Moreover, several optimization techniques have been developed to find suitable solutions for implementing the unit commitment, such as priority list, dynamic programming, Lagrangian relaxation, genetic algorithm, etc. GA is a population-based search algorithm that follows the principle of "survival of the fittest" and is a stochastic technique that can be used to provide solutions to UC problems. UC is a non-convex, large-scale, non-linear, and mix-integer blend optimization problem, with several limitations. The non-convex condition is

due to the binary on/off condition of the generating unit, and the non-linear characteristic comes from the non-linear generation cost curve. Therefore, the GA technique is believed to be a suitable solution for large non-linear engineering optimization problems such as UC. GA continues to be developed by combining it with other techniques for increased performance and accuracy.

Priority list (PL) techniques have been implemented in many existing optimization methods to solve the UC problem [19, 20]. The method is simple and fast but produces less optimal solutions. The PL algorithm can be easily programmed and is suitable for handling UC problems involving multiple generators, and Delarue (2017), in his paper, proves that PL works well in electric power systems with intermittent RES generators under low load conditions [17]. On the other hand, GAs are characterized by exhaustively explore the search space, thereby ensuring the possibility of finding a close to the optimum solution. As one of the stochastic methods, GA relies on a population of candidate solutions. Therefore, determining the candidate solution population as the initial population will make the GA process to achieve its convergence faster. Furthermore, we can accomplish this after the PL method's scheduling results are used as the initial population of the GA process [7, 17]. Therefore, the combination of the PL and GA methods could be a new option for UC optimization.

III. OVERVIEW OF TIMOR POWER SYSTEM

The Timor power system is an electrical system that supplies the electric power needs of the Timor island, in East Nusa Tenggara province, Indonesia [1]. This electrical system was developed based on a microgrid system with a diesel-powered power plant, strengthened by coal-fired steam power plants, and currently with RES-based power plants. The fuel mix ratio in the Timor electric power system is 65.09%, which means that most of the power plants still use fuel oil, so RES is still very potential. Since 2015, Timor power systems operate 5 MWp Solar PV plants and contribute to electric power production.

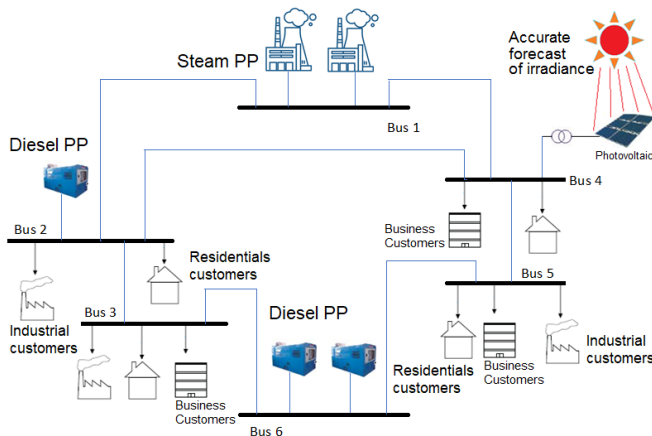


Fig. 2 Timor electricity power system [1]

The single line diagram of the Timor power system can be seen in Fig. 2, and the list of generating units is described in TABLE I. It is necessary to adjust the generating unit operation schedule in daily system operations to compensate for the

intermittent RES generator output fluctuation. In this study, we built a simulation model of an electric power system with reference to the electric power system of Timor, East Nusa Tenggara, Indonesia [4]. The Timor electric power system was chosen as a case study because the electricity system is rapidly developing and has the most potential for utilizing solar power in Indonesia.

TABLE I Power generations data of Timor power system [1]

	U1	U2	U3	U4	U5
Pmax(MW)	16	16	5	6	6
Pmin(MW)	10	10	0	3	3
a(\$/Jam)	1000	1000	-	100	100
b(\$/kWh)	16,19	16,19	-	1500	1500
c(\$/kW^2h)	0,00048	0,00048	-	0,022	0,022
MUT(jam)	8	8	1	1	1
MDT(jam)	8	8	1	1	1
HSC(\$)	4500	4500	-	50	50
CSC(\$)	9000	9000	-	100	100
CS(jam)	0	0	0	0	0
IS(jam)	-1	-1	-1	-1	-1
	U6	U7	U8	U9	U10
Pmax(MW)	6	6	3	3	3
Pmin(MW)	3	3	1	1	1
a(Rp/Jam)	125	125	125	125	50
b(Rp/kWh)	1500	1500	1500	1500	40
c(Rp/kW^2h)	0,025	0,025	0,025	0,025	0,001
MUT(jam)	1	1	1	1	1
MDT(jam)	1	1	1	1	1
HSC(1000 Rp)	50	50	50	50	20
CSC(1000 Rp)	100	80	100	100	50
CS(jam)	0	0	0	0	0
IS(jam)	-1	-1	-1	-1	-1

Information: U1, U2: steam generated power units, U3: Solar PV, U4 – U10: Diesel power units

In addition to system data, the forecast data for the power output of solar PV plant is shown in TABLE II below:

TABLE II Output of a solar PV plant [1]

Hour	1	2	3	4	5	6	7	8
PV (kW)	0	0	0	0	0	0	460	1733
Hour	9	10	11	12	13	14	15	16
PV (kW)	2534	2907	2883	3800	3805	3420	2500	1600
Hour	17	18	19	20	21	22	23	24
PV (kW)	100	0	0	0	0	0	0	0

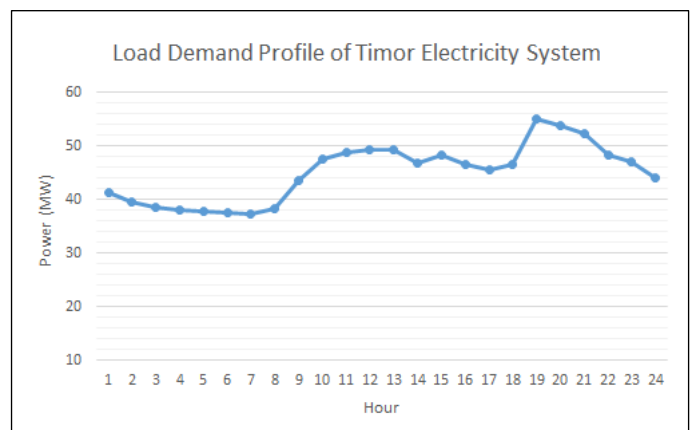


Fig. 3 Load profile of Timor electricity system [1]

Timor electric power systems' load profile is shown in Fig. 3, which shows the typical characteristics of electricity use in developing areas with the domination of residential customers and few industrial and business customers with slow growth.

IV. PL & GA ALGORITHM FOR UC OPTIMIZATION IN MICROGRID SYSTEM

This section discusses applying the GA technique to unit commitment problems in power systems with RES. This optimization process for UC begins with the PL technique to get the population initials and continues with optimization using the GA technique. Following are the steps for implementing the PL and GA methods for UC solutions [7, 17]:

1. Initialization

The generation of the initial solution is essential, mainly for the UC problem. The initial solution is usually generated at random. The selection of the candidate solutions in this study was carried out using the priority list (PL) technique.

2. Evaluation

Stage of evaluating the fitness value of the initial population candidate solutions.

3. Selection

Selection allocates more copies of those solutions with higher fitness values and imposes the fittest mechanism's survival on the candidate solutions.

4. Recombination / crossover

combine parts of two or more parent solutions to a new possible better solution. A properly designed recombination mechanism will determine success.

5. Mutation

The mutation is a genetic operator used to maintain genetic diversity from one generation of a GA chromosome population to the next.

6. Replacement

Replacement of parent populations with offspring populations made by selection, recombination, and mutation

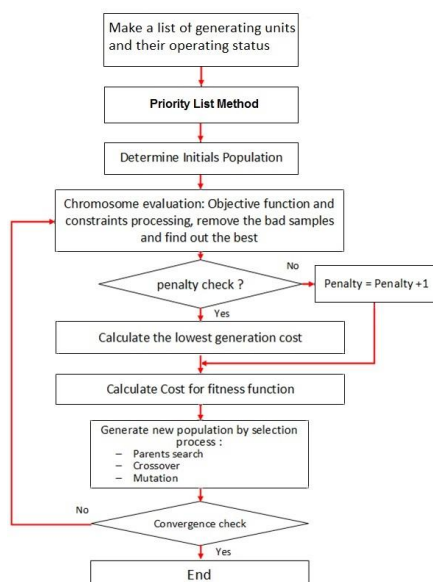


Fig. 4 Flow chart of PL and GA for UC in microgrid system

The flow chart of the optimization process for implementing UC in the microgrid system is shown in Fig. 4. The novelty of this algorithm is to use PL and GA techniques, with PL is done first for UC to get the initial population, then continue to dispatch with PL + GA, where one individual GA in the initial population stage uses the dispatch value from PL to accelerate the convergence of lowest operating costs.

For solving the UC problem, the first step is to use the priority list (PL) technique to obtain the initial population. The priority order of the generating units in TABLE I can be obtained based on each unit parameter. Generators with a higher capacity and lower heat rate (HR) will receive higher priority. For machines with low capacity and higher HR will have less priority. The PL and calculated heat rate are shown in equations (18) and (19) [17, 20].

$$HR_i = \frac{F_i(P_{imax}(t))}{P_{imax}(t)} \quad (18)$$

$$Cost_i = HR_i \times F_i P_{ih} \quad (19)$$

The PL method results are shown in **Erreur ! Source du renvoi introuvable.** (output power in MW) and will be used as the GA's initial population. This operating schedule is obtained from the PL calculation process based on the heat rate to meet the electrical load.

TABLE III Generator scheduling from PL

Hour/Unit	P1	P2	P3	P4	P5	P6	P7	P8	P9
01:00	1	1	1	1	0	0	0	0	0
02:00	1	1	1	1	0	0	0	0	0
03:00	1	1	1	1	0	0	0	0	0
04:00	1	1	1	1	0	0	0	0	0
05:00	1	1	1	1	0	0	0	0	0
06:00	1	1	1	1	0	0	0	0	0
07:00	1	1	1	0	0	0	0	0	0
08:00	1	1	1	0	0	0	0	0	0
09:00	1	1	1	1	0	0	0	0	0
10:00	1	1	1	1	1	0	0	0	0
11:00	1	1	1	1	1	0	0	0	0
12:00	1	1	1	1	1	0	0	0	0
13:00	1	1	1	1	1	0	0	0	0
14:00	1	1	1	1	0	0	0	0	0
15:00	1	1	1	1	1	0	0	0	0
16:00	1	1	1	1	1	0	0	0	0
17:00	1	1	1	1	1	0	0	0	0
18:00	1	1	1	1	1	0	0	0	0
19:00	1	1	1	1	1	1	0	0	0
20:00	1	1	1	1	1	1	0	0	0
21:00	1	1	1	1	1	1	0	0	0
22:00	1	1	1	1	1	0	0	0	0
23:00	1	1	1	1	1	0	0	0	0
00:00	1	1	1	1	0	0	0	0	0

Once the initial population has been created, we must evaluate the fitness of each candidate solution. In the process, all constraints are checked. First, the spinning reserve (SR) limits will be reviewed hourly using the schedule from the initial population. If any SR is breached within one hour, the penalty count will be added to the penalty function. Second, the minimum up/downtime constraints must be met so that individuals can enter the load dispatch stage. If these constraints cannot be met, the individual will be given a calculated penalty.

After the load dispatch stage is completed, each individual will enter the process of calculating the fitness function. The penalty function is the multiplication of the penalty factor and penalty count (20). The penalty function, start-up costs, and fuel costs obtained from the load dispatch stage will be added to get each individual's fitness value in the population (21).

$$Penalty\ function = penalty\ factor \times penalty\ count \quad (20)$$

$$Fitness = \frac{1}{startup\ cost + fuel\ cost + penalty\ func} \quad (21)$$

After evaluating all individual populations and calculating their fitness value, the selection stage can be carried out. The method used is the "roulette wheel" method due to the wheel's proportion being assigned to each of the possible selections based on their fitness value. Therefore, the best individual will be kept to be used in the next generation. The next stage is recombination, where several individuals are recombined to make new offspring. This process consists of selecting two individuals at random and recombining them with probability P_R .

In the proposed Priority List - Genetic Algorithm method, the one-point cross-over is used between two large groups of parents from individual candidate solutions (Fig. 5). In this case, the cross-over site is randomly selected on the string's length, and then the parts of the two strings outside this point of intersection are exchanged. The individual chromosome for this recombination comes from two major groups: the father's chromosome and the mother's chromosome, cross-over to obtain new possible better solutions.

```

individu no2 [16,5 16,5 5,1 3,0 0,0 0,0 0,0 0,0 0,0]
individu no3 [14,0 16,3 5,2 3,0 0,0 0,0 0,0 0,0 0,0]
for every g in individu

convert population in integer (p1 = 165 , p2 =140) format to binary format:

p1 = [1 0 1 0 0 1 0 1]
p2 = [1 0 0 0 1 1 0 0]

single point crossover, random point, for example 3:

c1 = [1 0 1 . 0 1 1 0 0]
c2 = [1 0 0 . 0 0 1 0 1]
    
```

Fig. 5 Population chromosome in GA

While recombination operates on two or more parent chromosomes, the next stage of mutation is carried out to add diversity to the population and ensure that it is possible to explore the entire search space. The cross-over process shown by genes in both individual parents will be exchanged based on the cross-over point Fig. 5.

After recombination, the next stage is mutation. The mutation is a technique that moves randomly, approaches the optimal point, and possibly moves away. The purpose of mutation is to add diversity to the population and ensure that it is possible to explore the entire search space. The mutation performed is a variation of the well-known "bit flip" mutation where each bit in the string is converted from 0 to 1 or vice versa with probability P_m . The primary function of these mutations in GA is to avoid the local optima trap.

In the final stage, the offspring population made through selection, recombination, and mutation replaces the original parent population. The steps are repeated in an iterative process until stopping conditions are reached. During the evaluation process, the best individuals are saved from being reintroduced to the next generation. Thus, convergence is accelerated, and the best individuals' information is preserved to get the string with the lowest value of total operating costs.

This computational process is coded and simulated in MATLAB R2016a. The results of the convergence check will produce the optimal value of the UC implementation.

V. SIMULATION RESULTS

A microgrid system simulation model has been prepared to test the proposed UC algorithm. The simulated microgrid consists of steam generating units, dispatchable diesel engines, and a solar PV plant. The implementation of the unit commitment is set based on the generating unit's capability and availability, and the dispatch arrangement is based on the lowest operating cost of the generating unit. The cost rate for each generator is modeled by the quadratic function for fuel costs and start-up costs. The energy cost of PV generation is also modeled by the multiplication of kWh of production and the selling price rate. The operating costs of all sources will be calculated using formula (1), and the characteristics of each element of the grid are listed in TABLE I. The time-based solar photovoltaic power output forecast is used to calculate the UC setting (see TABLE II). The optimal UC schedule together with dispatch is shown in TABLE IV and Fig. 7, and here it can be seen that the obtained UC schedule meets all constraints and produces a quality solution.

TABLE IV Best dispatch power production of generator units

Hour/Unit	P1	P2	P3	P4	P5	P6	P7	P8	P9
01:00	16,50	16,50	5,39	3,00	0,00	0,00	0,00	0,00	0,00
02:00	16,50	16,50	3,55	3,00	0,00	0,00	0,00	0,00	0,00
03:00	16,50	16,10	3,00	3,00	0,00	0,00	0,00	0,00	0,00
04:00	16,50	15,60	3,00	3,00	0,00	0,00	0,00	0,00	0,00
05:00	16,50	15,30	3,00	3,00	0,00	0,00	0,00	0,00	0,00
06:00	16,50	15,00	3,00	3,00	0,00	0,00	0,00	0,00	0,00
07:00	16,50	16,50	3,74	0,00	0,00	0,00	0,00	0,00	0,00
08:00	16,50	16,50	3,53	0,00	0,00	0,00	0,00	0,00	0,00
09:00	16,50	16,50	5,12	3,00	0,00	0,00	0,00	0,00	0,00
10:00	16,50	16,50	5,66	3,00	3,00	0,00	0,00	0,00	0,00
11:00	16,50	16,50	6,81	3,00	3,00	0,00	0,00	0,00	0,00
12:00	16,50	16,50	6,41	3,00	3,00	0,00	0,00	0,00	0,00
13:00	16,50	16,50	6,53	3,00	3,00	0,00	0,00	0,00	0,00
14:00	16,50	16,50	7,46	3,00	0,00	0,00	0,00	0,00	0,00
15:00	16,50	16,50	6,78	3,00	3,00	0,00	0,00	0,00	0,00
16:00	16,50	16,50	5,85	3,00	3,00	0,00	0,00	0,00	0,00
17:00	16,50	16,50	6,45	3,00	3,00	0,00	0,00	0,00	0,00
18:00	16,50	16,50	7,61	3,00	3,00	0,00	0,00	0,00	0,00
19:00	16,50	16,50	8,00	7,95	3,00	3,00	0,00	0,00	0,00
20:00	16,50	16,50	8,00	6,84	3,00	3,00	0,00	0,00	0,00
21:00	16,50	16,50	8,00	5,40	3,00	3,00	0,00	0,00	0,00
22:00	16,50	16,50	8,00	4,23	3,00	0,00	0,00	0,00	0,00
23:00	16,50	16,50	8,00	3,09	3,00	0,00	0,00	0,00	0,00
00:00	16,50	16,50	7,97	3,00	0,00	0,00	0,00	0,00	0,00

In this case, the spinning reserve is specified as 10% from the load, mutation probability 0.8, and maximum iteration 500 times. The iteration process will achieve convergence to get the

least total operating costs of the microgrid system with the RES generator shown in Fig. 6. It has been shown here that the process of obtaining low operating costs is carried out properly using genetic algorithm techniques.

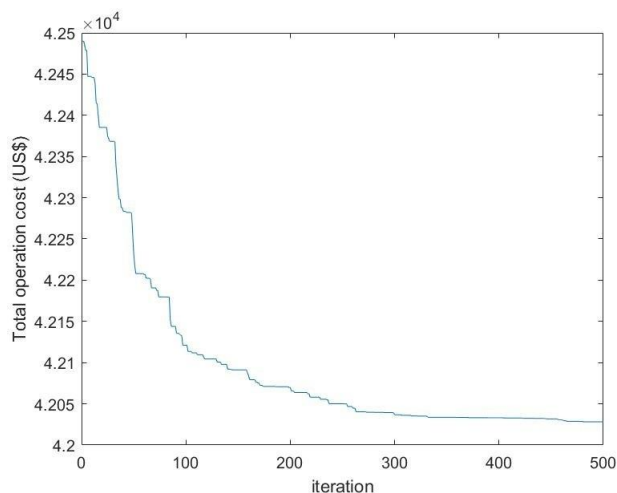


Fig. 6 GA convergence for the interconnected configuration

The results obtained for implementing the PL + GA algorithm in managing the unit operating schedule to meet the electrical load requirements are shown in Fig. 7.

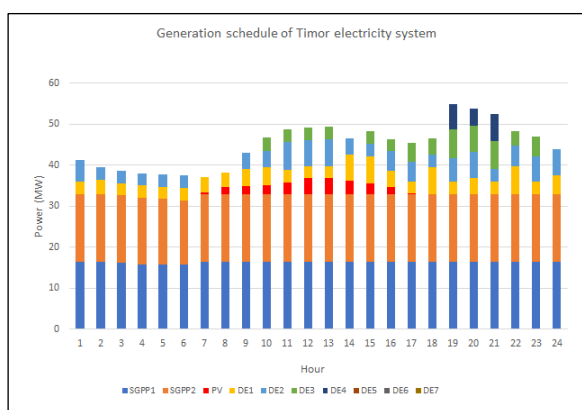


Fig. 7 Generation schedule of Timor Microgrid system using PL+GA optimization

As a comparison, the PL and GA algorithms' efficacy and efficiency are then compared with the PL algorithms. The results of calculations using the two algorithms are shown in TABLE V, which shows that using the PL and GA algorithms gives the least operating costs, even though the time is a little longer. These results can prove that to optimize unit commitment implementation on the island power system with the RES generator, PL and GA algorithms may be used for better and more accurate results in a relatively short time.

TABLE V Comparison of optimization techniques

Method	Total fuel cost (\$)	Total operational cost (\$)	Elapsed time (s)
PL	3.9885e+04	4.2049e+04	1.6566
PL+GA	3.9447e+04	4.2028e+04	1.9581

VI. CONCLUSIONS

In this paper, we propose a unit commitment solution using an optimization algorithm of the improved priority list and genetic algorithm, considering the contribution of renewable energy generation in the microgrid power system. In the microgrid system, to obtain appropriate and better optimization results for implementing the unit commitment, the priority list algorithm and genetic algorithm are applied. In order to simulate the effectiveness of the PL + GA algorithm, computation time and operating costs are compared with other optimization methods for deterministic cases. Here, the PL + GA algorithm shows better performance compared to other optimization methods. For this reason, the use of a combination of this optimization algorithm can be suitable for application in microgrid systems with renewable energy generators. As the regulator, the government can also determine and recommend this method as a solution for supplying electricity in remote areas and islands. In this study, it can also be seen that the penetration of renewable energy sources can help alleviate the cost of supplying electricity and stringent reserve requirements.

ACKNOWLEDGMENT

We thank Mr. Muhammad Yasirroni, research assistant from University of Gadjah Mada, Yogyakarta, Indonesia, for assistance with technical coding and MATLAB programming of the simulation model in this paper.

VII. REFERENCES

- [1] PT PLN (Persero), "Indonesia Electricity Supply Business Plan 2016-2025," PT PLN (Persero), Jakarta, Indonesia, 2016.
- [2] K. M. Banjar-Nahor, L. Garbuio, V. Debusschere, N. Hadjsaid and T.-T.-H. Pham, "Study on Renewable Penetration Limits in a Typical Indonesian Islanded Microgrid Considering the Impact of Variable Renewables Integration and the Empowering Flexibility on Grid Stability," in *2018 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe)*, Sarajevo, 2018.
- [3] E. Zafeiratou and C. Spataru, "Sustainable island power system – Scenario analysis for Crete under the energy trilemma index," *Sustainable Cities and Society*, vol. 41, pp. 378-391, 2018.
- [4] I. Rendroyoko, N. I. Sinisuka and D. P. Koesrindartoto, "Optimizing Unit Commitment Schemes for Variable RES Power Plant Integration in Microgrid Systems," in *2019 2nd International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*, Denpasar, 2019.
- [5] IRENA, "Transforming small-island power systems: Technical planning studies for the integration," IRENA 2018, Abu Dhabi, 2018.
- [6] M. Hand, S. Baldwin, E. DeMeo, J. Reilly, T. Mai, D. Arent, G. Porro, M. Meshek and D. Sandor, "Renewable Electricity Futures Study (Entire Report)," National Renewable Energy Laboratory, 2012.
- [7] J. P. Fossati, "Unit Commitment and Economic Dispatch in Micro grid," University of Montevideo, Montevideo, Uruguay, 2012.
- [8] L. Sigrist, E. Lobato, F. M. Echavarren, I. Egido and L. Rouco, *Island Power Systems*, Boca Raton, FL: CRC Press, 2016.
- [9] S. Crossa, D. Padfield, R. Ant-Wuorinen, P. King and S. Syri, "Benchmarking island power systems: Results, challenges, and solutions for Long Term Sustainability," *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 1269-1291, 2017.
- [10] K.-H. Jo and M.-K. Kim, "Improved Genetic Algorithm-Based Unit Commitment Considering Uncertainty Integration Method," *Energies*, vol. 11, p. 1387, 2018.

- [11] S. Kazarlis, A. Bakirtzis and V. Petridis, "A genetic algorithm solution to unit commitment problem," *IEEE Transaction on Power System*, vol. II, no. I, pp. 83-90, 1996.
- [12] S. Salam, "Unit Commitment Solution Methods," *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, vol. 1, no. 11, 2007.
- [13] M. F. Anjos and A. J. Conejo, Unit Commitment in Electric Energy System, Hanover, MA 02339: Foundation and Trends in Electric Energy System, 2017.
- [14] H. Liang and H. Gooi, "Unit commitment in microgrids by improved genetic algorithm," in *IEEE conference proceedings IPEC'10*, Singapore, 2010.
- [15] K. S. Swarup and S. Yamashiro, "Unit Commitment Solution Methodology Using Genetic Algorithm," *IEEE Transactions on Power Systems*, vol. 17, no. 1, pp. 87-91, 2002.
- [16] S. Y. Abujarad, M. Mustafa and J. Jamian, "Recent approaches of unit commitment in the presence of intermittent renewable energy resources: A review," *Renewable and Sustainable Energy Reviews*, vol. 70, pp. 215-223, 2015.
- [17] Sarjiya, A. Mulyawan and A. Sudiarso, "Unit Commitment Solution Using Genetic Algorithm Based on Priority List Approach," *Journal of Theoretical and Applied Information Technology*, vol. 72, pp. 394-403, 2015.
- [18] H. S. Madraswala and A. S. Deshpande, "Genetic Algorithm Solution to Unit Commitment Problem," in *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Delhi, India, 2016.
- [19] E. Delarue, D. Cattrysse and W. D'haeseleer, "Enhanced priority list unit commitment method for power systems with a high share of renewables," *Electric Power Systems Research*, vol. 105, pp. 115-123, December 2013.
- [20] Y. Tingfang and T. O. Ting, "Methodological Priority List for Unit Commitment Problem," in *International Conference on Computer Science and Software Engineering*, Hubei, China, 2008.



Ignatius Rendroyoko (Member, IEEE) was born in Semarang, Indonesia in 1970. He graduated from the Institute Technology of Bandung (ITB), Indonesia in 1994 and served as an electrical engineer in PLN since 1995. After completing his M.Eng.Sc. Degree in Monash University - Australia in 2002, he is currently active in power distribution technology and implementation

asset management and smart grid development initiatives in PLN. Since 2016 he is taking a Ph.D. program in ITB, with specific research field on the integration of RES generation with intermittent characteristics in microgrid power system.

This author became a Member (M) of IEEE since 2017.



Second B. Author was born in Medan, North Sumatera, Indonesia, in 1950. After graduating from ITB with a degree in Electrical Engineering in 1974, he completed Masters and Doctorates in Electronique, Institute National Polytechnique de Grenoble, France and Electronique, Electrotechnique, Automatique, Universite Paul Sabatier-Toulouse III, France. He is currently working as a Full Professor and Senior Lecturer in the School of Electrical Engineering and Informatics in ITB. His research interests include electrical insulation, maintenance engineering, economic of electrical energy system, statistics and optimization theory and its applications, and risk analysis.



Vincent Debuschere

G2Elab, University Grenoble Alpes, CNRS, Grenoble INP (Institute of Engineering University Grenoble Alpes), Grenoble, France.

Vincent Debuschere (Member, IEEE) received the PhD degree in ecodesign of electrical machines from the Ecole Normale Supérieure de Cachan, Cachan, France, in

2009. He joined the Electrical Engineering Laboratory, Grenoble Institute of Technology, in 2010 as an associated professor. His research interests include renewable energy integration, modeling of flexibility levers for smart grids, multi-criteria assessment, and optimal design of complex systems.



Deddy P. Koesrindartoto was born in Jakarta, Indonesia, in 1970. He graduated from the Institute Technology of Bandung (ITB), Indonesia in 1993 as electrical engineer. He is an Economist by training, received a Ph.D. in Economics with a minor in Statistics, and an MSc. in Industrial Engineering, from Iowa State University, USA. He is currently working

as an Assistant Professor at the School of Business and Management, the Institute Technology of Bandung (SBM ITB). His research interests include energy services industries, corporate finance, investment management, capital markets, statistics for business, and complex adaptive system.