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

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*Abstract:* Integration of renewable energy generators with existing electrical power systems is an effective strategy to strengthen energy security in islands and remote areas. However, in the case of high penetration of renewable energy sources (RES), operations and economic aspects must be considered. One of the power plant integration schemes is the Unit Commitment (UC), a daily scheduling method to achieve optimization goals while still meeting various operational, environmental, and technical constraints. However, the existing UC method is a generic one, therefore it is necessary to develop an optimization method with a new approach based on improved PL-GA to manage the generation scheduling in microgrid power systems. The proposed solution method is the PL-GA Algorithm, an improvement from the previous studies, with optimization on economic dispatch using GA. This algorithm uses a simple and fast PL technique for the generation scheduling and dispatch stages to obtain the initial population. Then, an accurate and more flexible GA technique is used for the economic dispatch stage to avoid local optima to get the lowest total operating costs. This method has been simulated on the electricity system in Eastern Indonesia, a developing electricity system with intermittent RES power plants with good results.

*Keywords*: Integration of RES, unit commitment, optimization techniques, priority list, genetic algorithm, economic dispatch

## 1. Introduction

Referring to the Indonesian government's program to encourage economic growth in eastern Indonesia, the development of the electricity infrastructure in Maluku, Papua, and Nusa Tenggara has been significantly encouraged. The development of electricity supply for islands and remote areas is carried out by utilizing local energy potentials using renewable energy sources (RES) [1]. Recently, renewable energy plants have been carried out in the eastern part of Indonesia, requiring affordable and sustainable electricity [2, 3].

Efforts to provide electricity infrastructure in developing countries like Indonesia, especially for islands and isolated areas, are generally carried out by providing a microgrid system with diesel generators [4, 5]. Generally, most islanded microgrid power systems rely on diesel generators for their electricity supply due to flexibility, fast operation, and minimum technicality, but high operating costs [6]. Along with the development of RES technology and the program to reduce fuel oil consumption, the integration of RES is increasingly being intensified. In operation, RES power plants are usually interconnected with other generators in the existing microgrid system. Moreover, in some cases, the RES power plant may cause power system instability due to its intermittency characteristics [7]. As the RES penetration of many microgrid systems is likely to increase in the future, anticipatory steps in the operation of the electrical system must be prepared immediately [8, 9]. 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]. In 2016, a solar photovoltaic (PV) plant was developed in Timor Island, East Nusa Tenggara, Indonesia, which became the largest-scale PV plant in Indonesia at that time [1].

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Electricity from this plant strengthens the power supply to the Timor power system, which steam-generated power plants and diesel engines mainly supply. However, due to the intermittency characteristics of PV plants, several times it has caused instability of the power system. For this reason, the Timor electric power system is selected as a case study in this paper.

One method that can create operational flexibility for a power system to vary the RES generator supply is the unit commitment method (UC) [11, 12, 13]. The UC method regulates the operation of the power system by determining the electrical operation schedule for each generating unit in a power system, including RES, to fulfill the load requirement at a minimal cost. As a result, the UC must meet several system demands, backup requirements, and other limitations optimally and keep operating costs low in operation. On the other hand, changes in the load and output power of the intermittent RES generator also cause variability, which affects the UC settings. Considering these conditions, the UC must arrange and ensure the availability of spinning reserves of sufficient and reliable capacity to meet the load requirements. Furthermore, uncertainty about intermittent RES generator primary energy availability can cause instability in the power system. Therefore, implementing the UC scheme in power systems with intermittent RES requires optimization techniques to obtain the lowest operational costs.

Numbers of optimization techniques have been developed to find suitable solutions for implementing the unit commitment, such as priority list (PL), dynamic programming (DP), Lagrangian relaxation, Genetic algorithm (GA), etc. GA is one of the stochastic techniques that can be used to provide solutions to UC problems. Given that UC is a non-convex, non-linear, and mixed-integer problem, the GA method is believed to be a suitable solution for large non-linear engineering optimization problems such as UC. On the other hand, the priority list (PL) is one of the optimization techniques used to solve UC problems. It has the characteristics of simple, fast, and easy to combine with other methods. In one of the studies, Delarue (2017) has proven that PL can work well in electric power systems with intermittent RES generators under low load conditions [14]. This study result may become the reason for using the PL-GA algorithm in UC optimization on microgrid systems with an intermittent RES generator [7]. Many studies have been carried out by combining several methods to solve this UC problem, namely the priority list-based GA (PLGA) [15, 16], the GA and Lambda relaxation (GALR) [17, 18, 19], and the extended PL (EPL) [20]. In the research with the algorithm above, there are still some things that can be improved. For example, the UC study using the PLGA algorithm for UC and lambda iteration for ED may suffer local optima. Also, in the study using the extended priority list (EPL), the results may be more suitable for small and simple electrical systems.

This paper aims to set up an optimization algorithm for the unit commitment scheme to integrate intermittent RES power generation into the existing microgrid electricity system. The proposed new method is the PL-GA algorithm with an approach in generation scheduling and dispatch stages using a simple and fast priority list (PL) technique to obtain the initial population. The initial population is obtained from a combination of one individual from the best chromosomes (inherited) from the PL process and random collections from this process. Furthermore, the economic dispatch stage uses an accurate and flexible GA technique to avoid local optima in obtaining the lowest total operating cost. With this optimization algorithm, the arrangement of the operating schedule of the generating units by the microgrid's intelligent control system can be carried out to meet the electricity supply requirement with the lowest operating costs. Finally, a simulation model was developed based on the Timor power system to assess the algorithm as a reference for the implementation of UC for islands microgrid system. The paper is structured as follows. The Concept of UC is described in Section 2, including RES conditioning and optimization algorithms for UC. Section 3 presents the application of the UC in the microgrid system. The UC procedures based on the PL-GA algorithms are described in Section 4. The simulation studies results are described in Section 5, along with an analysis of operating cost, SR requirements, and computation time. Conclusions are drawn in Section 6.

## 2. The Unit Commitment Concept

*A. The 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 [13]. Optimization of the UC implementation is subject to several constraints such as power balance, spinning reserves, and individual constraints such as unit output limits, ramp rates, and minimum up/down hours. The UC scheme in power systems with RES generation is shown in Figure 1 below.

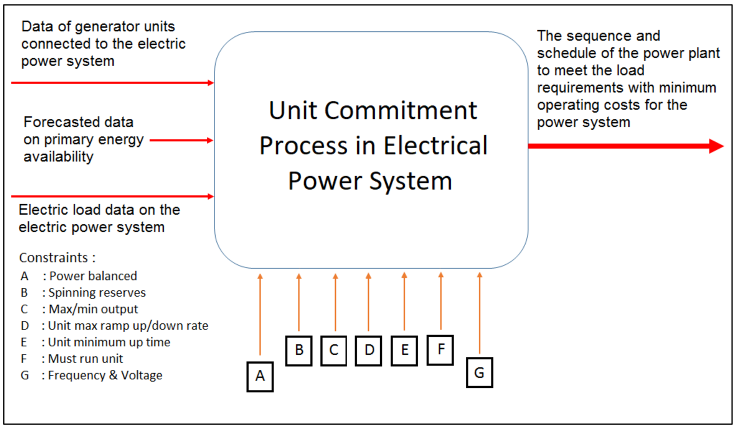


Figure 1. Flow chart of unit commitment in electric power system

In electrical power systems, the main purpose of UC implementation is to minimize the total operation cost (TOC) [10].

$$Minimize\ TOC = \sum_{t=1}^{T} \sum_{i=1}^{N} (U_{it}.F_{it}(P_{it}) + U_{it}.S_{it}) \quad (1)$$

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 |
| $U_{it}$ | On/off status of i unit at time t, (1: unit is on, 0: unit is off), |
| $F_{it}(P_{it})$ | fuel cost function of the i-th unit, with i-th unit start-up cost at t-hour, where $a_i$, $b_i$, $c_i$ fuel cost coefficient, |
| $P_{it}$ | Power output, generation output from the i-unit at t-hour, |
| $Pmax_i$ | maximum generated output power of i-th unit, |
| $Pmin_i$ | minimum generated output power of i-th unit |
| $S_{it}$ | start-up cost of i-th unit at t-th hour, |
| $D_t$ | load requirement, |
| $U_n$ | maximum output of unit n |
| N | number of power generating units, |
| t, T | time, total period of time |
| $SR_t$ | spinning reserve at t-th hour, |
| $RU_i, RD_i$ | ramp-up, ramp-down of i-th unit |
| $MUT_i, MDT_i$ | minimum up time, minimum down time of i-th unit |

In equation (1) above, there are two functions used; first is the fuel cost per MW, as follows:

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

And the second is start up cost of generator unit :

$$S_{it} = \begin{cases} HSC_i, if\ MDT_i < T_{offi} \leq MDT_i + T_{co} \\ CSC_i, if\ T_{down,i} < MDT_i + T_{cold,i} \end{cases} \quad (3)$$

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

1. Power balance
The power generation always be equal to the customer's load requirement.

$$\sum_t \sum_i (P_{it}.U_{it}) = D_t \quad (4)$$

2. Spinning reserve (SR)
The total power generated must be greater than the sum of load and spinning reserve to ensure the stability of the power system. The total SR must be larger than 10% of the load requirement.

$$\sum_t \sum_i \left(U_{it}.Pmax_i - P_{t,n}\right) \geq 10\%\ D_t \quad (5)$$

$$\sum_{i=1}^{N} (U_{it}.Pmax_i) \geq (D_t + SR_t), 1 \leq t \leq T \quad (6)$$

3. Power generating limit
The maximum and minimum limit of active power generated:

$$Pmin_i.U_{it} \leq P_{it} \leq Pmax_i.U_{it} \quad (7)$$

4. Minimum up/downtime
The minimum time on/off limits of generating units.

$$T_{on}(i,t) \geq MUT(i), if\ U(i,+1)\ must\ be\ off \quad (8)$$

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

5. Ramp up/downtime
The generating unit's time limit to be ready for full operation (ramp-up) or time to go inoperative (ramp-down).

$$P_{i,t} - P_{i,t-1} \leq RU_i,\ if\ power\ increase \quad (10)$$

$$P_{i,t-1} - P_{i,t} \leq RD_i,\ if\ power\ decrease. \quad (11)$$

6. Must run units
The RES plants are treated as a must-run unit and directly calculated into the power system.

$$P_{RE}(t) = P_{output}(t) \quad 0 \leq t \leq 24 \quad (12)$$

7. System's Frequency and voltage
Limits of system frequency and voltage are :

$$\mathrm{V}^{\mathrm{min}} \leq \mathrm{V} \leq \mathrm{V}^{\mathrm{max}} \quad (13)$$

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

*B. UC with intermittent RES plant*

For electric power systems with RES, such as solar PV and wind turbine power plants, the operating arrangements of each generating unit are formulated in the form of constraints as stated in the previous section, adjusted to its primary energy availability [21]. 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 present considerable variability.

In preparing the UC implementation, the readiness of the RES power plant must also be considered according to the availability of primary energy. For intermittent RES, weather forecasting, historical data, and analysis are critical in preparing the generation schedule. With accurate 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. Thus, the output of solar PV can be presented as [21]:

$$P_V = \begin{array}{ll} 0, & G < G_i \\ \mu.G, & G_i \ll G < G_{rate} \\ P_{rate,} & G \gg G_{rate} \end{array} \quad (15)$$

$P_v$ is the power output of solar PV, $G_{in}$ and $G_{rate}$ denote the minimum and rated insulation, and $\mu$ is the 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].

$$Net\ Load = Load - P_V \tag{16}$$

Due to the RES 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.

## 3. Optimization method for unit commitment

The UC has two main interconnected parts: the operation scheduling of generating units (UC) and the economic dispatch (ED) [22]. 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/down time.

On the other hand, GAs are characterized by exhaustively explore the search space, thereby ensuring the possibility of finding a solution close to the optimum. Furthermore, 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 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. Therefore, the combination of the PL-GA methods could be an alternative option for UC optimization.

## 4. Overview of Timor electricity power system

The Timor power system is an electrical system that supplies electricity to customers in Timor Island, East Nusa Tenggara province, Indonesia [1]. This electrical system was developed based on a microgrid system with diesel-powered power plants, 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 27.5%, which means that most of the power plants still use fuel oil, so RES development is still very potential. The operation of this power system is carried out to meet the load requirements based on a merit order. Since 2016, Timor power systems operate 5 MWp Solar PV plants and contribute to electric power production.

The single line diagram of the Timor power system can be seen in Figure *2*, and the list of generating units is described in Table 1. In this study, we built a simulation model of a power system with reference to the Timor power system, East Nusa Tenggara, Indonesia [1]. The Timor 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.

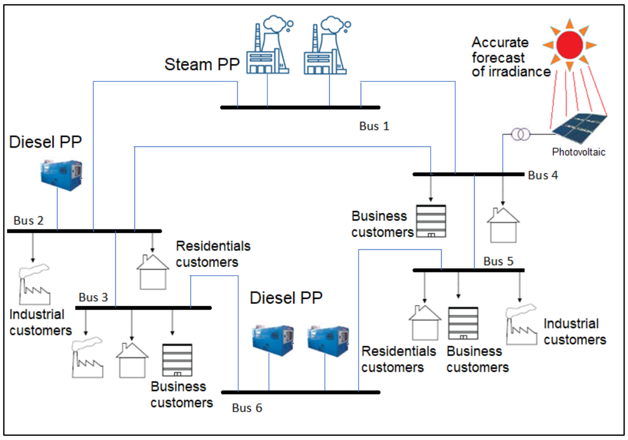


Figure 2. Timor electricity power system

Table 1. Data of Power generations on Timor power system

| | SG1 | SG2 | PV3 | D4 | D5 |
|---|---|---|---|---|---|
| Pmax (MW) | 16 | 16 | 5 | 8 | 8 |
| Pmin (MW) | 10 | 10 | 0 | 3 | 3 |
| a ($/MW^2h) | 0.09928 | 0.09800 | - | 0.08 | 0.08 |
| b ( $/MWh) | 7.6233 | 8.0433 | - | 61.60 | 61.9 |
| c ($/hour) | 896.77 | 890.92 | - | 619.0 | 619.0 |
| MUT (hour) | 8 | 8 | 1 | 1 | 1 |
| MDT (hour) | 8 | 8 | 1 | 1 | 1 |
| HSC ($) | 9500 | 9500 | - | 100 | 100 |
| CSC ($) | 15700 | 15700 | - | 500 | 500 |
| CS (hour) | 0 | 0 | 0 | 0 | 0 |
| IS (hour) | -1 | -1 | -1 | -1 | -1 |
| | **D6** | **D7** | **D8** | **D9** | **D10** |
| Pmax (MW) | 8 | 8 | 4 | 4 | 4 |
| Pmin (MW) | 3 | 3 | 1 | 1 | 1 |
| a ($/MW^2h) | 0.09 | 0.085 | 0.025 | 0.025 | 0.025 |
| b ($/MWh) | 61.9 | 61.9 | 96.60 | 95.60 | 96.60 |
| c ($/hour) | 619.0 | 619.0 | 755.4 | 755.4 | 755.4 |
| MUT (hour) | 1 | 1 | 1 | 1 | 1 |
| MDT (hour) | 1 | 1 | 1 | 1 | 1 |
| HSC ($) | 100 | 100 | 80 | 80 | 80 |
| CSC ($) | 500 | 500 | 150 | 150 | 150 |
| CS (hour) | 0 | 0 | 0 | 0 | 0 |
| IS (hour) | -1 | -1 | -1 | -1 | -1 |

*Information: SG1, SG2: steam generated power units, PV3: Solar PV, D4 – D10: Diesel units*

In addition to system data, the forecast data for the power output of solar PV plant is shown in Table 2 below:

Table 2. Output of a solar PV plant

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| PV (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0,460 | 1,733 |
| Hour | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| PV (MW) | 2,534 | 2,907 | 2,883 | 3,800 | 3,805 | 3,420 | 2,500 | 1,600 |
| Hour | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| PV (MW) | 0,100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Timor electric power systems' load profile is shown in Figure 3, which shows the typical characteristics of electricity use in developing areas.

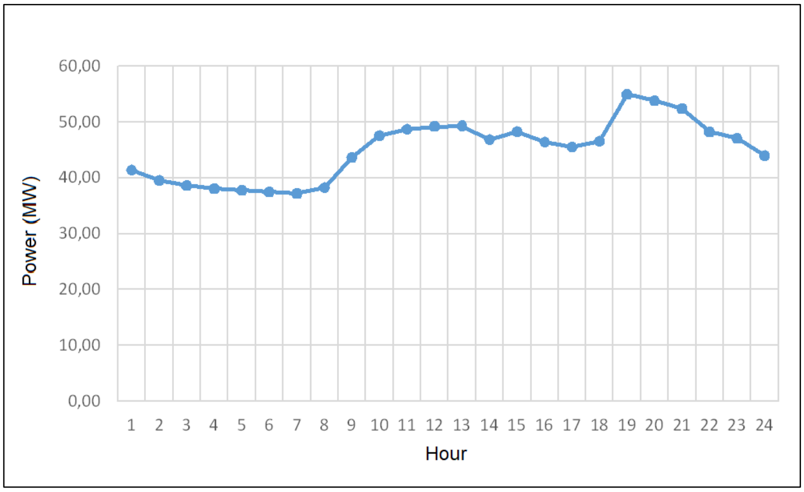


Figure 3. Load profile of Timor electricity system

**5. The Proposed Methodology of PL & GA Algorithm**

As explained in the previous paragraph, the calculation of the solution for UC in a microgrid system with RES plant is carried out in two parts: the generation scheduling problem (UC) and the economic dispatch (ED) problem [21]. This optimization process for UC begins with the PL technique to get the initials population.

The proposed method is the PL-GA algorithm, which is an improvement from previous studies. The algorithm begins with UC and the economic dispatch stage using the priority list. The calculation of the priority list of generating units is carried out based on each unit parameter. Generators with higher capacity will receive higher priority. Units are committed with the highest priority (lowest cost), one after the other, until the load demand plus the SR requirements are fulfilled in the priority list order during every time interval [23]. The HR calculation is given in (17). The priority list of generating units can be checked by checking the Pmax and HR values. The PL and calculated heat rate are shown in equations (17) and (18).

$$HR_i = \frac{F_i(P_{imax}(t))}{P_{imax}(t)} \tag{17}$$

$$Cost_i = HR_i \times F_i P_{ih} \tag{18}$$

After the initial chromosomes for the UC process are obtained, the next is the calculation of dispatch using the PL method to minimize total operation cost. The result here is the chromosome scheduling from the PL method, which contains each generating unit's operational status and power output as the initial populations. The PL method results are shown in
*Table* 3 and 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 load requirement. Finally, the initial population for the GA dispatch problem is formed using one chromosome using the solution of priority-based dispatch (inheritance) while letting the rest of the population in random.

Once the initial population has been achieved, it is followed by evaluating 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 fulfilled so that individuals can enter the load dispatch stage. If these constraints cannot be met, the individual will be given a calculated penalty.

Table 3. Generator units scheduling from PL

| Hour/ Unit | SG1 | SG2 | D4 | D5 | D6 | D7 | D8 | D9 | D10 |
|---|---|---|---|---|---|---|---|---|---|
| 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 | 1 | 0 | 0 | 0 | 0 | 0 |
| 08:00 | 1 | 1 | 1 | 1 | 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 | 1 | 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 | 0 | 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 |

After the load dispatch stage is completed, each individual will enter the process of calculating the fitness function. The penalty function (PF) is the multiplication of the penalty factor ($P_{fc}$) and penalty count ($P_c$) (19). 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 (20).

$$PF = P_{fc} \times P_c \quad (19)$$

$$Fitness = \frac{1}{startup\ cost + fuel\ cost + PF} \quad (20)$$

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 2 (two) individuals at random and recombining them with probability $P_R$. After recombination, the next stage is mutation. 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 Pm. 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. Then, 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 are preserved with the lowest total operating costs.

The novelty of this research is the PL-GA algorithm, which is an improvement from previous optimization algorithm studies. The algorithm begins with UC and the economic dispatch stage using the priority list. Then, it further optimized the economic dispatch using a GA with the objective to minimize total operating costs. For the GA dispatch problem, the UC schedule is fixed based on the solution of the previous stage. The GA dispatch problem utilizes PL-based dispatch as the basis by initializing one chromosome using a priority-based dispatch (inheritance) solution, while the other populations are collected randomly. The flow chart process of the proposed algorithm PL-GA is shown in Figure *4* below.

This computational process is coded and simulated in MATLAB R2020a and Jupyter. The results of the convergence check will produce the optimal value of the UC implementation.

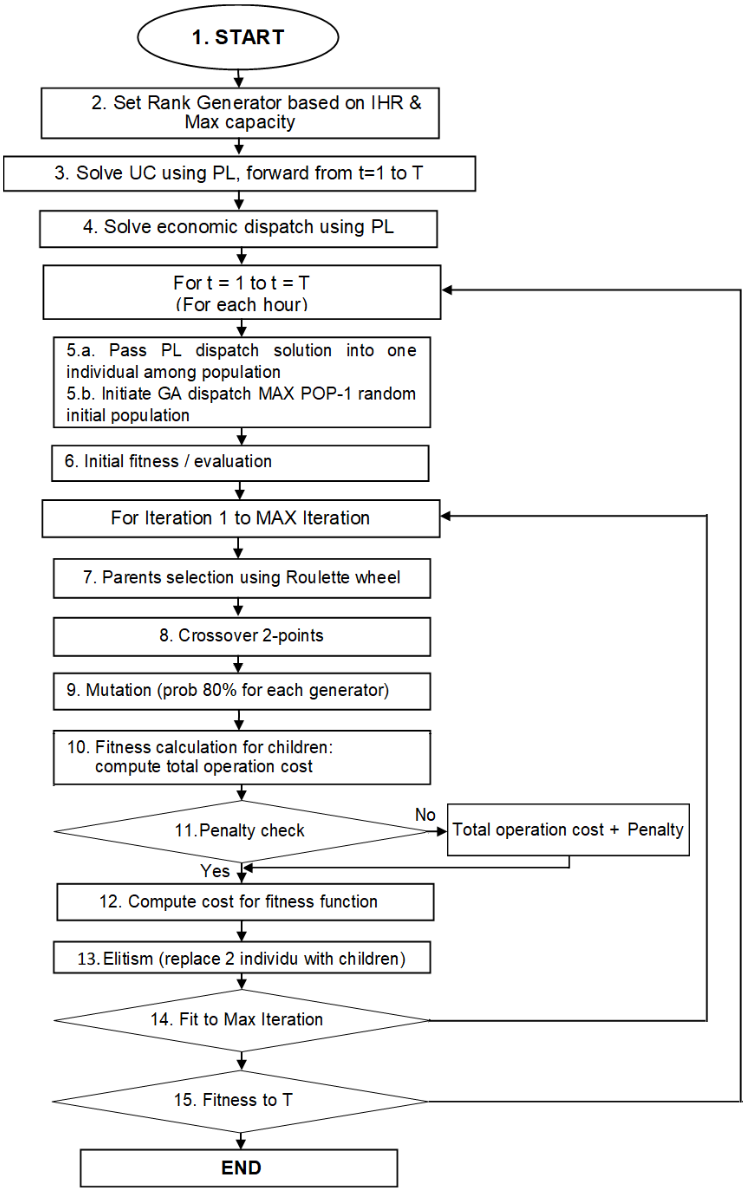

Figure 4 Framework flow chart of PL-GA algorithm

## 6. Simulation Results

A microgrid system simulation model has been prepared to test the proposed UC algorithm. The simulated microgrid consists of steam generating units, dispatch-able 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 rates for each generator are modeled with a quadratic function for fuel costs and start-up costs, as shown in Table 1. 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 1. The time-based solar photovoltaic power output forecast is used to calculate the UC setting (see Table 2). The optimal UC schedule together with dispatch is shown in
Table 4 and Figure *6*, and here it can be seen that the obtained UC schedule meets all constraints and produces a quality solution.

Table 4. Best dispatch power production of generator units

| Hour | SG1 | SG2 | PV | D4 | D5 | D6 | D7 | D8 | D9 | D10 | Load | TOC ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **01** | 15.66 | 13.73 | 0.00 | 0.00 | 3.00 | 3.00 | 3.00 | 3.00 | 0.00 | 0.00 | 41.39 | 4369.68 |
| **02** | 16.00 | 16.00 | 0.00 | 0.00 | 4.55 | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 39.55 | 4175.42 |
| **03** | 16.00 | 16.00 | 0.00 | 0.00 | 3.63 | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 38.63 | 4078.30 |
| **04** | 16.00 | 16.00 | 0.00 | 0.00 | 3.08 | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 38.08 | 4020.23 |
| **05** | 16.00 | 15.76 | 0.00 | 0.00 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 37.78 | 3988.56 |
| **06** | 16.00 | 15.38 | 0.00 | 0.00 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 37.48 | 3956.89 |
| **07** | 16.00 | 14.74 | 0.46 | 0.46 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 37.20 | 3927.33 |
| **08** | 16.00 | 14.53 | 1.73 | 1.73 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 38.26 | 4039.24 |
| **09** | 16.00 | 16.00 | 2.00 | 2.00 | 6.12 | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 43.65 | 4608.28 |
| **10** | 16.00 | 16.00 | 2.05 | 2.05 | 6.66 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 47.57 | 5022.12 |
| **11** | 16.00 | 16.00 | 2.88 | 2.88 | 7.81 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 48.69 | 5140.37 |
| **12** | 16.00 | 16.00 | 3.80 | 3.80 | 7.41 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 49.21 | 5195.26 |
| **13** | 16.00 | 16.00 | 3.81 | 3.81 | 7.53 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 49.33 | 5207.93 |
| **14** | 16.00 | 16.00 | 3.20 | 3.20 | 5.46 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 46.88 | 4949.28 |
| **15** | 16.00 | 16.00 | 2.50 | 2.50 | 7.78 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 48.28 | 5097.08 |
| **16** | 16.00 | 16.00 | 1.60 | 1.60 | 6.85 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 46.45 | 4903.88 |
| **17** | 16.00 | 16.00 | 0.10 | 0.10 | 7.45 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 45.55 | 4808.86 |
| **18** | 16.00 | 16.00 | 0.00 | 0.00 | 8.00 | 3.61 | 3.00 | 0.00 | 0.00 | 0.00 | 46.61 | 4920.77 |
| **19** | 16.00 | 16.00 | 0.00 | 0.00 | 8.00 | 8.00 | 3.95 | 3.00 | 0.00 | 0.00 | 54.95 | 5801.25 |
| **20** | 16.00 | 16.00 | 0.00 | 0.00 | 8.00 | 7.84 | 3.00 | 3.00 | 0.00 | 0.00 | 53.84 | 5684.07 |
| **21** | 16.00 | 16.00 | 0.00 | 0.00 | 8.00 | 6.40 | 3.00 | 3.00 | 0.00 | 0.00 | 52.40 | 5532.04 |
| **22** | 16.00 | 16.00 | 0.00 | 0.00 | 8.00 | 5.23 | 3.00 | 0.00 | 0.00 | 0.00 | 48.23 | 5091.80 |
| **23** | 16.00 | 16.00 | 0.00 | 0.00 | 8.00 | 4.09 | 3.00 | 0.00 | 0.00 | 0.00 | 47.09 | 4971.45 |
| **00** | 16.00 | 16.00 | 0.00 | 0.00 | 5.97 | 3.00 | 3.00 | 0.00 | 0.00 | 0.00 | 43.97 | 4642.06 |

In this simulation, the generation data are taken from Table 1, with the spinning reserve set at 10% of the load, the population size of 30, the maximum iteration value of 200, a crossover probability of 1.0, and a mutation probability of 0.8. As a result, the iteration process will achieve convergence to get the lowest total operating costs of the microgrid system with the RES generator shown in Figure *5*. Furthermore, it is shown here that the process is carried out properly using GA techniques.

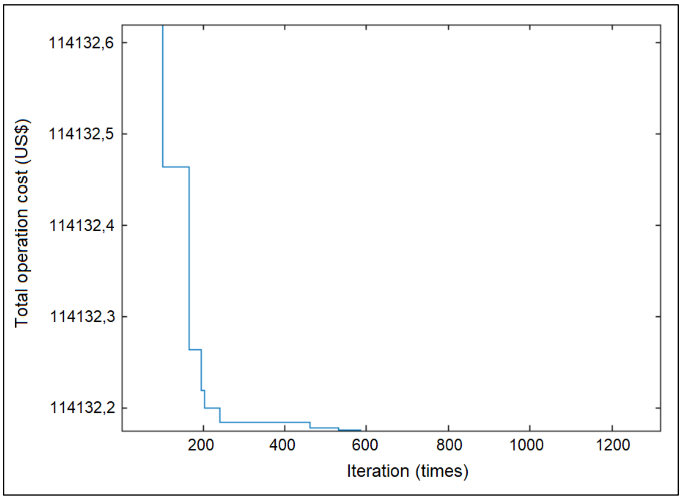


Figure 5. GA convergence for the interconnected configuration

The results obtained for implementing the PL-GA algorithm in managing the unit operating schedule to meet the electrical load requirements are shown in Figure *6*.

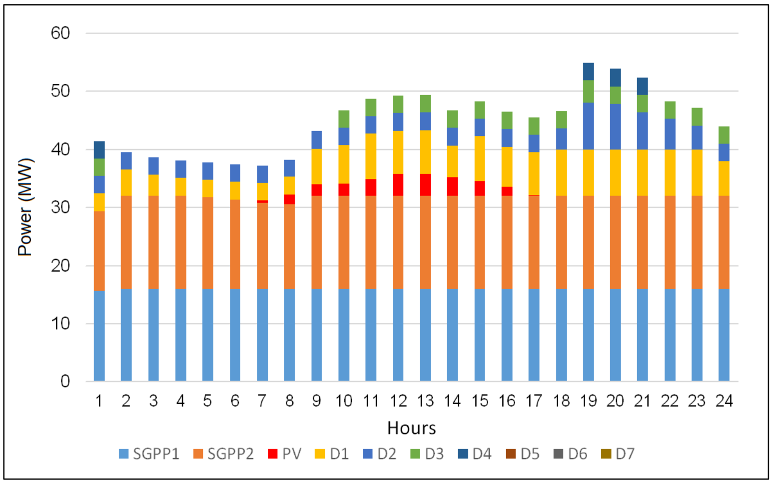


Figure 6 Generation schedule of Timor electricity system using PL-GA optimization

A comparative analysis was carried out between the simulation results with other methods and total operating costs realization (as the baseline). The effectiveness and efficiency of the PL-GA algorithms are then compared with the simulation model using the PL algorithm [14, 23] and the GA-LR-GA algorithm [19] and with total operating costs realization of the Timor power system. Table 5 shows that the PL-GA method turns out to have effective performance, can provide solutions that are close to optimal, and the computation time runs quite fast enough. Compared to the GA-LR-GA method, the calculation results of the proposed algorithm are slightly larger, but the runtime shows a much shorter time. The GA-LR-GA method does have the capability to provide optimal results but requires a long calculation time.

Table 5. Comparison of total operating cost

| Method | Total fuel cost ($) | Average Total operational cost ($) | Elapsed time (s) |
|---|---|---|---|
| Real TOC [1] | 125,916.12 | 179,880.17 | - |
| GA-LR-GA [19] | 109,493.08 | 113,378.48 | 630.05 |
| PL [14, 23] | 117,457.64 | 121,586.55 | 4.57 |
| PL-GA | 110,246.72 | 114,132.12 | 39.61 |

On the other hand, the proposed algorithm seems to give better results than the Priority List algorithm. The PL method is indeed very fast, but the resulting solution is sometimes not optimal. On the other hand, the use of the PL-GA algorithms provides least average operational costs, even though the time is a bit longer. The correctness of the simulation results of the PL-GA algorithm may also be validated by comparing it with the results of the calculation of the total operation cost realization. The TOC cost realization is obtained from the Levelized cost of energy (LCOE) of the Timor electric power system, and the comparison results show that the proposed optimization algorithm can provide significant operating cost-efficiency benefits.

From the simulation results and the discussion above, it can be justified that the PL-GA algorithm works well with the accuracy of the results are quite good and acceptable. Therefore, the PL-GA algorithm is feasible to implement the unit commitment method on the integration of the microgrid power system with the RES generator by providing accurate results in a relatively short time.

The availability of RES, in this case, solar energy, varies greatly, so several scenarios need to be made with variations in the integration of solar PV to the grid. In this condition, the proposed UC method's ability to overcome this variability is demonstrated. This simulation has been performed with multiple levels of PV penetration, as shown in Figure *7* below.

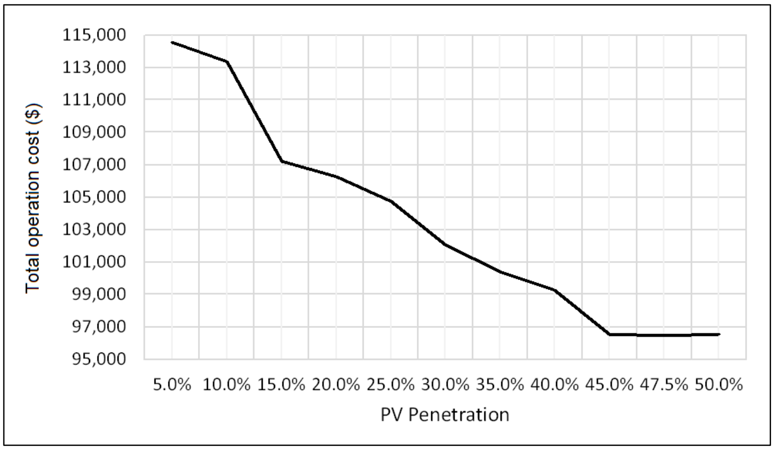


Figure 7. TOC with different PV Penetration

Figure *7* shows that the penetration of renewable energy sources reaches its optimal percentage at 47.5%, where the minimum total operating costs are achieved. When penetration was increased by more than 47.5%, it was found that the total cost increased. This is because the required SR has to be increased to ensure the reliable operation of the power system. The system resilience of 47.5% PV integration has proven that the PL-GA algorithm can work well considering the frequent occurrence of instability at 10% penetration. This condition is in line with the relationship between SR and TOC, as shown in Figure *8*.

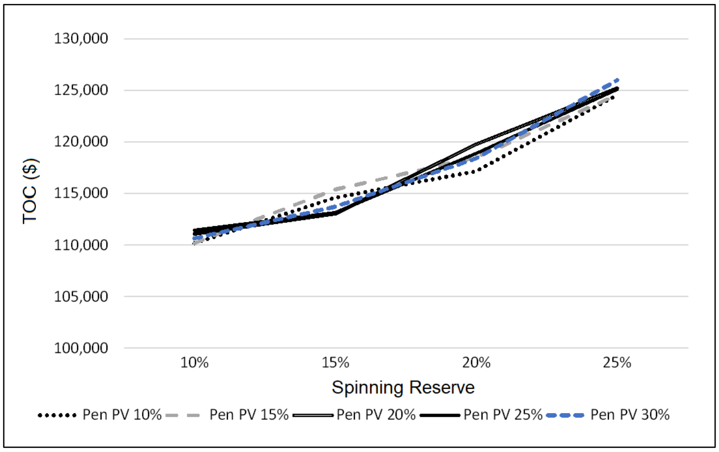


Figure 8. Effect of SR and PV Penetration to TOC

Figure 8 shows that spinning reserve (SR) comes at a cost. However, due to the Priority List (PL) algorithm, the exact value of SR can reduce the total cost (because it forces the PL to turn on the unit which normally shuts down based on the PL).

Refer to the simulation results above, it is known that the optimization method using the PL-GA algorithm is feasible to be applied to a microgrid system with a RES generator. Of course, this action can be ascertained with several precautions such as rechecking all generating unit capability and daily load profiles, determining the required SR level, ensuring ramp rate capability of generating engines, and performance and reliability of control systems. These steps are precautionary measures to make sure the solution works properly.

## 7. Conclusions

In this paper, we propose a unit commitment solution using an optimization algorithm of the improved priority list and genetic algorithm (PL-GA), considering the contribution of RE generation in the microgrid power system. Research in this field is very needed to support the microgrid RES integration program for islands, and the existing optimization methods still have limitations and require improvement.

In the microgrid system, to obtain relevant and better optimization results for implementing the unit commitment, the priority list algorithm and genetic algorithm are applied. The solution approach uses a combination of PL and GA methods, where PL is a fast optimization technique, and GA can solve optimization problems simultaneously and has a global search technique to overcome variability and uncertainty. In order to justify the results of the PL-GA algorithm, the accuracy of the calculation results of operating costs and computational time has been compared with other optimization methods, namely the GA-LR-GA and PL methods. The PL-GA algorithm shows fairly good performance at a relatively low total operating cost and short computation time than other optimization methods. Considering these results, using a combination of PL-GA optimization algorithms can be feasible and suitable to be applied to a microgrid system with a RES generator. This algorithm can be practically implemented in microgrid intelligent control systems.

Utility companies, especially PLN, can apply this method to the microgrid control system to integrate the RES generator into the existing microgrid system. In this study, it can also be seen that the penetration of RES can help alleviate the cost of supplying electricity and stringent reserve requirements.

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