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SIMULATION OF UNIT COMMITMENT AND ECONOMIC DISPATCH USING HARMONY SEARCH ALGORITHM ON MICROGRIDS

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ABSTRACT

In the electricity operating system, generation scheduling is a very important part because it involves the problem of electricity system operational costs. The ideal generation schedule is a schedule that meets operating constraints, low operating costs while still meeting customer demands. This can be done by optimizing the generation schedule, namely determining units that operate with low operating costs, meet the physical requirements of the generator, and fulfill customer needs. Optimization can be done either by analytic mathematical methods or heuristic or metaheuristic search algorithms. This study uses the Harmony Search Algorithm method to obtain optimal generation scheduling. HSA is one of the currently developing algorithms because it has several advantages compared to other heuristic algorithms. HSA imitates a music concert that looks for the appropriate notes so that harmony occurs which produces beautiful sounding music. In this study, the HSA method was applied to microgrids to obtain optimal generation scheduling. Microgrids are characterized by their scattered generation components with types of generators originating from renewable energy such as Solar Cells, Wind Turbines, Energy Storage Systems, Fuel Cells, etc. The simulation results in this study show the best value obtained and the time used to obtain the best value.

Keywords:
Optimization, Generation Scheduling, Harmony Search, Microgrid, Renewable Energy.

INTRODUCTION

Generally, Microgrids are based on Renewable or environmentally friendly environment energy sources such as Solar Cell (Solar Photovoltaic),Wind Turbine Power, Micro Turbines, Combustion turbines, Stirling Engines, Geothermal System, Fuel Cell, Small hydropower[1],[2] and Energy Storage System such as battery, Super Capacitor, Low-and high-speed flywheel, Superconducting magnetic energy storage system (SMES)

The operation of Microgrid need a suit management, especially, related to Generation Scheduling. To achieve a low operating cost of generation, it is necessary to optimize the right generation scheduling, either by using analytical mathematical models or using heuristic or meta-heuristic models. One of the most widely used meta-heuristic models today is the Harmony Search Algorithm (HSA). In this study, using the Harmony Search algorithm to get the optimal generation scheduling.

The aim of this study is to apply the Harmony Search Algorithm (HSA) to Scheduling Generation Optimization and to obtain an optimal generation scheduling model on a microgrid using the Harmony Search Algorithm. The benefits of this research are that it can be used as a reference in the use of meta-heuristic algorithms for optimizing generation problems in the electricity system and also useful for further research that uses Artificial Intelligent as a problem-solving tool, especially the problem of optimizing operation and maintenance.

Microgrids

Microgrids are generally part of the Electric Power Distribution System or Medium Voltage Network and are located at the end of the Distribution Substation and within the microgrid there are generally various types of distributed energy resource units (DER) and various types of electricity and/or heat end users. DER units include Distributed Generation (DG) and Distributed Storage (DS) units with different capacities and characteristics. The point of connection of the microgrid electricity to the utility system, on the low-voltage bus from the substation transformer, is the Point of Command Coupling (PCC). Microgrids serve a wide range of customers, for example, residential buildings, commercial entities and industrial estates[3],[4].

There are two types of microgrid configurations used, namely AC microgrid and DC microgrid [5], However, AC microgrids configurations are widely and commonly used because to integrate into existing systems, AC microgrids have not undergone many modifications from the infrastructure side. These microgrids are usually characterized by a radial topology as this configuration has minimum impact on the grid operation as well as on the protection schemes normally adopted in distribution networks.

Generation Scheduling

Scheduling the operation of power plants in the electricity industry focuses on scheduling the company's generation facilities. With scheduling, what must be considered is the decisions that must be made, which plants will operate or which are online (committed) and the availability of generators, generating units incorporated in the system, and generating units that use fuel.

Economic Dispatch and Unit Commitment.

Inspired by the terms used in conventional electricity systems, some authors propose that Energy Management System (EMS) functions are divided into two categories [6], namely: *Unit Commitment (UC)* and *Economic Dispatch (ED).* Based on the time scale of the management cycle, the day-ahead scheduler and short-term/real-time dispatchers are possible. The agreed schedule takes into account inter-temporal parameters of each generator (*minimum run time, minimum down time, notification time, etc.)* but does not specifically define the level of production generated by the generating unit, which in this case, is determined a few minutes before the Dispatcher sends power. In the Short term/Real Time Dispatcher, it is based on short term load forecast information.

Although UC and ED are strongly interrelated, in some literature these linkages are rarely considered as a whole system. Furthermore, a surveillance control system that is applied to a microgrid using UC with a Rolling Horizon (RH) strategy[7]. UC-RH is expected to deal with the problem of reducing the influence due to uncertainty from forecasting or forecasting data used by MGSC/EMS. Data, including estimates of battery "charging" and "discharging" conditions, predictions of electricity/water consumption and power generation from renewable energy. The UC function in MGSC/EMS provides an optimal set-point for one prediction of the Rolling Horizon (T1/4 2 days) with a sampling time of 15 minutes. The ED function is used to set set-points over a shorter period (ie, 1 – 5 minutes) based on the results of electricity/water load measurements and generation from renewable energy.

Harmony Search Algorithm (HSA)

The Optimization Algorithm aims to get the best element in a selection group that meets predetermined limits [8]. The use of optimization algorithms to solve real-world problems began in the 1940s. Optimization algorithms have two main categories. The first category includes exact algorithms and the second category is heuristic or meta-heuristic algorithms. The meta-heuristic algorithm used in this study is an algorithm that can cover a wider range of problems.

Geem et al. [9] proposed a well-known population-based meta-heuristic algorithm, known as the Harmony Search Algorithm (HSA). This algorithm mimics the process of creating new harmonies in music to solve optimization problems. HSA has proven to provide outstanding results on a broad scope of optimization problems because of its ability to handle different optimization problems in various fields, such as university timelines[10], structural design[11], water distribution[12], and other research field. The main advantage of this algorithm is that it is easy to code and apply to various problems.

The ability of the HS algorithm to strike a balance between exploitative and explorative ranges is the reason for its strength and success. In the search for harmony, the exploitative range is mainly dominated by the Pitch Adjustment Rate (PAR) and bandwidth (BW), while the explorative range is basically controlled by the HS memory-accepting rate (HMCR).

The HS algorithm is applied to different areas because it has special advantages, namely HS only requires simpler mathematical operations compared to traditional heuristic algorithms, does not use prime sums or gradient searches for decision variables, and does not consider derived values because it uses stochastic inspection.

The HS algorithm process contains five main steps [9],namely:

Step 1: Initialize HS parameter values, such as HMCR, BW, PAR, number of iterations (NI), and HM size (HMS).
The objective of the optimization problem will be determined in this step, using either the maximum or minimum objective function $f(x_i)$, where x_i will be the possible solutions of N (N ∈ all decision variables x_i).

Step 2: The HM value will be initialized, as x_i in the upper and lower bound ranges, using the following equation:
$x_i = lowerbound + R_1 \times (upperbound - lowerbound)$.{$R_1$ is a random value (0 − 1)} (1)

Step 3: New harmonies are improvised using a combination of three main parameters: HMRC, PAR, and BW. Improvisation has two main steps, as shown in Algorithm 1.
First, two random values (a & b) will be made between (0 ~ 1), and if ($a > HMCR$), new value x_j will be made using Equation (1), as the resulting new vector (x'_j).
Second, if value ($a < HMCR$), random value of HM (x_i) will be chosen, and if value ($b < PAR$), x_i will be modified by using equation (2).
$x'_j = x_{new,j} \pm bw * rand$ (2)

Step 4: Memory is updated if a new vector is generated from the last step (x'_j) better than the worst vector in HM, based on the objective function.

Step 5: After each improvisation, the algorithm checks for termination criteria, such as the maximum number of improvisations, to end the search process. The pseudocode then describes the process of improvising the HS algorithm.

Objective Function

The problem of economical power delivery, which is used to minimize active power production costs, can generally be stated in equation (11) as follows [13]**:**

$$\boldsymbol{Min}\left[\sum_{i=1}^{n} \boldsymbol{F_i(P_i)}\right] \qquad (12)$$

$$P_{i,}^{min} \leq P_i \leq P_{i,}^{max}$$

and in general, $F_i(P_i)$ is a quadratic curve and its equation can be shown in equation (13):

$$F_i(P_i) = c_i + b_i Pi + a_i Pi^2 \qquad (13)$$

hence:

a_i, b_i, and c_i is a known coeffisient value

n : number of generator;
Pi : aktive power generated;
D : real power load;
P_L : real power losses.

Generation Output

If Lagrange function method and The Kuhn-Tacker condition is applied to Optimization Constraint, Economic Disatch proble can be reformulated as shown in Eqution (14)[6]:

$$\boldsymbol{L(P,\lambda) = \sum_{i=1}^{n} Fi(Pi) + \lambda(D + P_L - \sum_{i=1}^{n} Pi),} \tag{14}$$

And Equation (14) is rearranged, yield Eq. (15) as follow:

$$L(P,\boldsymbol{\lambda}) = \sum_{i=1}^{n} \boldsymbol{Fi(Pi)} - \boldsymbol{\lambda}\left(\sum_{i=1}^{n} \boldsymbol{Pi - PL}\right) + \boldsymbol{\lambda(D)} \tag{15}$$

$PFi(2a_iP_i+b_i)=\lambda$ for $P_i^{min} \leq P_i \leq P_{i,}^{max}$
$PF_i(2a_iP_i+b_i) \leq \lambda$ for $P_i = P_{i,}^{max}$
$PF_i(2a_iP_i+b_i) \geq \lambda$ for $P_i = P_{i,}^{max}$

where PF_i is *unit penalty factor*, as shown in Equation (16):

$$PF_i = \frac{1}{1 - \frac{\partial PL}{\partial Pi}} \tag{16}$$

Unit Commitment

Unit Commitment problem can be very difficult. As a theoretical exercise, let's postulate the following situation:

- We have to make a loading pattern for period M
- We have N units committed and ready to delivering
- M load levels and operating limits on N units such that each unit can supply an individual load and any combination of units can supply a load.

Next, assume we will build commits by means of enumeration (brute force). The total number of combinations we need to try every hour is shown in equation (17) below,

$$C(N,1) + C(N,2) + \ldots + C(N,N-1) + C(N,N) = 2^N - 1 \tag{17}$$

with $C(N,j)$: a combination of N items taken from j at a time shown in Equation (18), namely:

$$C(N,j) = \left[\frac{N!}{(N-j)!\,j!}\right] \tag{18}$$

$j! = 1 \times 2 \times 3 \times \ldots xj$

For the entire period in the interval M, the maximum number of possible combinations is $(2^N-1)^M$, which can be a terrible number to think about.

System Modelling [14]

Various kinds of modeling techniques have been developed by researchers to model the components of a network. The performance of each power plant is modeled both deterministically and through a probability approach.

PLTS *(Photovoltaic Modul)* [6]

A Photovoltaic Cell consists of several cells connected in series and parallel to obtain the desired terminal output voltage and current and exhibits non-linear I-V characteristics. The PV Cell equivalent model provides dynamic non-linear I-V characteristics. The current and voltage equations in the Solar Cell (PV Modul) under conditions affected by the illumination effect are stated in Equations (19) and (20).

$$I_a = N_p I_{1g} - N_p I_o \left(exp \frac{(V + IR_s}{V_t} - 1 \right) \tag{19}$$

$$V_t = (\frac{a\,k\,T_p}{q}) \tag{20}$$

The generated current is shown in Equation (21), namely:

$$I_{1g} = \frac{G}{G_r} [I_{lr} + m(T_c - T_r)] \tag{21}$$

which reverse saturation current from PV Cell is stated in Equations (22) and (23):

$$I_a = I_{or} (\frac{T_a}{T_p})^{3/n} exp \left(-b \left[(1/T_p) - (\frac{1}{T_r}) \right] \right) \tag{22}$$

$$I_{or} = \frac{I_{scr}}{\left[\exp \left({}^{V_{ocr}} / {}_{V_{tr}} \right) - 1 \right]} \tag{23}$$

Cell temperature can be calculated by using equation (24) as follow:

$$T_c = T_{air} + \left[\left(\frac{\tau\alpha}{U_i} \right) (1 - \frac{\eta}{\tau\alpha}) \right] G \tag{24}$$

where:

I_G = output current of PV modul, (A).
V = output voltage of PV modul, (V).
N_s = Number of modul in seri connection.
N_p = Number of modul in parallel connection.
$I_{l\,g}$ = Light generated current, (A).
I_o = Reverse saturation current at operating temperature, (A).
I_{sc} = Short Circuit Current at 28°C dan 1000 W/m^2 (=2.52 A).
a, b = Ideality factors (=1.92).
T_r = Reference Temperature (=301 K).
T_p = Cell temperature (K).
T_c = Cell temperature (°C).
k = Boltzman constant (=1.38×10^{-23} J/K).
G = Cell Illumination (W/m2) .
G_r = Illumination reference (=1000 W/m^2)
E_{go} = *Band gab* for silicon (=1.11 ev).
m = short circuit current temperature coefficient (= 0.0017 A/°C).
q = Electron charge (=1.602×10^{-19}C).
Ui = Heat transfer coefficient
I_{scr} = Short circuit reference
V_{ocr} = Open circuit voltage reference
Tα = Emmitance absorptance product

Battery Storage System

The power from the system and the AC load are regulated by the battery. The SoC of the battery at a certain time can be calculated using the following equation (25),

$$SoC(t) = SoC(0) + \eta_c \sum_{k=0}^{t} P_{CB}\,(k) + \eta_d \sum_{k=0}^{t} P_{DB}\,(k) \tag{25}$$

Where:

SoC(0) is the charging state of the battery at *t=0*, P_{CB} is the electric power charged to the battery, P_{DB} is the electric power discharged from the battery. η_c and η_d are the efficiency of each generator during charging and discharging.

The battery model describes the relationship between the voltage, current, and state of charge of the battery. The battery terminal voltage can be expressed as the open circuit voltage and the voltage drop across the internal resistance across the internal resistance of the battery (15). Equation (26) is the equation between the voltage and current in the battery.

$$V_B = V_r + I_B R_B \tag{26}$$

Where:

ςB = Battery terminal voltage (V).
I_B = Battery current (A) (positive when charging and negative when discharging).
V_r = Rest voltage (V).
R_B = Battery internal resistance (ohms).

Rest Voltage, V_r, expressed in Cell Temperature as follow:

$V_r = 2.04[1\text{-}0{,}001(T_c - T_r)]$

Resistance of battery during "charging" and "discharging" process is formulated in form:

$$R_{BC} = \frac{1}{BC}\left[R_1 + \frac{0{,}189}{(1{,}142 - SoC)}\right] + (SoC - 0{,}9)ln\left(300\frac{I_B}{BC} + 1\right) \tag{27}$$

$$R_{BD} = -\frac{1}{BC}\left[\frac{0{,}189}{SoC} + R\right] \tag{28}$$

$$R_i = 0{,}15[1 - 0{,}02(T_C - T_r)] \tag{29}$$

Battery charging condition is the comparison under instantaneous conditions between the amount of actual charge stored in the battery and the overall charging capacity of the battery at a certain battery current. This filling condition can be seen in Equations (27), (28), and (29). In modeling, the magnitude of the charging condition is shown in Equation (30):

$$SoC = SoC_0 + Q/BC \tag{30}$$

where:

BC = Battery Capacity;
SoC = Battery state of charge;
T_r = Temperature Reference;
T_c = Cell Temperature;
SoC_0 = SoC before;
Q = Amount of exchanged charge from the previous time to the time of interest (C);
BC = Battery Capacity (Ah).
I_B = Current Batteryi (A).

Diesel (Diesel Generator Plant[6]

Diesel Generator often acts as a backup in elctric power system. A Diesel Generator is used as a back-up if the energy demand from the load cannot be met by other generators such as solar modules, micro-hydro power plants, and storage batteries. The constraints of Diesel Generator are shown in Equation (31) below,

$$0 \le P_{BG}\,(k) \le P_{BG};\, max \tag{31}$$

Maximum power from Diesel Generator is $P_{BG,\, max.}$ The output of Diesel Generator is modeled by Equation (23) below,

$$FBG = \alpha_0 P_{BGR} + \alpha_1 P_{BG} \tag{32}$$

F_{BG} is generator fuel consumption back-up (l/hour), α_0 is generator fuel intercept coefficient (L/hour/kW_{rated}), P_{BGR} is rated generator capacity (kW), α_1 is slope of fuel generator (L/hour/kW_{output}) and P_{BG} is the generated power (kW).

Wind Turbine[6]

Wind Power Plant converts wind kinetic energy into electrical energy. Aerodynamic coefficient curves are used to study the dynamic properties of wind turbine blades. The P_{con} converted power from a Wind Tuebine is formulated in Equation (33),

$$\boldsymbol{P_{con} = (1/2)\rho A C_p(\lambda,\beta) V_w^3} \tag{33}$$

where, $A=\pi R^2$ is the area swept by the rotor disc, V_w is wind speed, ρ is air density and C_p (λ,β) is a dimensionless rotor aerodynamic coefficient which is a function of velocity ratio λ and pitch angle β angle. The coefficient can be defined as the percentage of air mass that is converted to mechanical energy by the rotor. Wind speed at any altitude can be calculated by the well-known Exponential Law equation which is shown in Equation (34),

$$\boldsymbol{\frac{V_w}{V_{wh}} = \left(\frac{Z}{Z_h}\right)^{\alpha}} \tag{34}$$

With, V_w is the wind speed at Z height, V_{wh} is the wind speed at Z_h hub height and α is the shear exponent which has a value of about 7 for open space. With the rotor characteristic C_p (λ,β), the aerodynamic torque of the rotor and the power curve can be calculated.

RESEARCH METHODOLOGY

This research is in the field of engineering that produces a problem-solving algorithm based on the data used. The problem solved is the optimum generation scheduling problem in a micro grid. The data used is data from related journals. In this journal, the distributed energy sources consist of 10 thermal generators, a solar power plant, a wind power plant, and an energy storage system in the form of a battery.

RESULTS AND DISCUSSION

Simulation Data

In this research, the data for simulation is taken from a microgrid network [6], with the following components, a PV system, a Wind Turbine, 10 units of thermal generators, and an energy storage battery. It is assumed that there is no fixed charge required for the battery, minimum SOC is 40% and charging and discharging efficiencies are 0.95 and 1.0 respectively. The total capacity of PV system installed is 1440kW (4×360 kWp) and total capacity of wind power installed is 560kW (4×140 kWp). The maximum penetration of renewable-battery system is limited to 1000kW.

The simulation is carried out four times based on the amount of demand (Pd), namely: Pd = 1000 kW, Pd = 1500 kw, Pd = 2000 kW, and Pd = 2500 kW

For analysis of Unit Commitment and Constrained Economic Dispatch problems using Mat Lab version 2022b.

Table 1. The Result of data simulation

	P_d = 1000 kW			Pd = 1500 kW			Pd = 2000 kW			Pd = 2500 kW		
	The Best (10^{-3})	Output kW)	Elapsed time	The Best (10-3)	Output kW)	Elapsed time	The Best (10-3))	Output kW)	Elapsed time	The Best (10-3)^{3})	Output kW)	Elapsed time
P_1	0.1701	227.47	2.014607 detik	6,722	600.00	2.028531 detik	-6,307	600.00	0.788629 detik	0,6887	600.00	2.041945 detik
P_2	-0,46547	185.05		-0,312	103.36		0,5888	100.32		0,9920	100.34	
P_3	0,82966	100.14		0,619	100.09		-0,3044	100.18		-1,6369	100.30	
P_4	0.91219	100.25		-0,081	100.19		0,5212	100.09		3,0289	100.49	
P_5	-362,88	50.23		-0.642	50.02		0,9414	50.13		-0,4688	50.76	
P_6	1,0538	100.07		0,2687	100.13		1,6118	100.19		0,45816	100.09	
P_7	-0,7103	100.11		0,3614	100.03		2,2816	100.16		-2,7388	100.05	
P_8	0,3637	50.11		1,453	50.05		-0,1649	50.34		-0,8986	50.41	
P_9	1,1919	50.02		-0,644	50.07		0,0635	50.01		-673,53	50.04	
P_{10}	428,34	50.06		0.292	50.03		-206,18	50.00		-908,7	50.03	

Table 2. The Result of data simulaation

		Optimal value using by *HSA*	Total Power Output Total (kW)	Total cost of generation ($/h)	Real Power Losses (kW)
1	Deman (P_d) = 1.000 kW	2.027.880,39	1.013,50	2.027.880,39	13,50
2	Demand (P_d) = 1500 kW	3.657.289,0361	1.303,97	3.657.289,04	33,88
3	Demand (P_d) = 2000 kW	4.158.349,41	1.301,42	4.158.349,41	33,75
4	Demand (P_d) = 2500 kW	4660442.1606	1.302,52	4.660.442,16	33,76

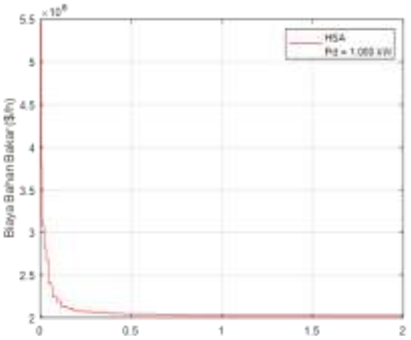


Figure 1, Graphic Simulation of *HSA* P_d = 1.000 kW

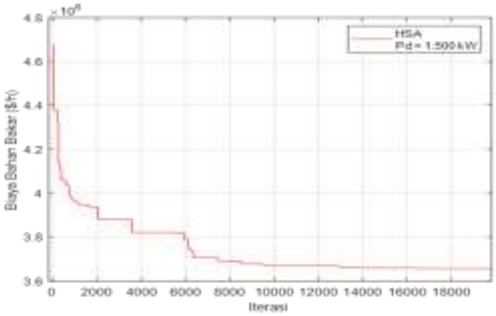


Figure 2, Graphic Simlation of HSA P_d = 1.500 kW

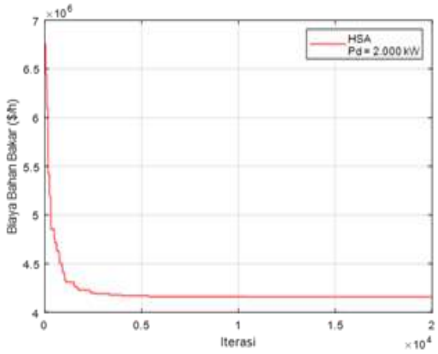
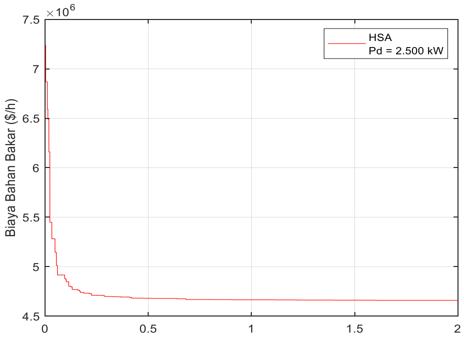


Figure 3, Graphic Simulation of HSA P_d = 2.000 kW



Gambar 4 Graphic Simulation of *HAS*, P_d = 2.500 MW

CONCLUSION

The conclusion of this report , as follow:

1. Harmony Search Algorithm (HSA) can be applied to Unit Commitment to find a low cost of Generation Operation;
2. The best value Nilai optimal terbaik yang didapatkan oleh *HSA* untuk P_d 1.000 MW adalah: **2.027.880,39** dan **Elapsed time-nya adalah 2.014607 seconds;**
3. The best optimal value obtained by HSA for Pd 1.500 kW is **3.657.289,0361 and** The **Elapsed time is 2.028531 seconds;**
4. The best optimal value obtained by HSA for Pd 2.000 kW is 3.657.289,0361 and The Elapsed time is **2.788629 seconds;**
5. The best optimal value obtained by HSA for Pd 2.500 kW is 3.657.289,0361 and The Elapsed time is **2.041945 seconds**

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