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Optimal Placement of Fast Charging Station using Hybrid Optimization Algorithm

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Abstract: Plug-in electric vehicle is considered to be one of solutions of environmental issues. Penetration of plug-in electric vehicle brings new problem on the distribution network as the load on the network increases. The distribution network reliability, voltage stability and power loss are the main factors in designing the optimum placement and management strategy of a charging station. The planning of charging stations is a complicated problem involving roads and power grids. The Hybrid between Genetic Algorithm and Particle Swarm Optimization (HGAPSO) used for solving the charger placement problem tested in this work. A good balance between exploitation and exploration is achieved by the HGAPSO. Furthermore, the likelihood of becoming stuck in premature convergence and local optima is minimized in HGAPSO. Simulation results establish the efficacy of the HGAPSO in solving charger placement problem as compared to other metaheuristics such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO).

Keywords: plug-in electric vehicle; optimization; charging station location; distribution network; power loss

1. INTRODUCTION

Environmental issues have become one of the factors for electric vehicles or PEV (Plug-in Electric Vehicles) to be introduced to the masses in order to substitute ICE (Internal Combustion Engine) vehicles. An electric vehicle or PEV is a vehicle that is driven by an electric motor with electrical energy stored in a battery. The growth of electric vehicles also shows a significant number, as research [1] stated that the predicted growth of electric vehicles in the world will reach 10% of all vehicles in 2020, while in Indonesia, presidential regulation no. 55 of 2019 which contains the acceleration program for electric vehicles in Indonesia. The electric vehicle program also mentions the development of infrastructure for charging public electric vehicles (SPKLU) [2].

According to the standards of the International Electrotechnical Commission (IEC) there are 3 basic levels of charging methods for electric vehicles. Level 1 refers to a single phase AC voltage, in America it is 120V/16A but in Europe and Southeast Asia it is 230V/16A. Level 2 refers to single or three phase AC voltage at 208-240V with a current rating of 80A. Level 3 refers to quick charge or fast charging. To get a short charging time, level 3 provides high voltage (300-500VDC) with high current (125-250A) [3].

Charging to full battery level is possible at home or in the office parking area while the user is working but not possible for recharging in the middle of the trip. 2 or 8 hours of charging is too long to wait until the battery level is fully charged, when the vehicle is charged to a charging station with charge levels 1 and 2. The level 3 charging method is more suitable for some people who are planning to own an electric vehicle because the time to fully charge usually will not more than 30 minutes. Combining this technology with the placement of charging stations according to the user's travel route will make electric vehicles accepted by the wider community. However, the charging station requires high power and is guaranteed to be sufficient to supply the electricity consumption of electric vehicles [4].

The placement of a charging station with fast charging creates a new problem in the case of plug-in electric vehicle penetration. A study should be conducted to determine the location of a charging station with fast charging that has minimal impact on the installed distribution network. Distribution losses must be low while the voltages of each bus and line loading limits must be kept at acceptable levels.

Several studies have conducted research on the optimal placement of charging stations on sub-stations [5]. A case study of the optimal placement of a charging station that considers traffic and driving distance has been carried out in research [6]. Another study also added renewable energy generation in the network for optimization along with the placement of charging stations [7]. Several heuristic methods have also been carried out such as particle swarm optimization in [8]. A method that combines two methods (hybrid) is also carried out in this study [9]

This study focuses on charging stations with level 3 charging methods on one feeder in the distribution system network. The hybrid genetic algorithm-particle swarm optimization (HGAPSO) optimization technique was used to find the optimal placement of the charging station.

2. PROBLEM FORMULATION

2.1 Objective Function

The main focus of this research is to determine the optimal charging station location with the aim of minimizing power losses and voltage deviation. An illustration of a power system with a charging station load is shown in Figure 1

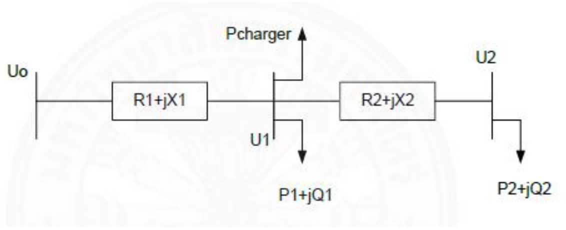

Figure 1 Power System with Charging Station Load

$$V_D = U_0 - (\Delta U_1 + \Delta U_2) = U_0 - [\left(\frac{(P_1 + P_{charger})R_1 + Q_1 X_1}{U_N}\right) + \left(\frac{P_2 R_2 + Q_2 X_2}{U_N}\right)] \quad (1)$$

Calculations of power losses and voltage deviation shown on equation 2 and 3

$$P_{loss} = \sum_{i=1}^{N_b} |I|^2 R_i \quad (2)$$

With,

P_{loss} = Active power losses
I = Current
R_i = Line resistance
X_i = Line reactance

$$V_d = Max_{i=2}^{m} \left(\frac{V_{rated} - V_i}{V_{rated}}\right) \quad (3)$$

V_{rated} is rated voltage on the system which valued at 1.0 pu.
V_i is voltage on the bus- i, and m is total bus on the system.
The objective function of this research is

$$Min(f) = \sum_{i=1}^{Nb} (P_{loss} + V_D) \quad (4)$$

2.2 Constraints

In the whole optimization process, some limitations or constraints on the system also need to be considered. Some of these constraints are:

- Maximum load

$$P_{demand}^{max} \geq \sum_{i=2}^{n} (P_{load} + P_{charger})_i \quad (6)$$

Keterangan :

n : numbers of bus in the system
P_{load} : existing load
$P_{charger}$: charging station load
i : bus-i
P_{demand}^{max} : maximum load on distribution transformer

- Bus Voltage

$$V_{min} \leq V_i \leq V_{max} \quad (7)$$

Description:

V_{min} and V_{max} : range between minimum and maximum voltage which allowed in the system
V_i : voltage on bus- i

The range of voltage value in this research is set ±10% from rated voltage, which rated at 0.9 - 1.1 pu.

3. ALGORITHMS AND IMPLEMENTATION

3.1 Genetic Algorithm (GA)

The steps for completing the optimization of PEV charging coordination are described as follows.

1. All input data is entered into the program. These data are network data, bus data, line data, existing load data, and PEV data.
2. Initialization of GA optimization parameters, maximum iterations.
3. Generate random positions of charging stations on the network and perform load flow analysis by Newton-Raphson method
4. Choose parents with roulette wheel
5. Do crossover and mutation to get the latest solution
6. Perform power flow analysis again with Newton-Raphson and display the power loss results on the network

If the optimization results violate the constraints, repeat the 4th to 6th optimization steps until an optimal solution is found

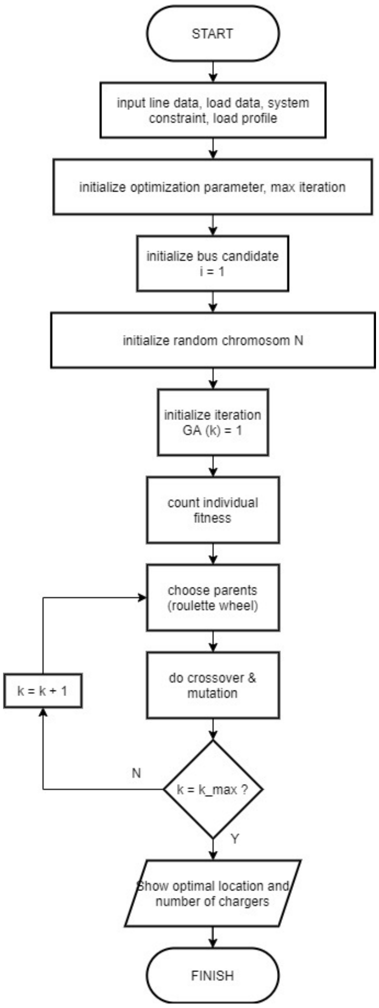

Figure 2. Optimization flowchart of charging station placement using GA

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3.2 Particle Swarm Optimization (PSO)

The steps for optimizing the placement of the PEV charging station location are explained as follows.

1. All input data is entered into the program. These data are network data, bus data, line data, existing load data, and PEV data.
2. Initialize PSO optimization parameters and enter maximum iteration parameters
3. Initialization of iteration for PSO algorithm i = 1 to find the optimal location of charging station.
4. Perform power flow analysis using the Newton-Raphson method for the existing load network and calculate network losses
5. Update particle location and velocity with

$$vel_{i,d}^{t} = w^{t} vel_{i,d}^{t} + c_1 r_1 \left(pbest_{i,d}^{t} - x_{i,d}^{t}\right) + c_2 r_2 \left(gbest_{i,d}^{t} - x_{i,d}^{t}\right)$$

   Where the weight of the particles is

$$W = Wmax - \frac{(Wmax - Wmin)}{(n-1)} \times (iter - 1)$$

6. Perform load flow analysis again with Newton-Raphson and show the network losses
7. If the losses violate the allowed network constraints, repeat the iteration until an optimal solution is found

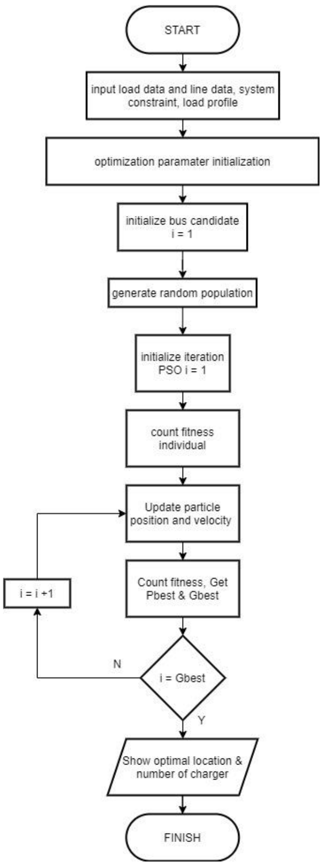

Figure 3. Flowchart of optimal placement of charging station using PSO

3.3 Hybrid Genetic Algorithm Particle Swarm Optimization (HGAPSO)

The steps for optimizing the placement of the PEV charging station location are explained as follows.

1. All input data is entered into the program. These data are network data, bus data, line data, existing load data, and PEV data.
2. Enter the GA and PSO optimization parameters.
3. Perform load flow analysis using the Newton-Raphson method to obtain power losses in the network.
4. Initialize a random solution of charging station locations on the network.
5. Select the parents with the roulette wheel.
6. Do crossover and mutation to get a solution.
7. Connect optimal results from GA to PSO operator
8. Re-run load flow analysis with Newton-Raphson from suboptimal results
9. Update particle velocity and position from PSO operator
10. Then do the selection of parents and crossover and mutation
11. Do the power flow analysis again with Newton-Raphson until you get Pbest and Gbest.
12. Iterate until you get the Gbest location for the optimal charging station
13. If the result still violates the constraint, do it again until you get the optimal solution.

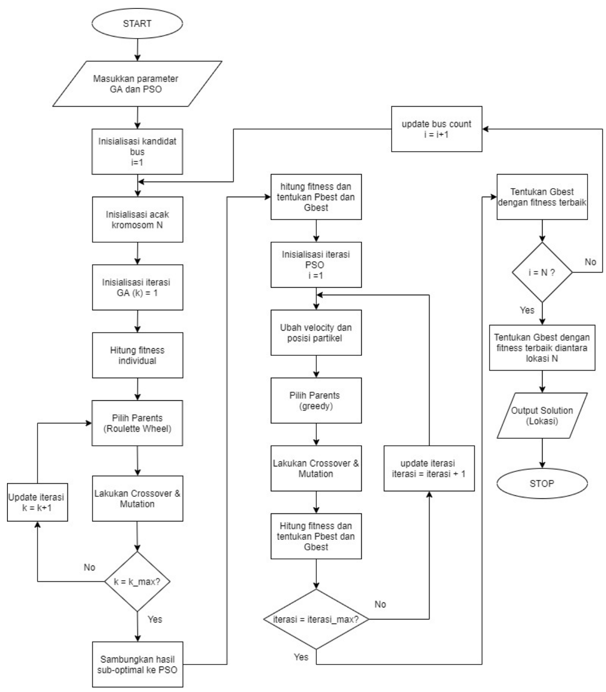

Figure 4. Optimization flowchart of charging station placement using HGAPSO

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4. RESULTS AND DISCUSSION

4.1 Existing Network Load Flow Analysis

Optimizing the coordination of charging plug-in electric vehicle (PEV) in this electricity distribution network using 20 kV distribution system data obtained from PT. PLN APJ South Surabaya which has 18 substations. In this study, the authors chose to use the Basuki Rahmat feeder which is interconnected with Simpang substation and Kupang substation as research case studies. At the Basuki Rahmat feeder 30 units of 20 kV/380 V distribution bus connected to the Kupang substations with a 150 / 20 kV transformer with a power of 60 MVA with a current of 360 A. The single line diagram of the Basuki Rahmat feeder can be seen in Figure 3.

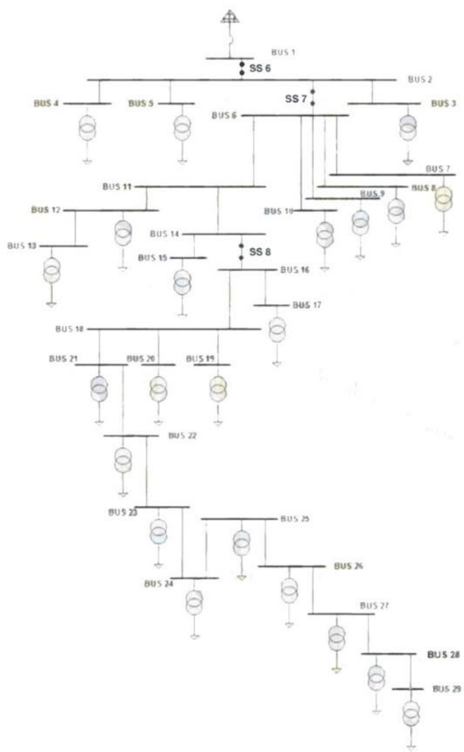

Figure 3. Single Line Diagram Basuki Rahmat Feeder Surabaya

The load flow analysis of the existing system is carried out when the charging station has not been installed into the network. Using the Newton-Raphson method [10], the analysis results obtained with total power losses of 0.009 MW and 0.005 MVAR. The results of the load flow analysis is shown on table 1

Table 1. Voltage and Load Profile of 30 Bus Feeder

Bus no	Voltage Magnitude	Angle degree	Load	
			P (MW)	Q (Mvar)
1	1.000	0	0	0
2	0.995	0.059	0	0
3	0.994	0.069	0	0
4	0.994	0.070	0.095	0.129
5	0.994	0.069	0.010	0.001
6	0.994	0.069	0.001	0.003
7	0.993	0.077	0	0
8	0.993	0.076	0.111	0.016
9	0.993	0.080	0.198	0.243
10	0.993	0.077	0.022	0.004
11	0.993	0.077	0.009	0.003
12	0.992	0.081	0	0
13	0.992	0.080	0.009	0.002
14	0.992	0.083	0.151	0.188
15	0.991	0.079	0	0
16	0.991	0.079	0.003	0
17	0.991	0.078	0	0
18	0.991	0.079	0.104	0.135
19	0.991	0.075	0	0
20	0.991	0.075	0.034	0.005
21	0.991	0.075	0.022	0.006
22	0.991	0.072	0.035	0.005
23	0.990	0.069	0.029	0.009
24	0.990	0.068	0.050	0.007
25	0.990	0.067	0.043	0.009
26	0.990	0.066	0.026	0.004
27	0.990	0.066	0.030	0.004
28	0.990	0.065	0.029	0.004
29	0.990	0.065	0.010	0.001
30	0.990	0.065	0.012	0.003

4.2 Optimization of Charging Station Location using Genetic Algorithm (GA)

The GA is used to find the optimal location of the charging station on the network with the scheme described in sub-chapter 4.3. The results obtained after the iteration process are Ploss 0.015 MW and Qloss 0.007 MVAR and the voltage profile on each bus is shown in Figure 5.

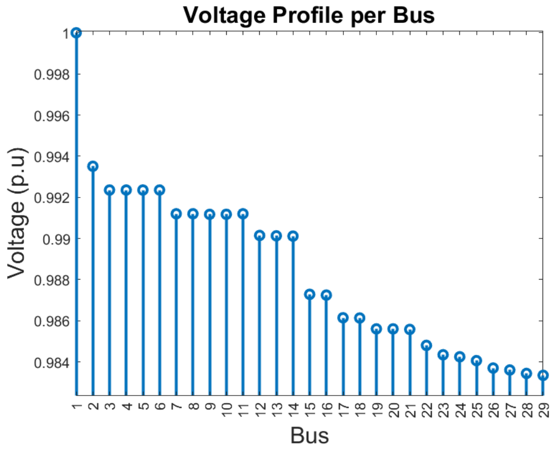

Figure 5. Voltage profile on each bus after the optimization with GA

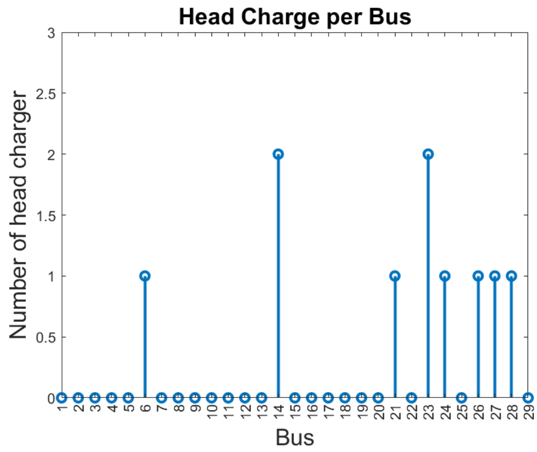

Figure 6. Number of head chargers installed on the network after GA optimization performed

It can be seen from the optimization results of charging stations installed on buses 6, 14, 21, 23, 24, 26, 27,28. With a total of 2 head chargers on buses 14 and 23 and 1 head charger on buses 6, 21, 24, 26,27 and 28. The total number of head charger is 10 units.

4.3 Optimization of Charging Station Location using Particle Swarm Optimization (PSO)

The PSO algorithm is used to find the optimal location of the charging station on the network with the scheme described in sub-chapter 3. The results obtained after the iteration process are Ploss 0.013 MW and Qloss 0.006 MVAR and the voltage profile on each bus is shown in Figure 7

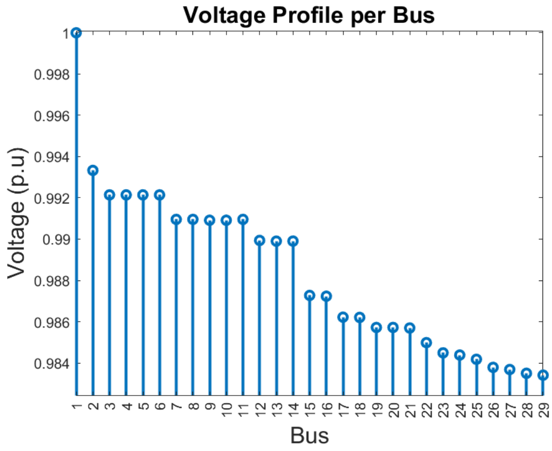

Figure 7. Voltage profile on each bus after PSO optimization

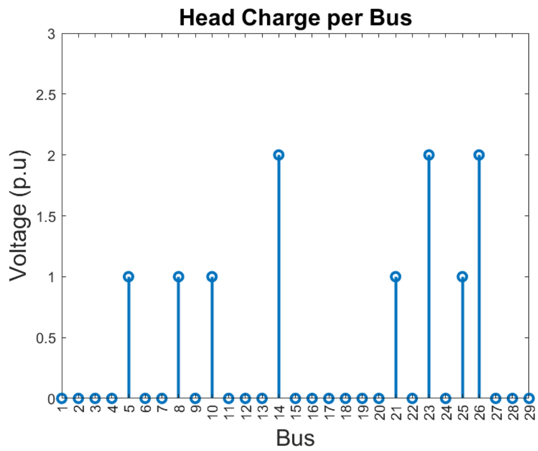

Figure 8. Number of head chargers installed on the networks after the PSO optimization performed

4.4 Optimization of Charging Station Location using Hybrid Genetic Algorithm Particle Swarm Optimization (HGAPSO)

The HGAPSO algorithm is used to find the optimal location of the charging station on the network with the scheme as described in sub-chapter 3. The results obtained after the iteration process are that there are Ploss of 0.012 MW and Qloss 0.006 MVAR and the voltage profile on each bus is shown in Figure 9.

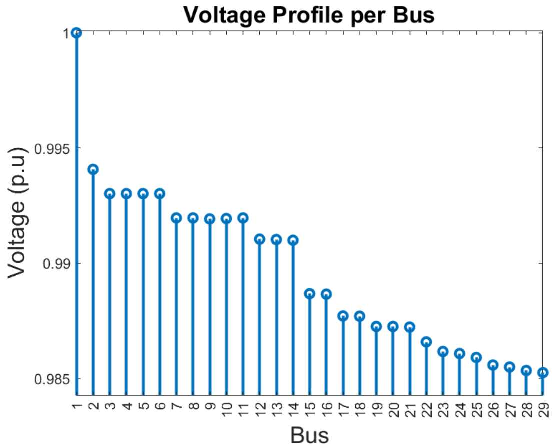

Figure 9. Voltage profile on each bus after HGAPSO optimization

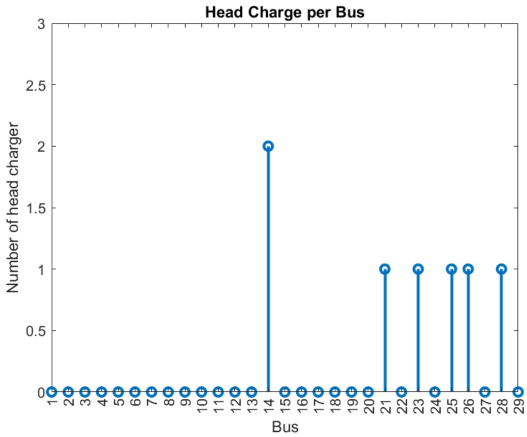

Figure 9. Number of head chargers installed on the networks after the HGAPSO optimization performed

It can be seen from the optimization results that charging stations are installed on buses 14, 21, 23, 25, 26 and 28. With a total of 2 charger heads on bus 14 and 1 head charger on buses 21, 23, 25, 26 and 28. The total of head charger is 7 units.

5. CONCLUSION

In the distribution system, the placement of charging stations that are not planned properly will cause problems such as voltage deviation and real power loss in the system. The Hybrid Genetic Algorithm Particle Swarm Optimization (HGAPSO) method is able to optimally place a number of charging heads on the bus compared to Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) with 7 charging heads and an real power loss of 0,26% and a voltage deviation of 1,3%.

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