Genetic Algorithm in Determining Wheeling Cost Allocation Using LRMC and MW-Mile

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ABSTRACT — Electricity deregulation has occurred in many countries. This deregulation primarily aims to introduce competitions to increase the efficiency and quality of service in the electricity supply industry. Generation values and transmission line functions will change significantly. Customers will welcome the free market, causing many companies to build their own generators in a wheeling operation scheme to meet their needs. Wheeling is the solution to this problem. The power flow method was used after adding wheeling to the system. This method was used to determine the system conditions after wheeling was added, considering that power flow map will change when there is a wheeling costumer. The study of the power flow method provides information on the amount of total power generated by the generator yet does not provide information on the power supplied by the generator in each transmission network. To address this shortcoming, the power tracing method was used. This method can provide information on the allocation of power supplied by generators in each transmission network in the system. This research discusses the power tracing method using the genetic algorithm (AG) method. AG is one of several optimization methods; it assumes the allocation of power flowing by the generator as the problem to be optimized. The wheeling pricing used the long run marginal cost (LRMC) method. This method projects future costs by taking into account changes in expenses that occur at any time within a specified period. In this study, the LRMC method was compared with another wheeling costing method, namely the MW-Mile method. The results showed that the LRMC method was cheaper than the MW-Mile method. From an economic perspective, the wheeling costs determination using the LRMC method was 14% up to 20% cheaper than the MW-Mile method.

KEYWORDS — Deregulation, Power Wheeling, Genetic Algorithm, Long Run Marginal Cost, MW-Mile.

I. INTRODUCTION

The deregulation of the electricity industry has caused many companies aim to install their generators without having to build a transmission network. Wheeling provides solution to these problems. There are various meanings of power wheeling.

Wheeling is defined as the distribution of electricity from the seller to the buyer using a transmission network owned by a third party [1]. Another definition is the use of transmission and distribution network facilities to distribute electricity belonging to other parties [2]. Wheeling also means that electric power is sent through a transmission or distribution line from one utility to another [3].

The recurrent problems in power wheeling is the determination of fair costs for owners of transmission lines and loads or industries that want to use wheeling. Numerous studies have discussed the determination of wheeling costs. Fairness in determining wheeling costs is a major topic of the discussion. There are various methods for determining wheeling costs, namely embedded costs, MW-Mile, MVA-Mile, marginal and incremental cost [4]–[8].

In previous research, wheeling pricing was calculated based on the power delivery distance [5]. This method is called the postage stamp. The greater the distance of power delivery from the generator to the load, the greater the wheeling price that must be paid. For the contract path method, the calculation of wheeling costs is based on the assumption that power delivery is limited to flowing along a continuous electricity path determined through the transmission system used by the wheeling company. Several wheeling pricing methods were combined [9]. The combined MW-Mile and postage stamp methods are very practical and implementable

The previous study determined wheeling costs using the MW-Mile method [10]. In this study, optimization was carried out using the optimal power flow (OPF) method so that the results were almost close to fair and competitive values. OPF is done so that the generation cost of the system is cheaper and more optimal [11].

The long run marginal cost (LRMC) method was examined [12]. The results promoted economical price and efficiency as they are future expansion costs in addition to operational ones. One of the weaknesses of this method is that it is sensitive to growth rates and load increases. Several methods used to calculate wheeling costs has also been reviewed [13]. These methodes include embedded costs, short run marginal costs, and long run incremental costs.

The power flowing at each bus in an interconnection system must be known in advance to determine the wheeling cost. Previous research traced the flow of power in a system using the genetic algorithm (GA) method [14]. The flow of power in each bus can be seen using this method. The results of power tracing using the GA method are more effective and faster than using other methods. Another modern method has also been described, namely a power flow tracing method using an artificial salmon tracking algorithm [15].

The importance of conducting power flow tracing when determining wheeling costs was explained in previous studies [16]. The pollinate flower algorithm (FPA) method was used in this study. This method can track active and reactive power with a simple problem formulation. Power flow tracing was also carried out in [17].

A popular method of tracking power flow is in [18]. The tracing methodology is based on the assumption that, at any network node, the incoming flows are proportionally distributed among the outcoming flows. This method used a topological approach to determine the contribution of each generator or load on each channel flow based on the calculation

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of the topological distribution factor. Power flow tracking has become very essential in wheeling pricing, and various methods are used to determine it. Several studies have also used this power flow tracing [19]–[21].

Another popular method was used [22]. This study generally agreed that the transmission systems should be allocated between generation and load based on their contribution to the maximum flow at each point. To determine the maximum flow conditions for each condition, the level of load variation and all safety criteria for contingencies must be considered.

Based on previous studies, this research used the optimal power flow (OPF) method to obtain optimal power flow at a low cost. OPF provides information on how much power is generated by the generator but does not provide information about the power flowing in each channel. The GA method tracks the power flow at every channel point since it is more effective and faster than other power flow tracing methods. To determine the wheeling cost, the LRMC method was used, where load conditions fluctuated on a three-year calculation period. This method was used due to its economical price and efficiency since it includes future expansion costs and operational costs. This research was conducted on a modified IEEE 14-bus test system. Researchers also compared the results of wheeling costs using the LRMC method with the MW-Mile method.

II. METHODS

This section explains OPF, tracing power flow using the GA, MW-mile, and LRMC methods.

A. RESEARCH DESIGN FLOW

This research began with a literature study to identify prior research on power wheeling, power flow tracing, GA, and the LRMC and MW-Mile methods for determining wheeling costs. Power flow tracing was carried out in the subsequent process. At this stage, a power flow tracing was carried out to determine the power flowing on each transmission line. The method that was used in tracing the power flow was the GA method. The power of each bus on the system that had been applied OPF was included in the objective function of the GA. Coding was created in tracing the power flow using the GA method assisted by Visual Code Studio software.

During the process, if the fitness value in the coding had a value of 1, the power flow tracing process stopped and then displayed the results. However, if the fitness value was less than 1, the process was repeated from the beginning to trace the power flow.

After tracing the power flow, the following process was determining the wheeling cost. The wheeling cost was determined using the LRMC and MW-Mile methods. The results of the two methods were then compared. The results could indicate which method is more effective and fairer in determining wheeling prices. Report writing was performed at the final stage of the research to know which method was more effective and fairer in determining wheeling prices.

B. OPTIMAL POWER FLOW

In the power system interconnection system, cost optimization was obtained by adjusting each generator's active and reactive powers to minimize operating costs. The method for reducing operating costs was the OPF. OPF is a power flow that considers the cost of each generator in a system [23], [24].

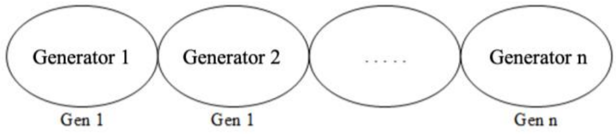

Figure 1. Chromosomes representatives.

OPF, formulated to minimize power plant operating costs, is shown in (1) and (2).

$$\min_{u} \sum_{i=1}^{\mathrm{Ng}} C_i\left(P_{Gi}\right) \tag{1}$$

$$C_i(P_{Gi}) = \alpha_i + \beta P_{Gi} + \gamma_{Gi}^2. \tag{2}$$

The following limitations were taken into considerations while solving the OPF problem.

Power flow equation:

$$\sum_{i=1}^{Ng} P_{Gi} - \sum_{i=1}^{Ng} P_{Di} - P_{loss} = 0 \tag{3}$$

$$\sum_{i=1}^{Ng} Q_{Gi} - \sum_{i=1}^{Ng} Q_{Di} - Q_{loss} = 0. \tag{4}$$

Wherein,

$$P_{loss} = \sum_{i=1}^{N} |V_i| \left|V_j\right| \left|Y_{ij}\right| \cos(\theta_{ij} + \delta_j - \delta_i) \tag{5}$$

$$Q_{loss} = \sum_{i=1}^{N} |V_i| \left|V_j\right| \left|Y_{ij}\right| \sin(\theta_{ij} + \delta_j - \delta_i). \tag{6}$$

Generation active and reactive limits:

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \tag{7}$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \tag{8}$$

$$P_{Gi}^2 + Q_{Gi}^2 \leq S_{Gi}^{max}. \tag{9}$$

Voltage limit:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max}\ . \tag{10}$$

Voltage angle limit:

$$\delta_{Gi}^{min} \leq \delta_{Gi} \leq \delta_{Gi}^{max} \tag{11}$$

where $F(P_g)$ represents the cost of fuel, P_{Gi} represents the active power output of the generator, P_{Di} represents the active power of the load, P_{loss} represents active power losses, Q_{Gi} represents the reactive power output of the generator, Q_{loss} represents reactive power losses, V_i and V_j show the voltage in branches *i* and *j*, Y_{ij} shows the acceptance matrix in the branch *i* and *j*, θ_{ij} shows the angle acceptance matrix, $\delta_j$and δ_i shows the angular voltage in branch *i* and *j*.

C. POWER FLOW TRACING

At this stage, GA method was utilized to trace the power flow. A GA is a stochastic method that applies models of biological processes to solve optimization problems. GA allows a population consisting of several individuals to evolve in accordance with rules to maximize the fitness value or minimize the cost function [25]. This study employed GA to track the power flow in the power system.

The initial step was that GA encoded multiple candidate values on a chromosome. Chromosomes are a matrix containing several randomly generated values. They are composed of several elements known as genes. The number of collected chromosomes is called the population. Representatives of the chromosomes can be seen in Figure 1.

The GA produced an objective value based on the quality of its fitness value and stopped the process when the fitness

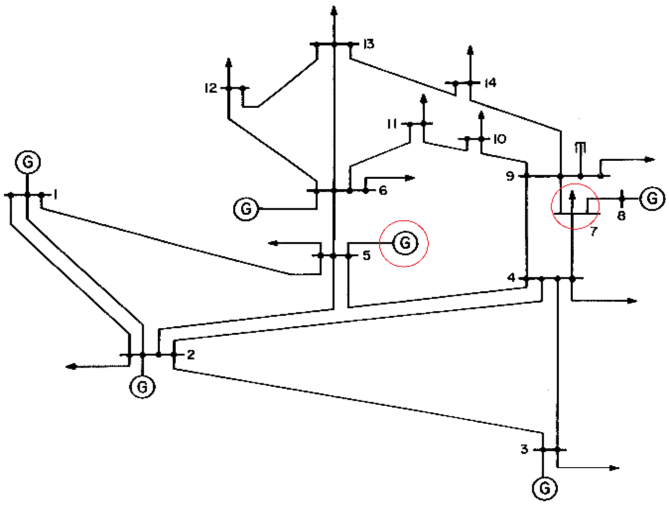

Figure 2. Single line diagram on a modified IEEE 14-bus test system for simulation.

value had a value close to or equal to 1. This process yielded the determination of the power flow in the interconnection system. The objective function of the GA in this research can be seen in (12)–(14).

$$\min\,(H) \sum_{i=1}^{n} \Delta P_{j-k}^{Gi} \tag{12}$$

$$\Delta P_{j-k}^{Gi} = \sum P_{j-k}^{Gi(tr)} - P_{j-k} \tag{13}$$

$$fitness = \frac{1}{(1+H)}. \tag{14}$$

P_{j-k}^{Gi} denotes the power flow flowing from channel j to k. $P_{j-k}^{Gi(tr)}$ denotes the power flow flowing from channel j to k by using GA. The number of genes in the GA depended on the number of generators in the system. The process of GA included selection, crossover, and mutation. The process stopped when the fitness value had a value close to or equal to 1.

As previousy mentioned, the GA process included selection, crossover, and mutation. The selection process is an operation that assures the chromosomal representation in the next generation is of better quality or depends on its fitness value. In the natural selection model, chromosomes with better fitness values are more likely to survive in the next generation. Most likely, the surviving chromosomes will pair or mate with other chromosomes. The method used to carry out the selection process was the roulette wheel method.

The subsequent process was the crossover process. This procedure involved the crossing of selected chromosomes to create new chromosomes. *Pc* represents a possibility of crossing over. Mutation operation is the process of altering the chromosome value. This mutation process replaces the chromosome in the population that was lost as a result of the selection process. The value to replace the missing chromosome will be randomly generated.

D. THE MW-MILE METHOD

The annual rate for each transmission facility has been specified [23], based on the facility's usage level by this transaction. It can be seen in (15). This method was used because it calculates the actual usage of the transmission line. These uses included the length of the transmission line, the power flow flowing on the transmission line, the transmission

TABLE I
GENERATOR DATA

Bus	Cost Function	Minimal Power (MW)	Maximal Power (MW)
1	3 + 0.043 P + 20 P ^{2}	232.4	332.4
2	3 + 0.250 P + 20 P ^{2}	40.0	140.0
3	3 + 0.010 P + 20 P ^{2}	0.0	100.0
5	3 + 0.250 P + 20 P ^{2}	40.0	140.0
6	3 + 0.010 P + 20 P ^{2}	0.0	100.0
8	3 + 0.010 P + 20 P ^{2}	0.0	100.0

line's capacity, and other factors that were calculated according to their use.

$$TC_t = TC * \frac{\sum_{k\in K} C_k L_k P_{t,k}}{\sum_{t\in T}\sum_{k\in K} C_k L_k P_{t,k}}. \tag{15}$$

TC_t is the price allocation of network users t, TC is transmission costs, C_k is the cost per MW per unit length of channel k, L_k is the channel length, $P_{t,k}$ is the power flow (MVA) in channel k to users t, T is the user, and K is the transmission channel. This method is very complicated because any change or addition of generators or loads on the transmission network will alter the transmission line's power flow calculation. This method was used in this study because the cost determination would be fair and would be carried out over a longer time period than other studies.

E. LONG RUN MARGINAL COST

Marginal operating cost is the cost to accommodate the marginal increase in each transacted power. The marginal operating cost per MW of transacted power can be estimated as the difference in the optimal power cost at all points of sending and receiving that power transaction [12], [26].

$$Marginal\ Cost = \sum BMC_i \times P_{i,t}. \tag{16}$$

BMC_i represents the marginal cost of the bus i and $P_{i,t}$. The marginal cost of the bus was obtained from the calculation of the OPF, which can be seen in (17).

$$\mathrm{IC}_i(P_{Gi}) = \frac{dC_i(P_{Gi})}{dP_{Gi}} = \beta + 2_{\gamma Gi}. \tag{17}$$

In the LRMC pricing methodology, a power system's operating costs and marginal gain were used to determine the price for transmission transactions. Over these years, all transaction expansion projects were identified and charged. These costs were then divided by the total power magnitude of all planned new transactions to calculate the marginal reinforcement cost. This method was also used to see whether it is more economically effective than other methods in determining wheeling costs.

III. CASE STUDY

This research was conducted using OPF on Matpower with the IEEE 14-bus test system. The IEEE 14 modification test system for simulation is shown in Figure 2. The 40 MW generator was installed on bus 5, while the 30 MW generator was placed on bus 7. The placement of wheeling actors on bus 5 and bus 7 indicates that electricity service providers and consumers are not directly connected to the same bus. This modified system provided lane boundaries on buses 5 to 6 and 9 to 14. In addition, the generation cost function is depicted in Figure 2 [27].

TABLE II
GENERATOR'S POWER FLOW IN THE SYSTEM

Channel	Generator					
	G1 (MW)	*G2 (MW)*	*G3 (MW)*	*G6 (MW)*	*G8 (MW)*	*G5 (MW)*
1	16.4	26.0	25.7	18.0	29.8	8.0
2	18.7	8.0	7.0	2.8	8.0	7.0
3	7.0	9.0	9.0	0.0	25.0	16.8
4	4.3	14.0	7.3	5.0	1.0	11.0
5	0.0	6.4	3.0	2.2	7.0	4.7
6	-9.0	-1.0	-10.4	-1.9	-4.0	-3.0
7	-16.7	-6.5	-30.2	-11.0	-10.0	-5.5
8	5.0	13.0	2.0	5.0	1.0	4.2
9	2.6	7.0	1.3	1.0	0.0	1.7
10	0.3	1.0	2.0	8.4	3.0	4.1
11	1.0	1.0	11.0	5.5	1.2	0.0
12	2.0	3.5	0.0	1.0	2.0	1.0
13	0.0	1.0	1.0	1.0	1.2	20.0
14	0.0	0.0	0.0	0.0	0.0	0.0
15	3.0	4.0	0.0	0.0	4.0	0.0
16	-2.0	0.0	-1.0	-2.0	-0.6	-1.0
17	0.7	0.2	0.1	0.0	0.0	0.6
18	-1.0	-3.6	-2.0	0.0	-4.5	-4.7
19	1.0	1.0	0.0	0.0	1.0	0.2
20	1.0	1.0	2.0	2.4	7.0	0.0

A. GENERATOR DATA

Each generator has its cost function and different power generation. The data can be seen in Table I.

B. LOAD PROFILE

This study used a load profile that changed every hour. Then, it was continued for the next three years. In the first year, during weekdays, the highest average load reached 342,8 MW and the lowest was 267,4 MW; meanwhile, during weekends, the highest load was 339,37 MW and the lowest was 264,71 MW. For the following year, load demand increased by 5%. On weekdays the highest load reachesd 356,5 MW, and the lowest load reached 278,1 MW. Then, on weekends, the highest load reached 352,9 MW, and the lowest was 275,3 MW. For the last year, on weekdays, the peak load was 370,8 MW, and the lowest was 289,2 MW. During the weekend, the peak load was 367,1 MW, and the lowest load was 286,3 MW.

IV. RESULT AND DISCUSSION

This section discusses wheeling calculation using the LRMC and MW-Mile methods on a modified IEEE 14-bus test system.

A. POWER ALLOCATION

After the OPF on the system was performed, each bus's power flow was traced. This search was conducted to determine the power flows flowing on each bus, so fairness was expected to occur in determining the wheeling cost. The GA method was used for this power tracing, and the results are shown in Table II.

According to Table II, there are several channels with negative flow. From the generator side, the channel flow was negative because the generator did not supply the power but received it from the load. From the load side, the channel flow was negative because the load did not accept power flow, but the power flow returned to the system. When determining the wheeling cost, the channel with a negative flow value was exempt from paying the channel's cost, which was instead covered by the transmission line provider.

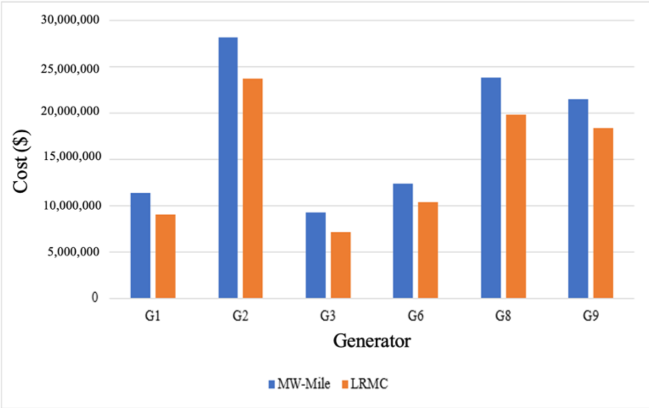

Figure 3. Comparison of wheeling costs of generators in three years.

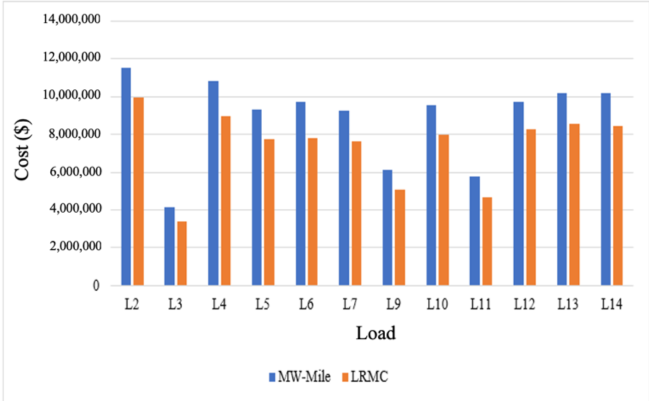

Figure 4. Comparison of the cost of wheeling loads in three years.

B. DETERMINATION OF WHEELING COST WITH LRMC

After tracing the power flow, the wheeling cost was calculated according to their respective contributions. The results revealed that the G2 generator had the most expensive operating costs, totaling $23,64 million over three years. On the other hand, the G3 generator had the lowest wheeling cost, which was $7,13 million. For loads, the most expensive wheeling cost was at L2 loads, which was $9,95 million in three years. Meanwhile, the cheapest was at L3 loads, which was $3,39 million. a variety of factors can affect the high or low cost of wheeling. One of them is the incorporation of all wheeling costumers, which causes the power flow map to change. There are differences in the cost function and specifications of the G2 and G3 generators. The quite significant difference in the generator cost function causes the high cost of the G2 generator.

C. WHEELING COST COMPARISON

After finding the power flow on each channel in the system, the wheeling cost was determined according to its contribution. The wheeling cost was compared using the MW-Mile and LRMC methods. This comparison was equivalent because both use power flow tracing with GA. These results can be seen in Table II.

The comparison results of the two methods can be seen in Figure 3 and Figure 4. Using the LRMC method, the experimental results revealed that the generator wheeler, specifically the G5 generator, was required to pay a transmission line rental of $36.22 million in three years. Using the MW-Mile method, the generator wheeler must pay a transmission line rental of $26,31 million in three years. Meanwhile, the load wheeler, namely L7, must pay a transmission line rental of $26.68 million in three years using the LRMC method. Meanwhile, using the MW-Mile method, the wheeler must pay a transmission line rental of $19,69 million in three years.

From this comparison, it is known that LRMC produces lower wheeling costs. This comparison is equivalent because the power flow tracing method used results from the same GA calculation. Wheeling costs with the LRMC method were 14% to 20% higher. Using the LRMC method, prices were calculated in more detail depending on changes in expenses and investment costs.

V. CONCLUSION

This research studied power flow tracking using the GA method. The determination of wheeling costs was calculated using the LRMC method and compared with the MW-Mile method. The simulation used a modified IEEE 14-bus test system to compare the two methods. The period in this study was set within three years. The simulation results clarify that the wheeling cost using the LRMC method was lower than that of the MW-Mile. It occurs since the LRMC method projects future costs by considering changes in expenses that occur at any time within a specified period. Economically, determining wheeling costs using the LRMC method was 14% up to 20% cheaper than the MW-Mile method, for example, on the G6 wheeling generator. In three years, the wheeling cost of the G6 plant using the MW-Mile method was $12,35 million. When using the LRMC method, wheeling costs droped by 15% to $10,34 million.

In the future, this method can be used to determine the wheeling over a more extended period. In addition, other wheeling cost method approaches can be implemented to determine wheeling cost and provide better results.

CONFLICT OF INTEREST

The authors of paper entitled “Genetic Algorithm in Determining Wheeling Cost Allocation Using LRMC and MW-Mile” declare the paper does not have conflicts of interest.

AUTHOR CONTRIBUTION

Conceptualization, Angga Cahya Putra and Sasongko Pramonohadi; methodology, Angga Cahya Putra, Sasongko Pramonohadi, and Sarjiya; writing—preparation of the original draft, Angga Cahya Putra; writing—review and editing, Sasongko Pramonohadi and Sarjiya.

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