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IMPROVED CUCKOO SEARCH FOR LOSS ALLOCATION IN TRANSMISSION LINE

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ABSTRACT

Electricity market reformation often involes the process of liberalisation, deregulation and privatisation. Privatisation has often resulted in competition between market participants in order to reduce cost and increase efficiency. Researchers have gained interest to allocate the transmission loss in transmission line which will lead to fair allocation of cost among market participants. Thus this paper proposed a new technique called Improved Cuckoo Search (ICS) as an approach to allocate transmission loss in transmission line. This technique is an improvement from previous technique called Cuckoo Search (CS), where cauchy distribution based on mutation technique is used instead of Levy Flight for its searching operator. The technique has been tested with IEEE 30 bus system in normal condition and showed improvement in terms of computational time and accuracy. Comparison between Cuckoo Search (CS) and Genetic Algorithm (GA) are also presented in this paper.

Keywords: Transmission Loss Allocation; Improved Cuckoo Search (ICS); Deregulation; Cauchcy Distribution

1. INTRODUCTION

Electricity market reformation often involves the process of liberalisation, deregulation and privatisation. Privatisation has often resulted in competition between market participants in order to reduce cost and increase efficiency. Competition in American electricity markets resulted in the right of co-generators and independent power producers (IPPs) to sell electricity to local utilities (Lo, 2002). On the other hand deregulation can be defined as the modification of existing regulation. It occurs when co- generators and IPPs begin to sell their their product to the private sector or any utility in the grid thus increasing the competition among market participants (Lo, 2002). Thus it becomes crucial to allocate loss among market participants as the end users now have the opportunity to choose their own suppliers. A lot of

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research have been conducted in order to allocate the transmission loss in order to have a fair cost allocation among market participants (Oloomi-Buygi & Salehizadeh, 2007).

Power tracing is another term that is being used by researchers to allocate power loss in transmission line. One of the earliest methods that has been used for power tracing is Proportional Sharing Principle (PSP) that has been introduced by Bialek (1996). His research assumes that the power leaving the node had the same proportion of the line flow to the node (Bialek, 1996). This method promises accurate loss allocation, but involved a complex mathematical process where matrices and vectors were involved in its process.

There is also a comparative study conducted in (Ansyari, Ozveren, & King, 2007) which put three different proportional sharing methods into comparison. This paper compared the proportional sharing method that has been proposed as in reference (Acha, Fuerte-Esquivel, Ambriz-Pérez, & Angeles-Camacho, 2005; Bialek, 1996, 1997; Kirschen, Allan, & Strbac, 1997; Kirschen & Strbac, 1999) which resulted in positive loss allocation. However, this comparative study is just focussed on one technique which is proportional sharing method.

Method based on circuit theories, equivalent current injection and equivalent impedance has also been proposed as in (Teng, 2005). This method allocates voltages, currents, power flow and losses contributed by generator. However, assumption that all generations in system would contribute to each line is not strong as the result proved that a generator may only inject power to a certain line.

On the other hand, another method proposed in (Parastar et al., 2008) is based on circuit theories which resulted in negative loss allocation. While in (Mustafa et al., 2009) a method based on modified nodal equation has been proposed with decomposition of voltage and current terms. However, this method assumes constant impedance and admittance in its loss calculation. There is also another method based on Thevenin theorem that has been proposed in (Liu, Mao, & Wang, 2010). Nevertheless, there is no result to demonstrate the effectiveness of this method.

Technique based on AC power flow and sensitivity theory has been proposed as in (Menezes & da Suva, 2006) which use analytical expression obtains from AC power flow equations. Despite the promising result showed by this technique, it required longer computational time. Another comparative study also has been conducted as in (Kazemi & Andami, 2006) which compared 4 different techniques to allocate the total loss in transmission line.

Even though all these methods provided a promising result, some of the techniques required complex mathematical process and derivation which were time consuming. There is also a method that requires longer computational time and allocates negative losses. Thus, as time goes by, researchers have come up with a new approach to allocate this loss by using optimization method to overcome all the drawback resulted in previous techniques.

One of the optimization methods that have been proposed to allocate this transmission loss is by using Genetic Algorithm (GA) as in reference (Sulaiman, Mustafa, & Aliman, 2009). This method was proposed due to simplicity. It doesn't involve complex mathematical derivations and gives an acceptable result with higher accuracy. However, this method requires a long computational time.

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To overcome this drawback, integration of Continuous Genetic Algorithm with (CGA) with Least Squares Support Vector Machine (LS-SVM) has been proposed in references (M.W. Mustafa, 2011; Mustafa et al., 2011). The output from proportional sharing method has been used to train the model before it can be adapted to GA-SVM. This method showed an improvement in the computational time required to allocate the transmission loss.

Besides incorporating GA with machine learning technique as SVM, some researchers proposed a method to allocate transmission loss based on Artificial Neural Network (ANN) as in reference (Choudhury & Goswami, 2009; Salar & Haghifam, 2010). This method used Shapley value game approached proposed in (Choudhury & Goswami, 2009) to train the neural network. Despite ANN is an efficient tool for prediction, the results demonstrate that as the number of busses increased the mean error is increased slightly. This indicates that, as the system becomes bigger and more complex, thus the error will increase.

Even though machine learning techniques provide promising results with shorter computational time, the process for generating training and testing data will be time consuming. Thus, a research proposed in reference (Rahman, Rahman, & Zakaria, 2013, 2014) uses a method called cuckoo search that does not involve complicated mathematical process since it only involves algorithm of the cuckoo breeding behavior which provides promising result without integrating with machine learning technique.

Cuckoo Search (CS) proposed in (Rahman et al., 2013, 2014) does provide a shorter computational time, however it still can be improved. Thus this paper proposed a method which is an improvement from CS method proposed in (Rahman et al., 2013, 2014). Instead of using the original searching operator, which is Levy flight, this paper proposed a new operating method to be integrated with CS method to improve the computational time.

2. IMPROVED CUCKOO SEARCH (ICS)TECHNIQUE

Cuckoo Search (CS) technique is an algorithm which is based on reproduction strategy developed by Xin She Yang and Suash Deb in 2009 (X.-S. Yang, 2010b). This algorithm utilized levy flight as its searching operator instead of random or quasi random manner. This is due to the study that showed that most animals and insects have indicated the characteristic of Levy flights (Brown, Liebovitch, & Glendon, 2007; X. S. Yang & Deb, 2010). Research shows how levy flight works efficiently as searching operator compared to random walks or Brownian motions (Sethi, Panda, & Sahoo, 2015).

However, for this proposed method of ICS, Cauchy distribution based on mutation technique is used to replace Levy flight as it searching operator. It has the same function as Levy flight, which is as searching operator. In CS, the offspring is determined by levy flight while for ICS, mutation is an operator to derive offspring from parents and enhance diversity of population (Kuo-Torng & Chun-Hsiung, 2008). A research has been conducted in (Zhang, He, & Zhu, 2016) shows that mutation based technique converge faster as compare to original CS technique.

The mutation from Evolutionary Programming (EP) is chosen for this proposed technique due to the reproduction operator used in EP for mapping the solution are much more heuristic and

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simpler. In addition, it gives a better convergence (Chiong & Beng, 2007). On the other hand, Cauchy distribution is chosen instead of Gaussian due to the research shown in (Chiong & Beng, 2007) which provided a better convergence.

For simplicity purpose, three idealized rules are implemented in this method (X.-S. Yang, 2010a):

a. Each Cuckoo lays one egg at one time and dumps the egg in random nest;
b. The best nest that has high quality egg will be carried to the next generations;

Number of nest are fixed and possibility for the host bird to discover the Cuckoo eggs are with probability of pa = 0.25 where it has been proven that it is sufficient for most optimization problem (X.-S. Yang, 2010a).

3. TRANSMISSION LOSS ALLOCATION BASED ON ICS

Implementation of this technique for transmission loss allocation is done by identifying the suitable objective function. Two objective functions were identified for comparison purpose. The first objective function is defined as the summation of real losses, loads and generators power mismatches as follows (Sulaiman et al., 2009):

$$\min(1) = \sum_{i \in nline} \Delta Loss_{i-j} + \sum_{k \in nbus} \Delta P_{Dk} + \sum_{m \in ngen} \Delta P^{Gm} \quad (1)$$

where,
$\Delta Loss_{i-j} = Loss_{i-j}^{LF} - Loss_{i-j}$,
$\Delta P_{Dk} = P_{Dk}^{LF} - P_{Dk}$ $(D = no. of\ load)$ and
$\Delta P^{Gm} = P^{Gm(LF)} - \left[\sum Loss_{i-j}^{Gm} + \sum P_{Dk}^{Gm}\right] (m = no. of\ generator)$

Note that $Loss_{i-j}^{LF}$ $\text{Loss}_{\text{i-j}}^{\text{LF}}$, P_{Dk}^{LF} and $\text{P}^{\text{Gm(LF)}}$ are obtained from load flow (LF) study.
On the other hand, the second objective function is defined as the summation of root mean square (RMS) error of real losses, loads and generator mismatches, as follows (Rahman et al., 2013, 2014):

$$\min(2) = \sqrt{\frac{\sum_{i \in nline} (\Delta Loss_{i-j})^2}{nline}} + \sqrt{\frac{\sum_{k \in nbus} (\Delta P_{Dk})^2}{nbus}} + \sqrt{\frac{\sum_{m \in ngen} (\Delta P^{Gm})^2}{ngen}} \quad (2)$$

Both of these objective functions are based on the real power balanced that can be defined as power injected from generator is equal to the load and power loss which can be expressed as follows (Sulaiman et al., 2009):

$$P^{Gi} = \sum_{n=1}^{nline} Loss_{i-j}^{Gi} + \sum_{k=1}^{nbus} P_{Dk}^{Gi} \quad (3)$$

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Where P^{Gi} is the real power from generator *i* , P_{Dk}^{Gi} is the contribution of generator *i* to load *k*, $Loss_{i-j}^{Gi}$ is the contribution of generator *i* to loss at line *i-j*, *nline* is the number of line and *nbus* is the total number of bus in the system. The particular line losss and load can be expressed as a fraction of individual generator as follows (Sulaiman et al., 2009):

$$Loss_{i-j} = \sum_{k=1}^{nG} x_{i-j}^{Gi} \left[Loss_{i-j}^{LF}\right] \quad (4)$$

$$P_{Dk} = \sum_{k=1}^{nG} y_k^{Gi} \left[P_{Dk}^{LF}\right] \quad (5)$$

where x_{i-j}^{Gi} is the fraction of each generator to the line loss, and y_k^{Gi} is the fraction each generator to load and *nG* is the number of generator in the system. These fractions are treated as optimization problem to allocate the transmission loss.

To implement these objective functions, the ICS technique is developed using MATLAB software and being tested with IEEE 30-Bus system which can be found in (Saadat, 2004). The overall flow for this technique is illustrated as in Figure 1. The number of nest chosen for this proposed technique is fixed to 25 nests and the simulation is repeated for 10 times for accuracy purpose. Nests in this algorithm will be represented as the solution. Result obtained from this technique is observed in two criteria which are accuracy and computational time. In addition, comparative study is done with the existing techniques, GA and CS.

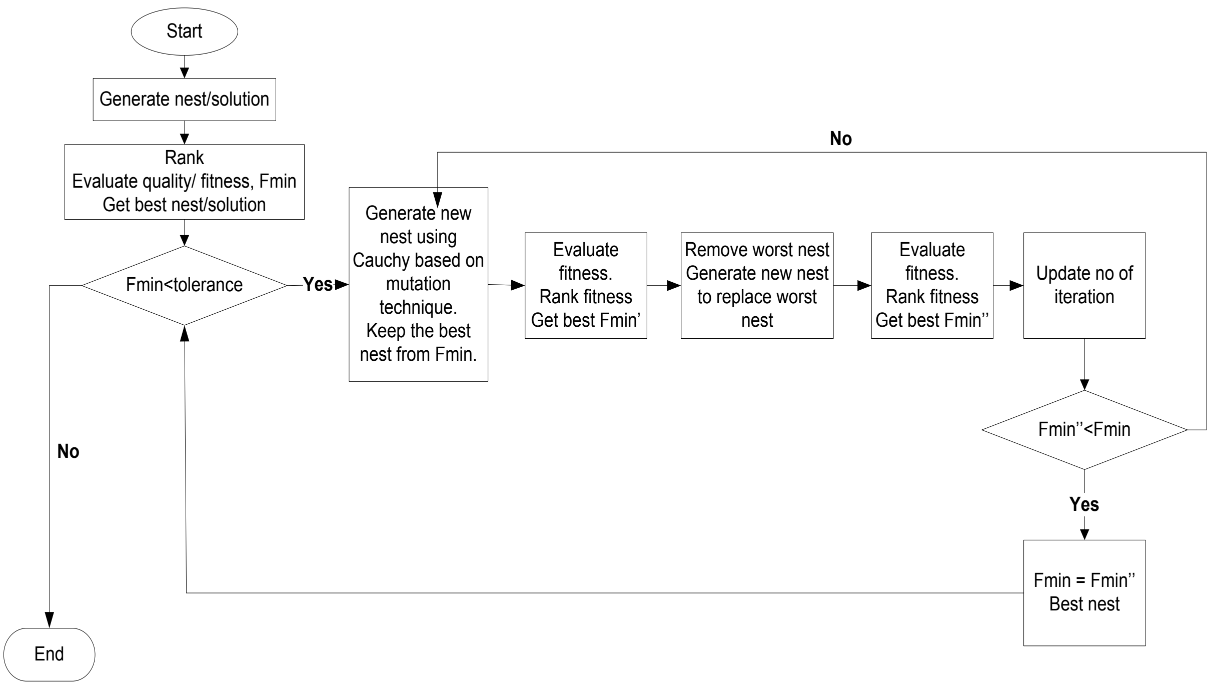

Figure 1: Flow chart of Improved Cuckoo Search

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4. RESULT AND DISCUSSION

This section presented the overall result of transmission loss allocation using ICS technique for IEEE 30- Bus system. Table 1 and 2 show the result for loss allocation for IEEE 30 bus system using the first and second objective function from equation (1) and (2) respectively.

Table 1 shows the result for transmission loss for IEEE 30-Bus system using the first objective function. The total loss allocates using ICS have been recorded to be 17.5985 MW, while CS technique gives a value of 17.5979 MW. These two values then were compared with GA technique which gave 17.5868 MW. Result from ICS technique gave the value that was almost the same as in load flow study which can be find as in reference (Rahman et al., 2013, 2014). In addition, time required for ICS technique to complete the simulation was only 4.06 seconds, while CS and GA technique took around 16.57 seconds and 86 seconds respectively. This shows that cauchy based and mutation techique proposed in ICS technique converge faster compared to levy flight and gaussian distribution used in GA.

On the other hand, Table 2 presented result for ICS technique using the second objective function. This result is compared with CS technique using the same objective function, while for GA technique, the first objective function is used as presented in reference (Sulaiman et al., 2009).

From this table it can be seen that there were no differences in the total loss allocation for ICS and CS technique. While for GA technique, there were slight differences. These results showed that ICS and CS technique provided a better accuracy as compared to GA technique.

For second objective function the time required for ICS to complete the simulation is only 1.73 seconds while CS technique required 14.74 seconds using the same objective function. This once again shows the advantages using the cauchy based on mutation technique and at the same time improving the computational time when it was tested with second objective function. Figure 2 shows the comparison of this 3 technique using both objective functions.

Comparison presented in Figure 2 shows that ICS did give a good accuracy with both objective functions. Besides that, time required by ICS had a bigger difference compared to CS and GA technique. This shows that ICS technique was capable to allocate loss with good accuracy and faster time.

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Table 1: Transmission Loss Allocation for IEEE 30-Bus System in Megawatt (MW) using First Objective Function

Line	**G1**	**G2**	**ICS**	**CS**	**GA**
1 to 2	2.2314	3.2321	5.4635	5.4635	5.4932
1 to 3	1.7606	1.0476	2.8082	2.8082	2.8306
2 to 4	0.8917	0.2148	1.1065	1.1065	1.0887
3 to 4	0.3476	0.4232	0.7708	0.7708	0.7654
2 to 5	2.8043	0.1909	2.9952	2.9947	2.9881
2 to 6	1.2269	0.8209	2.0478	2.0478	2.0592
12 to13	0.0000	0.0000	0.0000	0.0000	0.0000
4 to 12	0.0000	0.0000	0.0000	0.0000	0.0000
4 to 6	0.5804	0.0238	0.6042	0.6042	0.5969
6 to 8	0.1007	0.0027	0.1034	0.1034	0.1033
11 to 9	0.0000	0.0000	0.0000	0.0000	0.0000
6 to 9	0.0000	0.0000	0.0000	0.0000	0.0000
6 to 7	0.1047	0.2626	0.3673	0.3673	0.3665
7 to 5	0.1499	0.0011	0.1510	0.1510	0.1473
6 to 10	0.0000	0.0000	0.0000	0.0000	0.0000
9 to 10	0.0000	0.0000	0.0000	0.0000	0.0000
12 to 14	0.0576	0.0169	0.0745	0.0745	0.0734
12 to 15	0.1602	0.0572	0.2174	0.2174	0.2125
12 to 16	0.0528	0.0007	0.0535	0.0535	0.0521
14 to 15	0.0033	0.0027	0.0060	0.0060	0.0048
16 to 17	0.0093	0.0024	0.0117	0.0117	0.0093
15 to 18	0.0352	0.0039	0.0391	0.0391	0.0394
18 to 19	0.0044	0.0006	0.0050	0.0050	0.0037
10 to 20	0.0468	0.0340	0.0808	0.0808	0.0786
20 to 19	0.0160	0.0009	0.0169	0.0169	0.0144
10 to 17	0.0123	0.0021	0.0144	0.0144	0.0126
10 to 21	0.0966	0.0133	0.1099	0.1099	0.1066
10 to 22	0.0495	0.0023	0.0518	0.0518	0.0504
22 to 21	0.0006	0.0001	0.0007	0.0007	0.0000
15 to 23	0.0107	0.0206	0.0313	0.0313	0.0294
22 to 24	0.0316	0.0113	0.0429	0.0429	0.0399
23 to 24	0.0053	0.0007	0.0060	0.0060	0.0045
25 to 24	0.0074	0.0004	0.0078	0.0078	0.0072
28 to 8	0.0002	0.0000	0.0002	0.0002	0.0000
6 to 28	0.0487	0.0112	0.0599	0.0599	0.0583
28 to 27	0.0000	0.0000	0.0000	0.0000	0.0000
27 to 25	0.0202	0.0055	0.0257	0.0257	0.0263
25 to 26	0.0351	0.0094	0.0445	0.0445	0.0433
27 to 29	0.0485	0.0373	0.0858	0.0858	0.0814
27 to 30	0.1426	0.0188	0.1614	0.1614	0.1684
29 to 30	0.0324	0.0010	0.0334	0.0334	0.0311
TOTAL	**11.1255**	**6.4730**	**17.5985**	**17.5979**	**17.5868**

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Table 2: Transmission Loss Allocation for IEEE 30-Bus System in Megawatt (MW) using Second Objective Function

Line	G1	G2	ICS	CS	GA
1 to 2	4.3958	1.0677	5.4635	5.4635	5.4932
1 to 3	0.7629	2.0453	2.8082	2.8082	2.8306
2 to 4	0.9550	0.1515	1.1065	1.1065	1.0887
3 to 4	0.7271	0.0437	0.7708	0.7708	0.7654
2 to 5	1.7492	1.2460	2.9952	2.9947	2.9881
2 to 6	1.8650	0.1828	2.0478	2.0478	2.0592
12 to13	0.0000	0.0000	0.0000	0.0000	0.0000
4 to 12	0.0000	0.0000	0.0000	0.0000	0.0000
4 to 6	0.5584	0.0458	0.6042	0.6042	0.5969
6 to 8	0.0962	0.0072	0.1034	0.1034	0.1033
11 to 9	0.0000	0.0000	0.0000	0.0000	0.0000
6 to 9	0.0000	0.0000	0.0000	0.0000	0.0000
6 to 7	0.3350	0.0323	0.3673	0.3673	0.3665
7 to 5	0.1156	0.0354	0.1510	0.1510	0.1473
6 to 10	0.0000	0.0000	0.0000	0.0000	0.0000
9 to 10	0.0000	0.0000	0.0000	0.0000	0.0000
12 to 14	0.0680	0.0065	0.0745	0.0745	0.0734
12 to 15	0.1840	0.0334	0.2174	0.2174	0.2125
12 to 16	0.0347	0.0188	0.0535	0.0535	0.0521
14 to 15	0.0044	0.0016	0.0060	0.0060	0.0048
16 to 17	0.0108	0.0009	0.0117	0.0117	0.0093
15 to 18	0.0128	0.0263	0.0391	0.0391	0.0394
18 to 19	0.0047	0.0003	0.0050	0.0050	0.0037
10 to 20	0.0598	0.0210	0.0808	0.0808	0.0786
20 to 19	0.0159	0.0010	0.0169	0.0169	0.0144
10 to 17	0.0137	0.0007	0.0144	0.0144	0.0126
10 to 21	0.0753	0.0346	0.1099	0.1099	0.1066
10 to 22	0.0484	0.0034	0.0518	0.0518	0.0504
22 to 21	0.0004	0.0003	0.0007	0.0007	0.0000
15 to 23	0.0290	0.0023	0.0313	0.0313	0.0294
22 to 24	0.0406	0.0023	0.0429	0.0429	0.0399
23 to 24	0.0059	0.0001	0.0060	0.0060	0.0045
25 to 24	0.0021	0.0057	0.0078	0.0078	0.0072
28 to 8	0.0002	0.0000	0.0002	0.0002	0.0000
6 to 28	0.0435	0.0164	0.0599	0.0599	0.0583
28 to 27	0.0000	0.0000	0.0000	0.0000	0.0000
27 to 25	0.0197	0.0060	0.0257	0.0257	0.0263
25 to 26	0.0426	0.0019	0.0445	0.0445	0.0433
27 to 29	0.0622	0.0236	0.0858	0.0858	0.0814
27 to 30	0.1544	0.0070	0.1614	0.1614	0.1684
29 to 30	0.0312	0.0022	0.0334	0.0334	0.0311
TOTAL	**12.5245**	**5.0740**	**17.5985**	**17.5979**	**17.5868**

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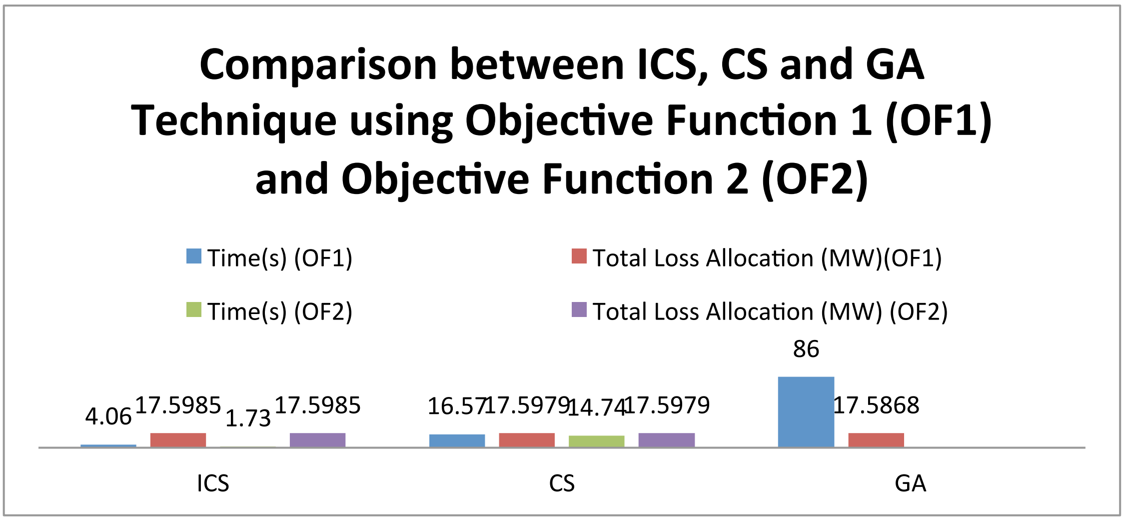

Figure 2 : Comparison between ICS, CS and GA Technique using Both Objective Functions

5. CONCLUSION

This paper has proposed a new improved technique known as the Improved Cuckoo Search to allocate the transmission loss. The proposed technique gave a good performance in terms of computational time where 4.06 seconds was recorded using the first objective function and 1.73 seconds using the second objective function. In terms of accuracy, there was not much significant difference compared from ICS, CS and GA. In addition, the proposed technique showed a better performance when incorporated with the second objective function. The proposed ICS technique also has outperformed the current loss allocations technique based on GA in terms of the accuracy and the computational time.

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