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Cost of Energy Losses Analysis Using a Hybrid Evolutionary Programming-Firefly Algorithm for Distributed Generation Installation

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ABSTRACT

This paper presents the Hybrid Evolutionary Programming-Firefly Algorithm (EPFA) technique for the cost of energy losses analysis of distributed generation (DG). In this study, EPFA is developed to determine the optimal size of DG while considering the system's energy losses. EPFA is developed based on embedded Firefly Algorithm (FA) properties into the classical EP technique. The objective of this study was to reduce the cost of energy losses while increasing the voltage profile and minimizing distribution system losses between the different operational strategies and types of DG. In this study, the analysis was done by considering DG type 1 and DG type 2. The proposed technique was tested using the IEEE 69-bus test system. In terms of economic concerns, power system planners can use the information acquired for utility planning to determine the right location and capacity of DG. Finally, the proposed method can determine the appropriate DG sizing while reducing the cost of energy losses and total losses in the system, based on the simulation results.

Keywords: Cost of Energy Losses, Distributed Generation, Evolutionary Programming, Firefly Algorithm, Voltage Profile Improvement.

1. INTRODUCTION

The power distribution network is one of the important parts of the power system. This is because it is the last part of power distribution to most customers such as industry, commerce, and resident. Therefore, the distribution network must be kept customers in good quality powerwith an acceptable voltage profile so power loss can be minimized. Thus, Distributed Generator (DG) has been introduced to improve the power quality of the distribution network. Installation of DG is one of the most popular methods to improve the performance of the test system. However, the selection of improper location and sizing of the DG installation will cause the overcompensated and under-compensated [1]. As a result, properly distributed generation unit distribution system allocation is crucial. The optimal DG sizing optimization for the distribution system will result from the optimal placement of DG. The definition, benefits, and challenges connected with small-scale electricity-generating were reviewed in references [2]–[5]. Stochastic optimization approaches should be improved in high-demand power systems due to load increases that cause voltage damage, which leads to current increases and system losses. These occurrences have been linked to non-optimal compensation parameter selections in a power system [6]. A reliable optimization mechanism is required to solve this problem.

Several conventional methods have been proposed for solving the DG allocation problem such as gradient-based method, linear programming, and loss sensitivity method. In general, these conventional methods may determine the optimal solution to a small-scale optimization problem

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*Corresponding Author: rafidah@unimap.edu.my in a short amount of time. Nonetheless, the fundamental issue is that it has difficulties coping with large-scale problems because of the large search space, which results in slow or no convergence [7]. Therefore, researchers have developed Metaheuristic as an alternative to the conventional approach particularly in Nature-Inspired Algorithms (NIA) [8]. Optimization techniques such as Firefly Algorithm (FA), Whales Optimization Algorithm (WAO), Evolutionary Programming (EP), and Ant Lion Optimization (ALO) have been developed to solve DG-unit problems, [9]–[13].

This study presented the comparative study between types of distributed generation (DG) on the cost of energy losses while considering voltage profile and loss minimization of the distribution system. The purpose of this project is to propose a meta-heuristic technique to improve the voltage profile and minimize losses of distribution systems between the different types of DG. There are two types of DG used in this study which are DG type 1, where DG is injected with only real power (P) and DG type 2 where DG is injected with both real (P) and reactive power (Q). The effectiveness of the developed technique is tested on IEEE 69-bus distribution system [14]. A Hybrid Evolutionary Programming-Firefly Algorithm (EPFA) will be used for the cost of energy losses analysis for distributed generation (DG) while improving voltage profile and minimizing the losses of the DG. The software that will be used to perform this optimization technique is MATLAB software. The best 5 optimal locations within the 69-bus test system and the DG sizing will be obtained. Then, the results that are obtained between the different types of DG will be compared in terms of cost of energy losses, voltage profile, and loss minimization and the best type of DG will be identified.

2. METHODOLOGY

The proposed method is developed to identify the optimal DG sizing for reducing power loss in distributed systems and analyze the cost of energy losses. The proposed hybrid EPFA was compared to EP and AIS methodologies to verify the results.

2.1 Problem Formulation

The optimal size of the DG is determined by using the MW output P_g of the DG as the variable to be optimized. The MVAR output of the distributed generator was determined using Equation (2) and the power factor of the system was set to be 0.85.

$$x_i = P_g \tag{1}$$

$$Q_g = P_g \, tan^{-1} \theta \tag{2}$$

$$cos\,\theta = 0.85 \tag{3}$$

$$\theta = Power\ factor\ angle \tag{4}$$

The purpose of this study is to analyse the effects of cost of energy losses (CL) prior to DG installation for single objective implementation while considering loss minimization. The objective function, Of_1, is denoted as follows in (5):

$$Of_1 = \min\,(CL) \tag{5}$$

The generator's limits can be set on an hourly basis if needed. This simulation makes it easy to model intermittent DG sources like solar and wind power. References [15]–[17] present a study of the annual *CL*. Equation (6) calculates the annual cost of energy loss, while equation (7) calculates the loss factor in terms of load factor (Lf).

$$CL = (T_{Loss}) * (K_p + K_e * Lsf * 8760) \tag{6}$$

Loss factor is expressed in terms of load factor (L_f) as in equation (7),

$$Lsf = k * L_f + (1 - k) + {L_f}^2 \tag{7}$$

Where $K = 0.2$, $L_f = 0.47$, $K_p = 57.6923$, $K_e = 0.00961538$

T_{Loss}: total real power losses (MW),
K_p: annual demand cost of power loss ($/kW),
K_e: annual cost of energy loss ($/kW h)
Lsf: loss factor.

When comparing the bus voltage to the reference bus, the voltage profile index (VPI) is used to determine the difference in voltage between the two buses. A voltage profile improvement (VPI) is used to measure the efficiency of voltage profile improvements in a system when DG is placed optimally. After solving for the VPI index, which should be less than 0.05 because the minimum voltage is set to be:

$$VPI = \frac{V_{no\min al} - V_{DG}}{V_{no\min al}} \tag{8}$$

The first step in the optimization process is by calculating the power flow solution to determine the nominal voltage at each bus. The top five locations for DGs installation are determine using the voltage ranking identification technique. This location was identified based on the rank of voltage profile in ascending order.

2.2 Proposed Hybrid-EPFA

Developing the proposed EPFA technique was done with the objective of reducing the CL value while still satisfying the voltage constraint in the system in consideration. The EPFA is developed based on Firefly Algorithm (FA) properties that have been embedded into the classical EP technique. Based on previous research, it appears that combining different optimization approaches can make the hybridising optimization process more efficient and robust. In this study, the convergence is set to 100 iterations to lessen the optimization's workload. The iteration is set to that value to limit the computational time caused by incorrect location. Since the system did not converge, such a condition may imply that the location is not suitable for installing any DG or that it is not recommended to place the DG. It is necessary to initialize DG sizing by creatinga random variable. Following the completion of the generate population step, the objective function is used to calculate the data's fitness level for analysis. To perform Firefly Algorithm (FA), the initial location of i_{th} solution was compared to that of its j_{th} neighbouring solution, after which the firefly attractiveness of i_{th} solution was evaluated. During the process of mutation, the value of individuals is randomly changed with a low probability of producing offspring. At that point, the data will be altered. Equation (9) is a general equation that uses the Gaussian mutation method as its foundation.

$$A_{i+mj} = A_{ij} + N(0, \beta(A_{j\,max} - A_{j\,min})\left(\frac{fi}{f_{max}}\right) \tag{9}$$

A_{i+mj} = Clone mutations
A_{ij} = Clones
N = Gaussian random number variable with mean μ and variance γ^2
β = Scale of mutation, $0 < \beta > 1$
$A_{j\,max}$ = Maximum random number for each variable
$A_{j\,min}$ = Minimum random number for each variable

f_i = Fitness for i^{th} random number
f_{max} = Maximum fitness

A new value will be calculated by applying the mutation formula in equation (9) to the original value. It will be possible to combine information from both parents, or from the original and mutations, in a single array of information. The combined data set will be assigned a new order of fitness values in accordance with the new order. The data from the parents as well as the first-generation mutations will be combined into a single set of information. As a result of the sorting of the combo data, the value with the lowest power losses will be obtained. This is followed by the execution of the convergence test. It is used to determine the optimization process's stopping criterion. This procedure will be repeated out till the convergence condition is met. The program will be halted if the difference between the maximum and minimum values is less than 0.0001.

As depicted in Figure 1, a flowchart for the proposed Hybrid EPFA is presented. The proposed technique was tested using the IEEE 69-bus test system, which was designed specifically for this purpose. The test system consists of a 69 branch, 9 lateral test system that was derived from a portion of the American PG&E distribution network (currency in $).

Studies were carried out using the EP and AIS algorithms to generate the same objective function to demonstrate the impact of a single DG installation with a variety of DG types. The mutation process is using the Gaussian mutation method. The analysis was done in terms of DG sizing, active power losses (P_{loss}), reactive power losses (Q_{loss}), *CL*, minimum voltage (V_{min}), maximum voltage (V_{max}), and voltage profile index (*VPI).*

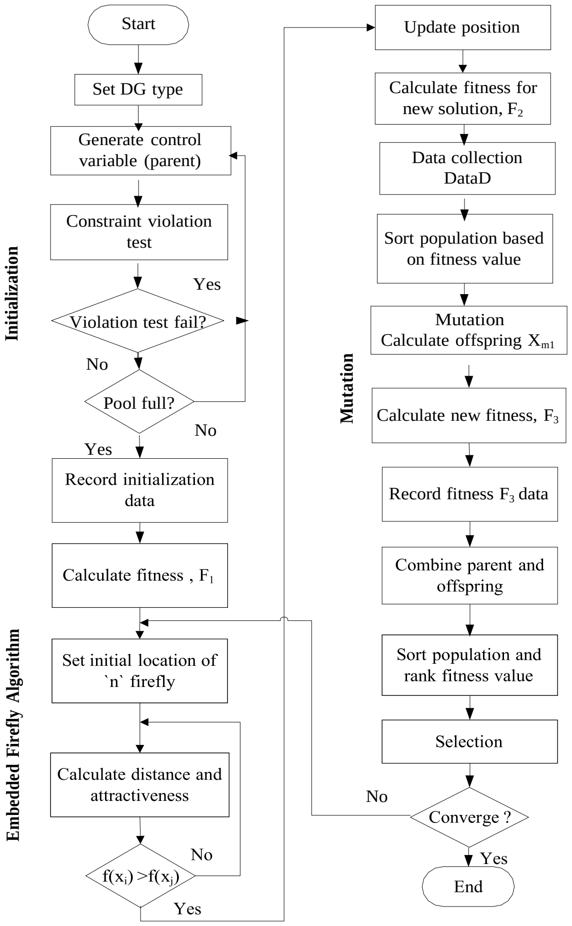

Figure 1. Flowchart for implementation of proposed Hybrid EPFA

3. RESULTS AND DISCUSSION

The case study employs the IEEE 69 bus test system. The total real (P_{loss})and reactive power losses (Q_{loss}) in the base case or without DG installation are 0.225MW and 0.102MVar,respectively. The cost of energy losses is recorded as $18,107.

Following that, the voltage ranking identification technique is used to determine the top five locations for DG installation. This location was determined using the rank of the voltage profile in ascending order. The voltage profile value for the base case is depicted in Figure 2. The graph indicates which buses have the lowest voltage profile based on their bus number: 61,62,63,64, and 65. These buses will then be installed with DG.

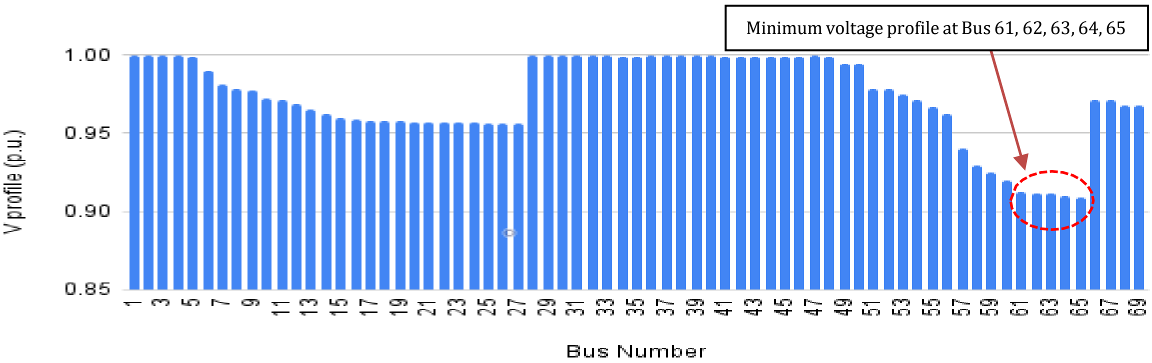

Figure 2. Voltage profile value for the base case

Table 1, Table 2, and Table 3 show the results for the proposed EPFA, EP, and AIS technique with DG type 1 respectively while Table 4, Table 5, and Table 6 indicate the results for the proposed EPFA, EP, and AIS technique with DG type 2 respectively. From these six tables, it is alleged that DG at bus 61 produces the lowest average P_{loss}, Q_{loss}, and minimum voltage, followed by bus 62, bus 63, bus 64, and bus 65. After DG is implemented at bus 61, all three optimization methodologies show a significant improvement in the cost of energy loss. As V_{min} is set to 0.95 in the formula for VPI, the outcome of VPI must be less than or equal to 0.05 to indicate VPI improvement. Based on all the six tables, bus 61 has the lowest VPI value for all of the five buses, showing the biggest improvement in VPI, especially EPFA optimization technique for DG type 2 with an average of 0.02744.

Next, the EPFA optimization technique resulted in the lowest value of average P_{loss}, Q_{loss}, and minimum voltage followed by AIS and EP optimization techniques. P_{loss} for DG type 1 with EPFA technique is 0.08321MW while 0.02317MW for DG type 2, thus, the result shows by DG type 2 outperformed the results for DG type 1. Since P_{loss} before installing DG is 0.225MW, the Power Loss Improvement Index for DG type 1 with EPFA technique is 63.01778% while 89.70222% for DG type 2 which shows the significant improvement for the power losses after installing DG type 2 with EPFA technique. The cost of energy losses for EPFA shows a significant cost reduction of $$6698.37 when compared to the cost of energy losses without implementing DG, which is $18,107. The cost of energy losses for AIS and EP optimization techniques show a significant cost reduction of $6718.12 and $6840.04 each for DG type 1. AIS and EP optimization techniques result in a significant cost reduction of $1865.16, followed by a cost reduction of $2131.52 and a cost reduction of $2131.52, respectively, in the cost of energy losses for EPFA with DG type 2. This is in comparison to a cost reduction of $18,107 in the cost of energy losses without the use of DG. The EPFA optimization technique, in conjunction with the installation of DG type 2 on bus 61, can save approximately $16241.84 in energy losses, resulting in a total savings of approximately $16241.84. Figure 3 depicts the cost of energy loss expressed as a percentage for both DG types at bus 61, with the EPFA technique saving 89.7% of the total cost of energy loss when compared to other techniques.

Table 1. Results for the proposed EPFA technique with DG Type 1.

DG Location	Simulation No	P_{DG} (MW)	P_{loss} (MW)	Q_{loss} (MVar)	Cost of energy losses ($)	Min Voltage (p.u)	Max Voltage (p.u)	VPI
61	1	1.86033	0.08321	0.04054	6698.03	0.96825	1.00000	0.03174
	2	1.85143	0.08322	0.04055	6698.87	0.96820	1.00000	0.03180
	3	1.86527	0.08321	0.04053	6697.75	0.96828	1.00000	0.03172
	4	1.89841	0.08323	0.04049	6699.46	0.96847	1.00000	0.03153
	5	1.88002	0.08321	0.04051	6697.75	0.96837	1.00000	0.03163
Average		1.87109	0.08321	0.04052	6698.37	0.96831	1.00000	0.03168
62	1	1.86767	0.08472	0.04129	6819.63	0.96828	1.00000	0.03172
	2	1.81071	0.08475	0.04138	6822.10	0.96795	1.00000	0.03205
	3	1.85694	0.08471	0.04130	6818.67	0.96822	1.00000	0.03178
	4	1.88682	0.08476	0.04128	6822.95	0.96840	1.00000	0.03160
	5	1.85969	0.08471	0.04130	6818.85	0.96824	1.00000	0.03176
Average		1.85637	0.08473	0.04131	6820.44	0.96822	1.00000	0.03178
63	1	1.84518	0.08701	0.04248	7003.69	0.96813	1.00000	0.03187
	2	1.78836	0.08698	0.04253	7001.13	0.96780	1.00000	0.03220
	3	1.81729	0.08696	0.04249	7000.07	0.96797	1.00000	0.03203
	4	1.70349	0.08737	0.04278	7032.79	0.96730	1.00000	0.03270
	5	1.78500	0.08698	0.04253	7001.57	0.96778	1.00000	0.03222
Average		1.78786	0.08706	0.04256	7007.85	0.96780	1.00000	0.03220
64	1	1.66319	0.09658	0.04745	7774.29	0.96700	1.00000	0.03300
	2	1.67368	0.09660	0.04746	7775.71	0.96706	1.00000	0.03294
	3	1.68881	0.09664	0.04748	7779.03	0.96715	1.00000	0.03285
	4	1.69325	0.09666	0.04748	7780.29	0.96717	1.00000	0.03283
	5	1.60627	0.09664	0.04747	7779.14	0.96666	1.00000	0.03334
Average		1.66504	0.09662	0.04747	7777.69	0.96701	1.00000	0.03299
65	1	1.47355	0.11215	0.05520	9027.33	0.96577	1.00000	0.03423
	2	1.44358	0.11209	0.05513	9022.80	0.96559	1.00000	0.03441
	3	1.41690	0.11211	0.05510	9024.47	0.96506	1.00000	0.03494
	4	1.45495	0.11210	0.05515	9023.72	0.96566	1.00000	0.03434
	5	1.42105	0.11210	0.05510	9023.85	0.96520	1.00000	0.03480
Average		1.44201	0.11211	0.05513	9024.44	0.96546	1.00000	0.03454

Table 2. Results for EP technique with DG Type 1.

DG Location	Simulation No	P_{DG} (MW)	P_{loss} (MW)	Q_{loss} (MVar)	Cost of energy losses ($)	Min Voltage (p.u)	Max Voltage (p.u)	VPI
61	1	1.83164	0.08326	0.04060	6702.34	0.96808	1.00000	0.03192
	2	2.02357	0.08399	0.04062	6760.96	0.96920	1.00000	0.03080
	3	1.90517	0.08324	0.04048	6700.56	0.96851	1.00000	0.03149
	4	2.29023	0.08912	0.04234	7174.09	0.97073	1.00000	0.02927
	5	2.11670	0.08525	0.04100	6862.26	0.96974	1.00000	0.03026
Average		2.03346	0.08497	0.04101	6840.04	0.96926	1.00000	0.03074
62	1	1.62951	0.08641	0.04231	6955.42	0.96687	1.00000	0.03313
	2	1.86756	0.08472	0.04129	6819.61	0.96828	1.00000	0.03172
	3	1.50337	0.08900	0.04355	7163.96	0.96612	1.00000	0.03388
	4	1.78533	0.08484	0.04145	6829.21	0.96780	1.00000	0.03220
	5	1.82071	0.08473	0.04136	6820.32	0.96801	1.00000	0.03199
Average		1.72130	0.08594	0.04199	6917.70	0.96742	1.00000	0.03258
63	1	1.58421	0.08883	0.04352	7150.51	0.96659	1.00000	0.03341
	2	1.71576	0.08728	0.04273	7025.56	0.96737	1.00000	0.03263
	3	1.68362	0.08754	0.04287	7046.41	0.96718	1.00000	0.03282
	4	1.90476	0.08729	0.04253	7026.53	0.96848	1.00000	0.03152
	5	1.65759	0.08780	0.04301	7067.86	0.96703	1.00000	0.03297
Average		1.70919	0.08775	0.04293	7063.38	0.96733	1.00000	0.03267
64	1	1.77075	0.09718	0.04771	7822.71	0.96762	1.00000	0.03238
	2	1.24317	0.10346	0.05037	8328.37	0.95948	1.00000	0.04052
	3	1.76724	0.09715	0.04769	7819.96	0.96760	1.00000	0.03240
	4	1.49007	0.09760	0.04788	7856.01	0.96597	1.00000	0.03403
	5	1.60199	0.09666	0.04748	7780.36	0.96664	1.00000	0.03336

DG Location	Simulation No	P_{DG} (MW)	P_{loss} (MW)	Q_{loss} (MVar)	Cost of energy losses ($)	Min Voltage (p.u)	Max Voltage (p.u)	VPI
Average		1.57465	0.09841	0.04823	7921.48	0.96546	1.00000	0.03454
65	1	1.33506	0.11260	0.05519	9063.58	0.96224	1.00000	0.03776
	2	1.33596	0.11259	0.05519	9062.87	0.96227	1.00000	0.03773
	3	1.61298	0.11350	0.05599	9136.11	0.96658	1.00000	0.03342
	4	1.38217	0.11224	0.05510	9034.77	0.96387	1.00000	0.03613
	5	1.53264	0.11250	0.05544	9055.96	0.96611	1.00000	0.03389
Average		1.43976	0.11269	0.05538	9070.66	0.96421	1.00000	0.03579

Table 3. Results for proposed AIS technique with DG Type 1.

DG Location	Simulation No	P_{DG} (MW)	P_{loss} (MW)	Q_{loss} (MVar)	Cost of energy losses ($)	Min Voltage (p.u)	Max Voltage (p.u)	VPI
61	1	1.83704	0.08325	0.04059	6701.18	0.96811	1.00000	0.03189
	2	1.96372	0.08349	0.04050	6720.77	0.96886	1.00000	0.03114
	3	1.81846	0.08331	0.04064	6705.89	0.96800	1.00000	0.03200
	4	1.98334	0.08363	0.04053	6731.78	0.96897	1.00000	0.03103
	5	1.76409	0.08362	0.04085	6730.99	0.96768	1.00000	0.03232
Average		1.87333	0.08346	0.04062	6718.12	0.96833	1.00000	0.03167
62	1	1.73364	0.08516	0.04165	6855.25	0.96749	1.00000	0.03251
	2	1.68035	0.08570	0.04195	6898.48	0.96718	1.00000	0.03282
	3	1.75152	0.08503	0.04157	6844.48	0.96760	1.00000	0.03240
	4	1.69316	0.08555	0.04187	6886.56	0.96725	1.00000	0.03275
	5	1.96886	0.08523	0.04137	6860.65	0.96887	1.00000	0.03113
Average		1.76551	0.08534	0.04168	6869.08	0.96768	1.00000	0.03232
63	1	1.80449	0.08696	0.04250	6999.94	0.96790	1.00000	0.03210
	2	1.90905	0.08732	0.04254	7028.97	0.96851	1.00000	0.03149
	3	1.77124	0.08701	0.04256	7004.08	0.96770	1.00000	0.03230
	4	1.94732	0.08765	0.04264	7055.35	0.96873	1.00000	0.03127
	5	1.82482	0.08697	0.04248	7000.60	0.96802	1.00000	0.03198
Average		1.85138	0.08718	0.04254	7017.79	0.96817	1.00000	0.03183
64	1	1.48290	0.09769	0.04792	7863.73	0.96593	1.00000	0.03407
	2	1.69282	0.09665	0.04748	7780.16	0.96717	1.00000	0.03283
	3	1.49726	0.09750	0.04784	7848.61	0.96602	1.00000	0.03398
	4	1.63263	0.09658	0.04745	7774.24	0.96682	1.00000	0.03318
	5	1.75388	0.09703	0.04764	7810.19	0.96752	1.00000	0.03248
Average		1.61190	0.09709	0.04767	7815.39	0.96669	1.00000	0.03331
65	1	1.43850	0.11209	0.05512	9022.70	0.96556	1.00000	0.03444
	2	1.30966	0.11288	0.05527	9086.27	0.96137	1.00000	0.03863
	3	1.43847	0.11209	0.05512	9022.70	0.96556	1.00000	0.03444
	4	1.59937	0.11329	0.05588	9119.23	0.96650	1.00000	0.03350
	5	1.40771	0.11213	0.05509	9026.30	0.96474	1.00000	0.03526
Average		1.43875	0.11250	0.05530	9055.44	0.96475	1.00000	0.03525

Table 4. Results for the proposed EPFA technique with DG Type 2.

DG Location	Simulation No	P_{DG} (MW)	Q_{DG} (MVar)	P_{loss} (MW)	Q_{loss} (MVar)	Cost of energy losses ($)	Min Voltage (p.u)	Max Voltage (p.u)	VPI
61	1	1.83312	0.96346	0.02317	0.01435	1865.05	0.97257	1.00000	0.02743
	2	1.83611	0.96503	0.02317	0.01435	1864.80	0.97257	1.00000	0.02743
	3	1.84563	0.97003	0.02318	0.01437	1866.27	0.97255	1.00000	0.02745
	4	1.83679	0.96539	0.02317	0.01435	1864.79	0.97257	1.00000	0.02743
	5	1.83887	0.96648	0.02317	0.01436	1864.87	0.97256	1.00000	0.02744
Average		1.83810	0.96608	0.02317	0.01435	1865.16	0.97256	1.00000	0.02744
62	1	1.81189	0.95230	0.02512	0.01541	2022.39	0.97233	1.00000	0.02767
	2	1.80841	0.95047	0.02512	0.01541	2022.40	0.97234	1.00000	0.02766
	3	1.80834	0.95044	0.02512	0.01541	2022.40	0.97234	1.00000	0.02766
	4	1.81770	0.95536	0.02514	0.01542	2023.42	0.97232	1.00000	0.02768

DG Location	Simulation No	P_{DG} (MW)	Q_{DG} (MVar)	P_{loss} (MW)	Q_{loss} (MVar)	Cost of energy losses ($)	Min Voltage (p.u)	Max Voltage (p.u)	VPI
	5	1.76755	0.92899	0.02808	0.01698	2260.46	0.97201	1.00000	0.02799
Average		1.80278	0.94751	0.02572	0.01573	2070.21	0.97227	1.00000	0.02773
63	1	1.77018	0.93038	0.02808	0.01698	2260.18	0.97201	1.00000	0.02799
	2	1.77028	0.93043	0.02808	0.01698	2260.17	0.97201	1.00000	0.02799
	3	1.76830	0.92939	0.02808	0.01698	2260.36	0.97201	1.00000	0.02799
	4	1.76808	0.92927	0.02808	0.01698	2260.38	0.97201	1.00000	0.02799
	5	1.76903	0.92978	0.02808	0.01698	2260.27	0.97201	1.00000	0.02799
Average		1.76917	0.92985	0.02808	0.01698	2260.27	0.97201	1.00000	0.02799
64	1	1.60277	0.84239	0.04077	0.02358	3281.84	0.97060	1.00000	0.02940
	2	1.60942	0.84589	0.04077	0.02358	3281.40	0.97059	1.00000	0.02941
	3	1.60920	0.84577	0.04076	0.02358	3281.38	0.97059	1.00000	0.02941
	4	1.60672	0.84446	0.04076	0.02358	3281.34	0.97059	1.00000	0.02941
	5	1.61065	0.84653	0.04077	0.02358	3281.53	0.97059	1.00000	0.02941
Average		1.60775	0.84501	0.04077	0.02358	3281.50	0.97059	1.00000	0.02941
65	1	1.39866	0.73511	0.06171	0.03396	4967.01	0.96872	1.00000	0.03128
	2	1.39519	0.73329	0.06170	0.03396	4966.76	0.96873	1.00000	0.03127
	3	1.39813	0.73484	0.06170	0.03396	4966.94	0.96873	1.00000	0.03127
	4	1.39456	0.73296	0.06170	0.03397	4966.78	0.96873	1.00000	0.03127
	5	1.39263	0.73195	0.06171	0.03397	4966.96	0.96873	1.00000	0.03127
Average		1.39584	0.73363	0.06170	0.03396	4966.89	0.96873	1.00000	0.03127

Table 5. Results for EP technique with DG Type 2.

DG Location	Simulation No	P_{DG} (MW)	Q_{DG} (MVar)	P_{loss} (MW)	Q_{loss} (MVar)	Cost of energy losses ($)	Min Voltage (p.u)	Max Voltage (p.u)	VPI
61	1	1.65289	0.86873	0.03159	0.01764	2542.62	0.97286	1.00000	0.02714
	2	1.72430	0.90626	0.02626	0.01552	2114.00	0.97275	1.00000	0.02725
	3	1.92490	1.01169	0.02497	0.01519	2010.34	0.97241	1.00000	0.02759
	4	1.99654	1.04935	0.02902	0.01693	2335.77	0.97228	1.00000	0.02772
	5	1.93015	1.01446	0.02519	0.01529	2028.03	0.97240	1.00000	0.02760
Average		1.84576	0.97010	0.02741	0.01611	2206.15	0.97254	1.00000	0.02746
62	1	1.88619	0.99135	0.02649	0.01604	2132.40	0.97221	1.00000	0.02779
	2	2.13801	1.12370	0.04920	0.02568	3960.02	0.97173	1.00000	0.02827
	3	1.77811	0.93454	0.02537	0.01548	2042.53	0.97239	1.00000	0.02761
	4	1.70236	0.89473	0.02801	0.01651	2254.42	0.97251	1.00000	0.02749
	5	1.78017	0.93563	0.02534	0.01547	2040.02	0.97239	1.00000	0.02761
Average		1.85696	0.97599	0.03088	0.01784	2485.88	0.97225	1.00000	0.02775
63	1	1.79384	0.94281	0.02820	0.01705	2269.88	0.97197	1.00000	0.02803
	2	1.77956	0.93531	0.02809	0.01700	2261.39	0.97199	1.00000	0.02801
	3	1.84146	0.96784	0.02926	0.01753	2355.27	0.97189	1.00000	0.02811
	4	1.55046	0.81490	0.04083	0.02215	3286.61	0.97234	1.00000	0.02766
	5	1.63040	0.85691	0.03317	0.01901	2669.92	0.97223	1.00000	0.02777
Average		1.71914	0.90355	0.03191	0.01855	2568.61	0.97208	1.00000	0.02792
64	1	1.75309	0.92140	0.04629	0.02594	3726.29	0.97036	1.00000	0.02964
	2	1.68282	0.88447	0.04227	0.02422	3402.46	0.97048	1.00000	0.02952
	3	1.65766	0.87124	0.04144	0.02386	3335.33	0.97052	1.00000	0.02948
	4	1.60035	0.84112	0.04078	0.02359	3282.48	0.97060	1.00000	0.02940
	5	1.66034	0.87265	0.04151	0.02389	3341.22	0.97051	1.00000	0.02949
Average		1.67085	0.87817	0.04246	0.02430	3417.55	0.97049	1.00000	0.02951
65	1	1.55359	0.81654	0.06910	0.03706	5562.03	0.96850	1.00000	0.03150
	2	1.54735	0.81326	0.06854	0.03682	5516.93	0.96851	1.00000	0.03149
	3	1.47393	0.77467	0.06357	0.03471	5116.80	0.96862	1.00000	0.03138
	4	1.52663	0.80237	0.06683	0.03609	5379.57	0.96854	1.00000	0.03146
	5	1.42592	0.74944	0.06199	0.03406	4989.68	0.96869	1.00000	0.03131
Average		1.50548	0.79126	0.06600	0.03575	5313.00	0.96857	1.00000	0.03143

Table 6. Results for proposed AIS technique with DG Type 2.

DG Location	Simulation No	P_{DG} (MW)	Q_{DG} (MVar)	P_{loss} (MW)	Q_{loss} (MVar)	Cost of energy losses ($)	Min Voltage (p.u)	Max Voltage (p.u)	VPI
61	1	1.96396	0.99479	0.02690	0.01602	2165.38	0.97234	1.00000	0.02766
	2	1.93512	0.98018	0.02541	0.01538	2045.66	0.97239	1.00000	0.02761
	3	1.97183	0.99877	0.02737	0.01623	2203.18	0.97232	1.00000	0.02768
	4	1.73682	0.87973	0.02560	0.01526	2061.01	0.97273	1.00000	0.02727
	5	1.71002	0.86616	0.02711	0.01585	2182.37	0.97277	1.00000	0.02723
Average		1.86355	0.94393	0.02648	0.01575	2131.52	0.97245	1.00000	0.02749
62	1	1.78334	0.90330	0.02530	0.01546	2036.47	0.97238	1.00000	0.02762
	2	1.85109	0.93762	0.02552	0.01561	2054.45	0.97227	1.00000	0.02773
	3	1.69686	0.85950	0.02831	0.01663	2279.03	0.97252	1.00000	0.02748
	4	1.97386	0.99980	0.03134	0.01813	2522.97	0.97205	1.00000	0.02795
	5	1.66079	0.84123	0.03072	0.01760	2472.43	0.97258	1.00000	0.02742
Average		1.79319	0.90829	0.02824	0.01669	2273.07	0.97236	1.00000	0.02764
63	1	1.87789	0.95119	0.03079	0.01819	2478.50	0.97182	1.00000	0.02818
	2	1.95965	0.99260	0.03641	0.02059	2930.83	0.97168	1.00000	0.02832
	3	1.67346	0.84764	0.03051	0.01793	2455.93	0.97216	1.00000	0.02784
	4	1.63603	0.82868	0.03276	0.01885	2637.35	0.97222	1.00000	0.02778
	5	1.87885	0.95168	0.03084	0.01821	2482.41	0.97182	1.00000	0.02818
Average		1.80518	0.91436	0.03226	0.01875	2597.01	0.97194	1.00000	0.02806
64	1	1.54563	0.78290	0.04182	0.02404	3366.64	0.97068	1.00000	0.02932
	2	1.60053	0.81070	0.04078	0.02359	3282.42	0.97060	1.00000	0.02940
	3	1.86264	0.94346	0.05729	0.03064	4611.62	0.97017	1.00000	0.02983
	4	1.49909	0.75932	0.04406	0.02500	3546.39	0.97075	1.00000	0.02925
	5	1.52201	0.77093	0.04280	0.02446	3445.19	0.97072	1.00000	0.02928
Average		1.60598	0.81346	0.04535	0.02554	3650.45	0.97058	1.00000	0.02942
65	1	1.53845	0.77926	0.06778	0.03650	5455.66	0.96852	1.00000	0.03148
	2	1.59971	0.81029	0.07388	0.03912	5946.94	0.96843	1.00000	0.03157
	3	1.73300	0.87780	0.09376	0.04775	7547.45	0.96820	1.00000	0.03180
	4	1.56506	0.79273	0.07018	0.03753	5649.22	0.96848	1.00000	0.03152
	5	1.56447	0.79244	0.07012	0.03751	5644.66	0.96848	1.00000	0.03152
Average		1.60014	0.81050	0.07514	0.03968	6048.79	0.96842	1.00000	0.03158

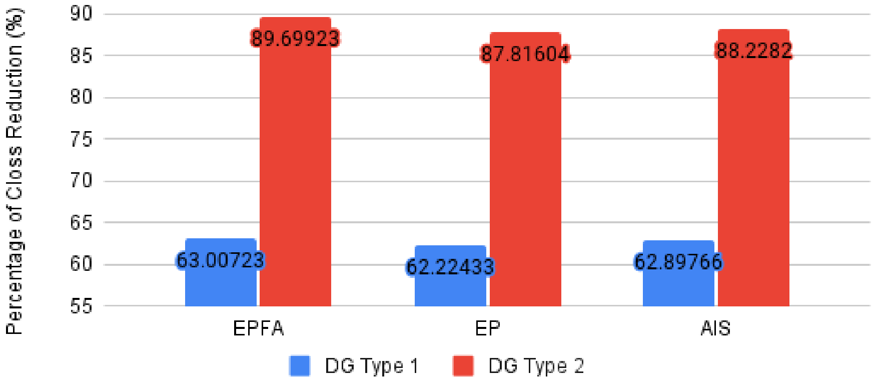

Figure 3. Comparison of cost of energy loss reduction for both DG types at bus 61.

4. CONCLUSION

This paper highlights a hybrid Evolutionary Programming-Firefly Algorithm (EPFA) technique for analysing the cost of energy losses in distributed generation (DG) and determining the optimal size of DG. EPFA with a different types of DG configurations have been successfully tested on theIEEE 69-bus test system. IEEE 69-bus test system is used to demonstrate the proposed technique.

For potential locations 61, 62, 63, 64, and 65, the five buses with the lowest voltage profiles were chosen. Then, EPFA is used to determine the optimal size of DG in the radial distribution network using two different types of DG, DG type 1 and DG type 2. EPFA is then compared to previously developed optimization techniques such as EP and AIS. The comparison of EPFA, EP, and AIS optimization techniques reveals that EPFA optimization produces the lowest average P_{loss}, Q_{loss}, and minimum voltage values for both types of DG. However, as compared to the installation of DG type 1, the installation of DG type 2 appears to have had a significant impact on loss reduction. EPFA for DG type 2 cost of energy losses has been reduced significantly, from $18,107 to $1865.16, compared to $18,107 for energy losses without DG. EPFA optimization technique withDG type 2 installed at bus 61, can save $16241.84 or 89.7% percent of energy cost.

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