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Firefly analytical hierarchy algorithm for optimal allocation and sizing of DG in distribution network

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ABSTRACT

Distributed generation (DG) can be beneficially allocated in distribution power systems to improve the power system's efficiency. However, specious DG's allocation and sizing may cause more power loss and voltage profile issues for distribution feeders. Therefore, optimization algorithms are vital for future intelligent power distribution network planning. Hence, this study proposes a multi-objective firefly analytical hierarchy algorithm (FAHA) for determining the optimal allocation and sizing of DG. The multi-objective function formulation is improved further by integrating analytical hierarchy process (AHP) with FA to obtain the weight of the coefficient factor (CF). The performance of the proposed approach is verified on the 118-bus radial distribution network with different bus voltage at DG location (V_{DG}) as regulated PV-bus during load flow calculations. The calculated CF and impact of the unregulated voltage at the PV-bus on the objectives function have been analysed. The findings show that the proposed techniques could allocate the DG at the most voltage deviation while minimizing the power loss and improving the radial distribution's voltage stability index (VSI). The experimental results indicate that the approach is able to improve the overall voltage profile, especially at PQ-buses, minimize the power loss while improving the network's stability index simultaneously.

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1. INTRODUCTION

Distributed generation (DG) is a technology of generating a small amount of electrical energy close to the load centre [1], [2]. DG can be a standalone facility for residential and commercial use or part of a microgrid [3], [4]. Industrial facilities, military bases, power supply, and huge colleges are potential locations to use DG. In other words, "electricity production within distribution networks or on the consumer side of the network" could be referred to as DG [5]. Solar energy, wind power, biomass, and solar thermal systems are among Malaysia's renewable energy sources that can be incorporated in the DG implementation [6]. An increase in power loss, an unbalanced power system, and rising operating costs are some of the effects due to poorly located DG units with the wrong size selection [7]-[9]. Hence, it is extremely important for the appropriate placement and optimal DGs to be investigated and analysed [10], [11]. As several factors must be considered when optimizing this particular problem, the multi-objective formulation has been studied for optimally allocating and sizing the DG. In relation to this study, previous researchers proposed numerous methods to solve multi-objective formulation associated with optimization methods such as pareto-front, weight-sum method and other multi-criteria decision approaches, including analytical hierarchy process (AHP) [12]-[14].

Saaty created the AHP model in the 1970s as a complex decision-making tool [14]. This model is based on the idea that when confronted with a difficult decision, the natural human tendency is to group the decision parts based on similar features. It involves developing a decision-making hierarchy and comparing each possible combination in each cluster as a matrix while each element within a hierarchy cluster is given weight in these steps. In the meantime, the consistency of ratio is used to assess the reliability of data while the steps to calculate the weights in AHP were discussed by Saaty [14]. Another study in [15] solves the multi-objective problem using AHP for order preferences by similarity to an ideal solution for power generation system optimization. Saaty [14], also proposed the AHP for prime power system phasor measurement unit (PMU) monitoring as a combinatorial way for monitoring the prime power system components. On the other hand, Babu and Maheswarapu [16] integrated the weighted-sum approach with AHP in order to solves the optimization problem with the idea of, the AHP optimising the objective function weights. Meanwhile, the research work in [17] applied AHP to calculate the resiliency scores to enhance strategy in distributed energy resources and automated switches. Srikanth [18] states that AHP is used for the optimised tuning in the algorithm proposed where the weights of alternatives used and selected were based on the AHP.

Numerous techniques were proposed for locating the optimal solution in the problem set this study is trying to solve and meta-heuristic techniques are one of the techniques widely used due to its promising results. The firefly algorithm (FA) is a well-known optimization algorithm invented by Xin-She Yang (2013) which takes inspiration from the flashing behaviours of a group of fireflies that used the bioluminescent communication method for interaction. The methodology of FA can be found in [19] and [20]. More importantly, Deb *et al.* [8] and used various optimization techniques to investigate the optimal size as well as the placement of the distributed generators in the grid and they found that FA to be able to locate good to optimal solutions with minimum fitness and standard deviation but the major drawback was that the computational time of the algorithm is extremely high [21]. Papadimitrakis *et al.* [22] supports the claim where the experiments conducted also indicated that the results obtained by FA provide superior results when compared against other algorithms [22].

This study focuses on incorporating AHP for automatic calculation of coefficient factor based on three objective functions into the FA where the proposed algorithm is called the firefly analytical hierarchy algorithm (FAHA). The main aim of this approach is to minimize the objective function which are voltage deviation (V_{DEV}), power loss (P_{loss}) and maximises the stability index (*SI*) in the distribution system. One of the major contributions of this study is that the AHP is modified based on load flow optimal output to obtain the objective function's weight or coefficient factors ($w1$=V_{DEV}, $w2$=P_{loss}, $w3$=SI). The methodology is then tested in a 118-bus radial distribution network for optimal DG allocation and sizing [23]. Authors in [23], [24] stated that any bus that attaches to megawatt generation can control its voltage magnitude and usually have regulated voltage between 1.0-1.05 p.u. Therefore, the location of DG becomes a voltage-controlled or also known as PV bus. However, a few authors in [25]-[27] varies the bus voltage and did not regulate bus voltage at the proposed DG location during the optimization process. Therefore, by referring to that reference, the bus chosen by the algorithm to allocate the DG will be considered as a voltage-control bus (PV-bus) of the load flow. The DG provides active power and controls the voltage at the DG location. Thus, this study will analyse the performance of the proposed technique based on three V_{DG} settings: varying V_{DG} (V_{DG} =V_{BUS}), V_{DG} regulated to 1.0 p.u, and 1.05 followed with the optimization process. Then, the power loss reduction along with the voltage profile improvement will be analysed. The algorithm is developed and simulated using MATLAB application software.

2. PROBLEM FORMULATION

This study expressed the problem formulation as a multi-objective optimization technique for DG allocation and sizing in a distribution network. This study's vital intention is to reduce the power loss, minimize voltage deviation while at the same time maximise the stability index (SI) with variation setting of voltage at the proposed DG location. All the objective functions are based on load flow results [28]. The fitness function within the system may be expressed via (1).

$$f_{min} = w1(V_{Dev}) + w2(P_{loss}) + w3\left(\frac{1}{SI}\right) \quad (1)$$

Where f, is the fitness function, V_{Dev} represents the voltage deviation, and P_{loss} is the normalized value of total power loss. The $1/SI$ is for SI maximization. While the *w1* is the coefficient factor for voltage deviation, *w2* is the power loss coefficient factor, and lastly, the coefficient factor for SI is represented by $w3$ ($w1 + w2 + w3 = 1.0$). The real power loss is expressed by [29].

$$P_{\text{loss}} = \sum_{i=1}^{n} P_{loss_i} \qquad i = 1,2,3 \dots n \tag{2}$$

Where n, is the number of lines. On the other hand, the voltage deviation (V_{Dev}) is the difference in measured voltage from the nominal value for each bus [20] where smaller V_{Dev} indicates better network conditions. The voltage deviation is defined by:

$$V_{Dev} = V_{iref} - V_i \tag{3}$$

V_{iref} is a reference voltage (V_{iref}=1.0) at the bus, and V_i is the actual voltage at the bus. The stability index (SI) [30], [31] is defined by:

$$SI_r = 2V_s^2V_r^2 - V_r^4 - 2V_r^2(PR + QX) - |Z|^2(P^2 + Q^2) \tag{4}$$

the transmission and receiving end voltages are denoted by Vs and Vr, respectively. Line impedance is Z, line resistance is R, and line reactance is X. The active power at the receiving end is denoted by P, whereas the reactive power is represented by Q. The load flow constraints are the real power and reactive power flow for equality constraint [6]. On the other hand, inequality constraints are given in (5), (6).

Power Generation Limit [32]: $P_{DG_{min}} \leq P_{DG} \leq P_{DG_{max}}$ (5)

Bus *Voltage Limit* [33]: $\left|V_i^{min}\right| \leq |V_i| \leq |V_i^{max}|$ (6)

Where $\left|V_i^{min}\right|$ and $|V_i^{max}|$ are the lower boundary and upper boundary of the bus's voltage and $|V_i|$ is the value of bus voltage, i^{th}.

3. PROPOSED ALGORITHM

In this study, the FA is integrated with AHP (FAHA) to determine the optimum allocation and sizing of DG in the distribution network. The multi-objective optimization process was simulated based on 20 populations, 200 iterations, and 20 independent trials. The load flow calculation using MATPOWER is applied to this algorithm to obtain the objective functions such as the power loss, voltage deviation, and the stability index. The proposed algorithm automatically calculates the coefficient factors for each objective function and uses them to determine the minimum fitness. Then, the objective function with the minimum fitness solution is considered as the optimal solution.

3.1. Firefly analytical hierarchy algorithm (FAHA)

AHP is used for multi-criteria decision techniques to rank the criteria involved in the selection process. In this research, the AHP was modified and incorporated into FA to identify the weight of coefficient factor (CF) of each objective function (criteria) involved in the optimization process. Therefore, the incorporation process is shown in Figure 1.

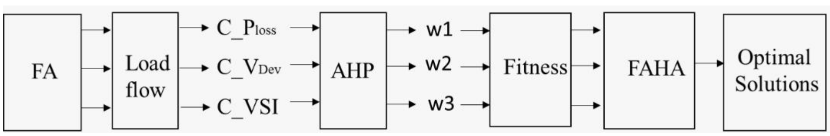

Figure 1. Incorporation of AHP into FA for optimal allocation and sizing of DG

The procedure in calculating the weight coefficients as per indicated [34]:
- Step 1: Problem is classified while knowledge required is determined.
- Step 2: The level of the decision-making hierarchy consisting of the objective, criterion and sub-criterion is constructed.
- Step 3: Data is collected from the results of load flow analysis based upon the results of relevant statistical test performed using the criterion in the form of numerical scale (refer table below).
- Step 4: Several criteria are compared in order to find the significance difference from the main eigenvalue and its equivalent normalized eigenvector from the comparison matrix. Then, the normalized eigenvector will be proposed as the weights to the criterion and the sub-criterion.

– Step 5: Assessment of the consistency index (CI) of the decision matrix is conducted because this particular index must not exceed the permissible range or else the test must be repeated.

$$CI = \frac{(\lambda_{max} - n)}{n-1} \tag{7}$$

Where n represents the criterion considered in the decision-making and λ_{max} denotes the judgment matrix's maximum eigenvalue. Next, in order to determine the consistency ratio (CR), the confidence interval (CI) is divided by the random confidence interval (RCI) shown in Table 1. The consistency ratio (CR) is a ratio used to measure the consistency of the weight obtained from the AHP calculation. The CI is comparable to the RCI. CR is calculated as (8).

$$CR = \frac{(CI)}{RCI} \tag{8}$$

The value of the ratio above must not exceed 0.10 or else the objective judgments have to be revised.

Table 1. Consistently indices

Parameter	Value			
Number of criteria	3	4	5	6
Random constancy index (RCI)	0.58	0.9	1.12	1.24

After obtaining the weight factors of w1, w2 and w3 from AHP calculations, all the CF will be used in the objective function calculation by each and every firefly in every iteration. Then, the optimal solution for DG location and sizing is determined by comparing all the fitness solutions found where the minimum solution is chosen as the optimal solution. The performance of the presented technique in this paper is verified using the IEEE 118-bus radial distribution network and referred to in [35]. Figure 2 shows that the cumulative real and reactive power demand of the 118-bus radial test system are 22.71 MW and 17.04 MVAr respectively while also producing minimum bus voltage of 0.8688 p.u. An in-depth explanation of FAHA is illustrated in Figure 3.

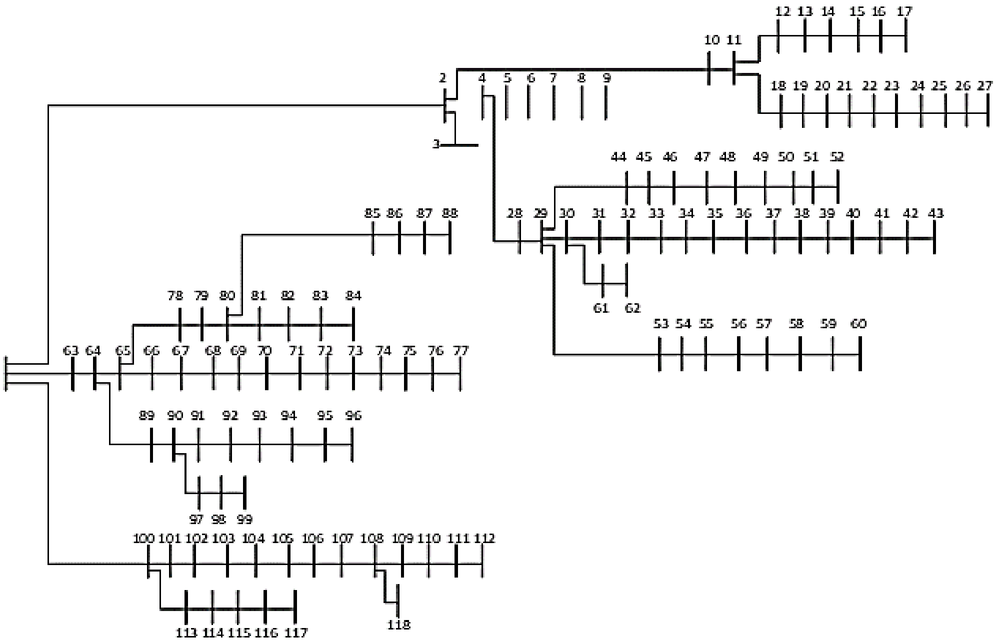

Figure 2. IEEE 118-bus distribution network system

3.2. Initial Presumption of the Distributed Generators

The data from the IEEE radial network were used to demonstrate the usability and the performance of the algorithm for determining the optimal location and size of DG with different V_{DG} settings. The initial presumptions applied in this study are as follows:

– Bus voltage boundary: 0.90 p.u ⩽ V⩽ 1.05 p.u
– The limit of the DGs' power generation: 0.5 MW ⩽ P_{DG} ⩽ 4MW
– The simulation is implemented based on the unregulated V_{DG} (V_{DG}= V_{BUS}) and regulated V_{DG} (V_{DG}=1.0 p.u to V_{DG}=1.05 p.u).
– The financial cost is not taken into account in this simulation.
– The DG type-1 is used: only active power is injected because it is more prevalent in the region of receiving constant sunshine annually [36].
– The number of DG units is added consecutively to achieve the target voltage profile within +-5% of the voltage regulation (0.95 p.u to 1.05 p.u).

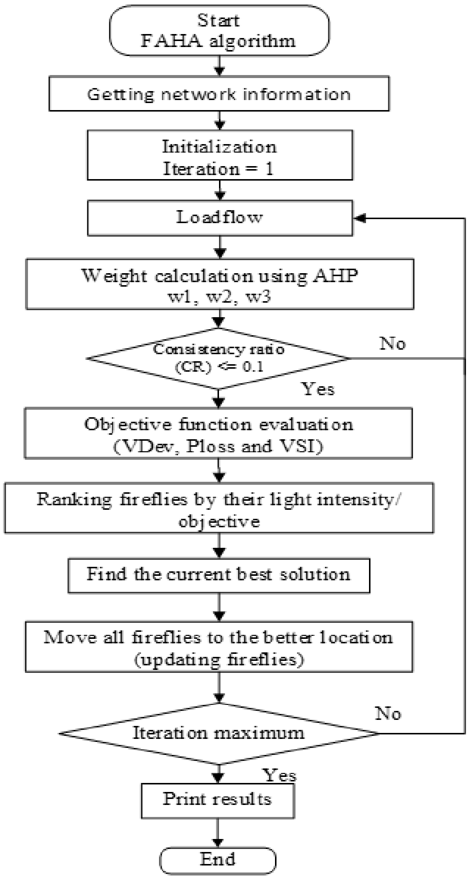

Figure 3. Flow Chart of FAHA

4. RESULTS AND DISCUSSION

The proposed meta-heuristic technique is implemented, analysed and verified on a 118-bus network. The overall load of the system is regarded as a snapshot load where 22.71MW, 17.04 MVar are the total real power of the base configuration with 1.2981MW as the real power loss value for the total connected load (TCL). The stopping criterion for the FAHA algorithm is set as 200 iteration and the population size = 20. Bus 1 is set as the supply source for the system which is also known as the slack bus or reference bus generally powered by a single source and has a fixed voltage of 1.0p.u. The single-line diagram of the system is illustrated in Figure 2 [35].The obtained results from the simulation of all V_{DG} settings were the fitness function, reduction in the power loss and the voltage deviation as well as the stability index at different settings. Figure 4 illustrates the convergence characteristic of FAHA based on 20 trials for V_{DG} = 1.0 and V_{DG} = 1.05 with 3DG as an example tested on the 118-bus network. As can be seen from the convergence curves, V_{DG}=1.0 has the overall best fitness solution when compared against V_{DG}=V_{BUS} and V_{DG}=1.05 based on the voltage deviation, power loss and stability index.

Table 2 displays the base case (without DG) results for power loss, minimum bus voltage and minimum stability index in the network. The coefficient factor of each objective function for different V_{DG} settings has been calculated using FAHA and is shown in Table 3. These weights will be used in fitness calculation for the optimization process.

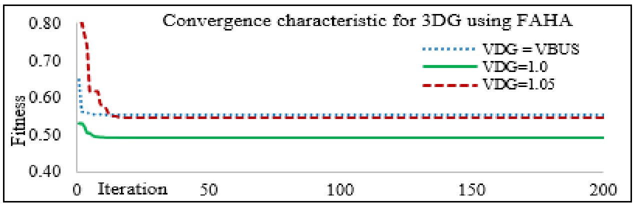

Figure 4. Convergence characteristic FAHA for 3 DG in the 118-bus network

Table 2. The base case for power loss, minimum bus voltage and minimum stability index

Number of DG	PV-bus (V_{DG})	Power Loss (MW)	Minimum bus voltage (Vp.u)	SI
0	Not Set	1.2981	0.8688	0.5699

Table 3. The coefficient factors (weight) using FAHA for fitness calculation

V_{DG} setting (PV-bus)	DG	*w1* (V_{Dev})	*w2* (P_{loss})	*w3* (SI)
V_{DG} = V_{BUS}	1	0.3074	0.3335	0.3591
(Unregulated V_{DG})	2	0.3224	0.2899	0.3876
	3	0.2172	0.3388	0.4440
	4	0.2139	0.3255	0.4607
V_{DG} = 1.0	1	0.3174	0.3117	0.3709
	2	0.3502	0.2288	0.4210
	3	0.2382	0.2252	0.5365
	4	0.2402	0.2041	0.5557
V_{DG} = 1.02	1	0.3159	0.3150	0.3691
	2	0.3458	0.2385	0.4157
	3	0.2256	0.2485	0.5259
	4	0.2224	0.2367	0.5409
V_{DG} = 1.03	1	0.3159	0.3150	0.3691
	2	0.3458	0.2385	0.4157
	3	0.2256	0.2485	0.5259
	4	0.2224	0.2367	0.5409
V_{DG} = 1.04	1	0.3124	0.3227	0.3649
	2	0.3339	0.2647	0.4014
	3	0.2212	0.2982	0.4806
	4	0.2242	0.2887	0.4871
V_{DG} = 1.05	1	0.3100	0.3278	0.3622
	2	0.3232	0.2883	0.3885
	3	0.2448	0.3306	0.4245
	4	0.2501	0.3161	0.4338

By referring to Table 3, the results show the weights of each objective function obtained from AHP. The weight of V_{DEV} is represented by w1 while w2 is the weight for P_{loss} and w3 is the weight that represents SI. It can be seen from the table that SI gives the most significant weight from AHP calculation for 1 DG, 2 DG and 3DG, followed by power loss and voltage deviation. Out of the three objective functions, the most significant weight indicates the most important objective among the three objectives. The weights were also verified by calculating the consistency ratio obtained less than 0.1. The proposed DG location, size and minimum fitness obtained from the optimisation process are shown in Table 4. As can be seen in these results, the proposed DG location and the DG size that can minimize the fitness function were obtained from the optimisation process. The location that the algorithm had chosen were the buses with low bus voltage and had significant voltage deviation. So, when the DG power is injected into those buses, the voltage that particular buses and nearby will increase.

Table 5 shows the impact of DG on bus voltage, power loss and stability index for unregulated and regulated V_{DG} by using FAHA. From the results, the DG allocation and sizing have proven to be able to reduce power losses. At PV-bus, P was generated and regulates the voltage. The line current will reduce when the voltage increases at the particular bus (DG location). Therefore, the power loss is also reduced due to I^2R losses. In general, regulated PV-buses produce smaller loss reduction compared to unregulated busses (V_{DG} = V_{BUS}). The results show that the loss reduction percentage decrease with the increasing value of V_{DG}. V_{DG} regulated to 1.0 p.u to 1.03 p.u give 37% to 41% loss reduction compared to 48% at unregulated V_{DG}. On the other hand, V_{DG} equal to 1.04 p.u to 1.05 p.u gives a smaller loss reduction, whereas the V_{DG} =1.05 p.u gives almost the same loss reduction as unregulated V_{DG}. V_{DG} =1.05 shows that the loss is higher due to the high current in the line. Indicates that V_{DG} = 1.05p.u is too large for radial distribution system. However, the power loss is still less than without any DG and notice that the 3DG is sufficient to reduce power loss at maximum value for these V_{DG} settings. Overall, retinal degeneration slow (RDS) regulated voltage from 1.0 p.u to 1.03 p.u produces a greater percentage loss. Normally, the power loss is calculated by I^2R. However, as the voltage magnitude increase (V_{DG}=1. 05 p.u), the loss percentage become greater and can be determined using V^2/R.

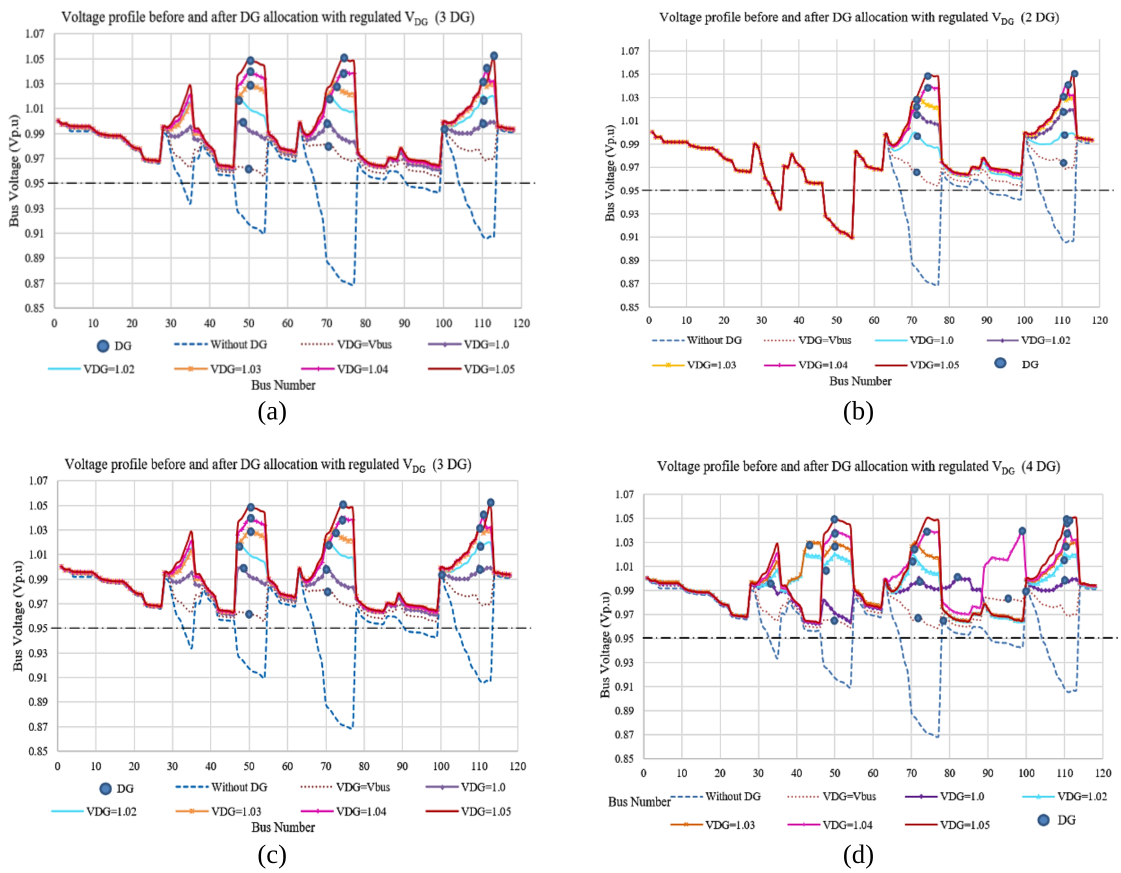

Figure 5. Voltage profile before and after (a) 1DG, (b) 2DG, (c) 3DG, and (d) 4DG installation for different V_{DG} settings on the 118-bus network

Table 5 also shows the minimum bus voltage, maximum bus voltage and stability index within the network. The results showed that voltage magnitude for PQ-buses are well within 0.95 p.u to 1.05 p.u (± 5%) for the minimum number of DG (1 DG). In general, the minimum bus voltage and stability index in the network after DG installation had been improved with unregulated V_{DG}. The minimum bus voltage improved from 0.8688p.u to voltage between 0.9053p.u and 0.9589 p.u. For V_{DG} = 1.0, the minimum bus voltage improved and achieved 0.95 p.u after 3DG and 4DG installation. V_{DG} = 1.05 also shows the minimum bus voltage increase until 0.9623p.u (4DG). For the SI value, the minimum SI in the network increased significantly with the number of DG. While regulated V_{DG} has much better SI than unregulated V_{DG} and without DG. Moreover, the results highlight that 3 DG is enough for this network to achieve a standard voltage regulation of ± 5% between 0.95 to 1.05 for the PQ (load) buses and SI of minimum, 0.85.

Figure 5 illustrates shows the comparison of voltage profiles without DG, unregulated V_{DG} and regulated V_{DG} of a 118-bus network. As shown in the figures, voltage profiles without DG were low, with all bus voltages below 0.95 p.u. When the voltage is low, the current in the line will increase and cause more power losses. Thus, when the DG is installed at the proposed location, which is the bus with a lower voltage, it will inject active power (P) to the bus and increase the bus voltage. Consequently, the voltage profile will be improved. Figure 5(a) shows that the 1 DG allocated to the lower bus in the network can improve the voltage profile which increased from 0.8688 p.u at the lowest bus (without DG) up to 0.9546 p.u, 1.0 p.u and 1.05 p.u after DG was optimally installed based on the implementation of FAHA. This is further validated in Figure 5(b) which shows that the improvement made in the optimally placed and sized 2DG setup were even more significant. In addition, Figures 5(c) and 5(d) both show the voltage profiles after the installation of 3DG and 4DG in the network. It can be seen that installing both 3 DG or 4 DG can improve all the buses within the network to achieve the standard voltage regulation, which is ± 5%. Therefore, installing 3DG is adequate to reduce optimal allocation and sizing of DG in the selected network. For unregulated V_{DG}, the voltage profiles were lower than regulated V_{DG}, and there are still many buses lower than 1.0 p.u. When V_{DG} is regulated from 1.0 p.u to 1.05p.u, the voltage at particular buses increases better than unregulated V_{DG}. For higher regulated V_{DG}, there were many buses increases between 1.02 to 1.05 p.u. When V_{DG} = 1.04 p.u, the bus voltage reaches almost the maximum value and the maximum bus voltage at V_{DG} = 1.05 p.u is too high for a radial network. However, the required bus voltage is only around 1.0 p.u. Therefore, it is proposed that only V_{DG} equal to 1.0 p.u to 1.03 p.u are suitable for the radial distribution network.

Table 4. The best fitness value and optimization results of the different V_{DG} settings and the DG number

V_{DG} setting (PV-bus)	DG	DG Location	DG Size(MW)	Fitness
$V_{DG} = V_{BUS}$	1	71	2.9785	0.7860
	2	109, 71	3.1199, 2.9785	0.7238
	3	50, 71, 109	3.0347,3.5058, 3.1201	0.5510
	4	50, 72, 96, 109	3.2213, 2.6297,1.8208, 3.1217	0.5322
V_{DG} = 1.0	1	71	2.9986	0.7628
	2	110, 71	2.8736, 2.9986	0.6939
	3	70, 48, 110	2.8411, 3.2632, 2.8736	0.4920
	4	82, 110, 72, 33	1.7923, 2.8815, 2.7197, 4	0.4879
V_{DG} = 1.02	1	71	3.6023	0.7660
	2	110, 71	3.6720, 3.6023	0.6968
	3	110, 71, 47	3.6720, 3.6023, 4	0.4910
	4	50, 70, 42, 110	3.5259, 3.3052, 1.9629, 3.6720	0.4846
V_{DG} = 1.03	1	71	2.9986	0.7628
	2	110, 72	4, 3.7154	0.7008
	3	72, 110, 50	3.7154, 4,4	0.4953
	4	110, 43, 71, 50	4, 2.0172, 3.6945, 3.9046	0.4891
V_{DG} =1.04	1	74	3.6603	0.7739
	2	111, 74	4, 3.6603	0.7080
	3	111, 50, 74	4, 4, 3.6603	0.5083
	4	50, 99, 74, 111	4, 2.8225, 3.2934, 4	0.5043
V_{DG} =1.05	1	74	3.9243	0.7794
	2	113, 74	4, 3.9243	0.7226
	3	113, 50, 74	4, 4, 3.9243	0.5440
	4	50, 74, 112, 111	4, 3.9244, 2.2514, 2.5348	0.5342

Table 5. DG impact on bus voltage, power loss and stability index for unregulated and regulated V_{DG} using FAHA on 118-bus system

V_{DG} setting (PV-bus)	DG	Minimum V_{bus} (p.u)	Maximum V_{bus} (p.u)	Loss (MW)	Loss reduction (%)	Minimum SI
Without DG	0	0.8688	0.9963	1.2981	21.67	0.5699
$V_{DG} = V_{BUS}$	1	0.9053	0.9971	1.0168	21.7	0.6758
	2	0.9095	0.9980	0.8052	38.0	0.6872
	3	0.90563	0.9980	0.6748	48.0	0.8365
	4	0.9589	0.9980	0.6179	52.4	0.8458
V_{DG} = 1.0	1	0.9053	0.9982	0.9200	29.1	0.6758
	2	0.9095	0.9992	0.5852	54.9	0.6872
	3	0.9611	0.9992	0.3638	72.0	0.8535
	4	0.9623	0.9994	0.3167	75.6	0.8578
V_{DG} = 1.02	1	0.9342	0.9053	0.9342	28.0	1.0172
	2	0.6177	0.9095	0.6177	52.4	1.0192
	3	0.4069	0.9627	0.4069	68.7	1.0192
	4	0.3741	0.9645	0.3741	71.2	1.0192
V_{DG} = 1.03	1	0.9496	0.9053	0.9342	28.0	1.0263
	2	0.6547	0.9095	0.6177	52.4	1.0292
	3	0.4480	0.9626	0.4069	68.7	1.0292
	4	0.4330	0.9647	0.3741	71.2	1.0296
V_{DG} = 1.04	1	0.9682	0.9053	0.9682	25.4	1.0393
	2	0.7100	0.9095	0.7100	45.3	1.0393
	3	0.5334	0.9631	0.5334	58.9	1.0393
	4	0.5096	0.9631	0.5096	60.7	1.0393
V_{DG} =1.05	1	0.9909	0.9053	0.9909	23.7	1.0493
	2	0.7987	0.9095	0.7987	38.5	1.0493
	3	0.6681	0.9636	0.6681	48.5	1.0493
	4	0.6252	0.9636	0.6252	51.8	1.0499

5. CONCLUSION

This study proposed a novel meta-heuristic technique for determining the appropriate allocation and the capacity of the DG units in the distribution network by implementing the FAHA by considering the multi-objective function approach. The AHP was integrated with FA to automatically or systematically calculate each objective function's accurate weight (coefficient factor) for obtaining the optimal fitness solution. This technique analyses the impact of different V_{DG} settings (regulated PV-bus) at the proposed DG location and size based on minimizing voltage deviation, power loss and improving stability index. In summary, the results yielded that the FAHA is effective for optimal allocation and sizing of DG to achieve overall minimum voltage deviation and power loss. At the same time, it improves the stability index in the network. This novel study also proved that the regulated V_{DG} from 1.0 p.u to 1.03 p.u with a minimum of 3 DG with sizes of 3.7154 MW, 4MW and 4MW would produce a percentage of losses of 65 %. In addition, the minimum bus voltage profile of within 0.95 to 1.05 and the SI is 0.85 as a minimum. Based on these findings, the regulated V_{DG} provided better optimisation performance than the unregulated V_{DG} and also improved the power loss, V_{Dev} and SI of the radial distribution network.

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