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Research article

Electrical and Electronic Engineering

**LOADABILITY INVESTIGATION OF POWER SYSTEM NETWORK  
INTEGRATED DISTRIBUTED GENERATION INCLUDING MULTI-  
SECTOR CONSUMERS****包含多部门消费者的电力系统网络分布式发电负荷研究**Yusran<sup>a</sup>, Yuli Asmi Rahman<sup>b</sup>, Prisma Megantoro<sup>c</sup><sup>a</sup>Electrical Engineering Department, Universitas Hasanuddin Gowa  
Makassar, Indonesia, [yusran@unhas.ac.id](mailto:yusran@unhas.ac.id)<sup>b</sup>Electrical Engineering Department, Universitas Tadulako Palu  
Palu, Indonesia<sup>c</sup>Electrical Engineering Department, School of Advance Technology and Multidicipline, Universitas Airlangga  
Surabaya, Indonesia*Received: April 20, 2020 ▪ Review: June 19, 2020 ▪ Accepted: July 15, 2020**This article is an open access article distributed under the terms and conditions of the Creative Commons  
Attribution License (<http://creativecommons.org/licenses/by/4.0>)***Abstract**

This article describes the hybrid approach of the Firefly Algorithm and power-voltage curve method in optimal placement of Distributed Generation while considering the actual load model. The actual load model is represented by six models. The six load models are a composite of industrial, residential, and commercial loads with dissimilar percentages. The Institute of Electrical and Electronics Engineers 30 Bus is selected as the testing object for the proposed method. The optimal Distributed Generation placement process was performed using the Firefly Algorithm, while evaluation of optimal Distributed Generation on the loading and stability index is continued using the power-voltage curve method. The results show that commercial loads contribute to high power loss values. The optimal Distributed Generation integration results in an increase the stability index from 53.83% at initial conditions to 90.84% at maximum load level when increasing the maximum loading limit to 95%.

**Keywords:** Metaheuristic Algorithm, Load Model, Voltage Stability, Power Loss, Loadability Margin

**摘要** 本文在考慮實際負荷模型的同時，介紹了在分佈式發電的最優佈置中，採用螢火蟲算法和功率-電壓曲線法的混合方法。實際負荷模型由六個模型表示。六個負載模型是百分比不同的工業，住宅和商業負載的組合。電氣和電子工程師協會 30 總線被選為該方法的測試對象。使用螢火蟲算法執行了最佳的分佈式發電佈置過程，同時使用功率-電壓曲線方法繼續對負荷和穩定性指標進行最佳的分佈式發電評估。結果表明，商業負載會導致較高的功率損耗值。最佳的分佈式

發電集成可將最大負載限制提高到 95%，從而將穩定性指數從初始條件下的 53.83% 提高到最大負載水平下的 90.84%。

**关键词:** 元啟發式算法, 負載模型, 電壓穩定性, 功率損耗, 負載裕度

## I. INTRODUCTION

High economic growth and a better business climate have resulted in increased consumption of electricity, both by household and industrial consumers. This has an impact of increasing demand for electricity supply to the system. In comparative data in ASEAN countries, the number of consumers is not linearly proportional to installed plants, as presented in Figure 1 [1]. Therefore, additional capacity is needed to support this needed increased electrical load. For example, in Asian countries, Indonesia has a projected electricity demand increase of 10.1% each year. Indonesia has established a target to develop 56,024 MW power plants from 2018 to 2027 [1].

Some aspects need to be reviewed to generate additional electric power system capacity. The addition of generation capacity must be conducted carefully, precisely, and efficiently. Electrical generation systems are categorized as bulk power or distributed systems.

Distributed Generation (DG) is described as a small electrical generation unit of 50 - 100 MW maximum capacity [2]. Generally, the DG is not part of a main generating system, and its location is not far away from the electrical load. The DG utilization has increased due to its essential function in an electrical power systems supply. This is caused by its high efficiency, small size, low investment costs, modular capabilities, as well as proximity to the energy sources owned by DG.

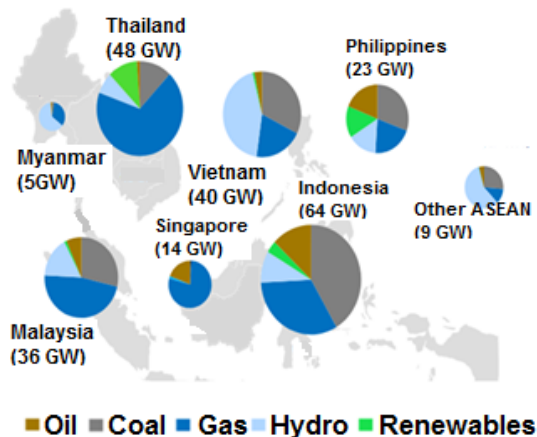


Figure 1. Mapping DG utilization in ASEAN countries [1]

In recent years, DG technology has utilized solar energy, wind energy, micro turbines and other methods of renewable energy generation. In terms of environmental impact and local wisdom, the target for renewable energy utilization is high, including in ASEAN countries. As part of the smart grid, DG has been explored in terms of benefits, technical challenges and implementation in several distribution networks [3]. The technical benefits of DG integration have been demonstrated both in simulated systems and actual electric power system [4], [5], [6]. The principal factor to be considered in DG integration is determining the proper placement and size. Inaccurate DG placement can result in a decrease of power [7].

DG optimization methods based on artificial intelligence continue to be developed [8]. The genetic algorithm (GA) [9], [11], particle swarm optimization (PSO) [11], [12], fast evolutionary (FE) programming [13], and artificial bee colony (ABC) [14] are some metaheuristic-based approaches. GA uses an evolutionary algorithm-based approach. In contrast, PSO and ABC are swarm algorithms. It's the same with GA, FE is a development of an evolutionary algorithm that uses a Gaussian mutation as the main search operator to obtain the optimal value solution. In contrast, PSO and ABC are swarm algorithms.

One of powerful swarm algorithm is the firefly algorithm (FA). The firefly algorithm is a new metaheuristic algorithm for optimization problems that have a very good convergence rate and strong exploration capability [15]. The FA, like other swarm algorithms, is inspired by collective social behavior. The FA uses the firefly as its basis, meaning that it is attracted to light and rhythm. The search process is not influenced by speed and does not use historical data to prevent premature convergence. This behavior causes the FA to have a high convergence rate and flexibility when solving optimization cases in several fields. Performance studies have been conducted on clustering cases and compared the optimization results of FA, PSO, ABC, and nine other methods [15]. Notably, the FA and other metaheuristic methods for DG placement have been performed in the same test system [16]. According to the optimization

results, the FA had superior performance and standard deviation.

The DG implementation tested in distribution networks with specific loads including residential, industrial, and commercial have been studied before [11], [17], [18]. In fact, the distribution network itself is a mixed load that involves three load categories with dissimilar percentages. The mixed load represents multi-sector consumers in a distribution network with real/active and reactive power necessities. However, the electrical system's load ability determines whether it can fulfill its load demands. As a useful tool for analysis, The P-V curve describes the relationship between changes in power and voltage both under normal conditions and at maximum loading. It is a reference for assessing the system's voltage stability.

DG integration in power systems will affect power injection availability and system loadability. Consequently, this paper analyzes the critical point changes in the distribution network that are caused by DG implementation with the FA method. This paper describes the multi-sector consumer's considerations with six actual load models. These six models illustrate the actual load conditions of real systems. This paper's findings are divided as follows: Part II explains the real load model, the mathematical formula for the proposed method, and the loadability analysis; Part III reports on how DG implementation has affected distribution network loadability; and Part IV contains the conclusion.

## II. METHODS/MATERIALS

In terms of demand-side management, electric vehicles, and DG, the development of electric power systems must pay special attention to load modeling. Load modeling demonstrates the correlation between load bus power and voltage, which is represented mathematically. The static model interprets the connection between real and reactive power as a bus voltage magnitude value and frequency function. One static load model that is generally utilized is the exponential model. It has fewer parameters than other models and can represent mixed loads.

### A. The Actual Load

The mixed model represents the actual load consisting of various consumer sectors. The mathematical representation of a multi-load [18] is expressed in Eqns. (1) and (2):

$$P_{Di} = P_{Doi} \left( \rho_1 \left( \frac{V_i}{V_o} \right)^{\alpha_i} + \sigma_1 \left( \frac{V_i}{V_o} \right)^{\alpha_r} + \tau_1 \left( \frac{V_i}{V_o} \right)^{\alpha_c} \right) \quad (1)$$

$$Q_{Di} = P_{Doi} \left( \rho_2 \left( \frac{V_i}{V_o} \right)^{\beta_i} + \sigma_2 \left( \frac{V_i}{V_o} \right)^{\beta_r} + \tau_2 \left( \frac{V_i}{V_o} \right)^{\beta_c} \right) \quad (2)$$

where  $P_{Di}$  is the real or active power,  $Q_{Di}$  is the reactive power requirement, and  $P_{Doi}$  and  $Q_{Doi}$  are the required active and reactive power values on bus  $i$ , respectively.  $V_o$  and  $V_i$  are the nominal and bus  $i$  voltage, respectively. The subscripts  $i$ ,  $r$ , and  $c$  denote the industrial, residential, and commercial loads, respectively. The active and reactive power exponents are denoted by  $\alpha$  and  $\beta$  coefficients, as shown in Table 1. These parameters are referenced from a previous study [20]. The weight coefficients  $\rho$ ,  $\sigma$ , and  $\tau$  are related to the percentage of each active and reactive power necessity for each consumer category. The real power coefficients are denoted by  $\rho_1$ ,  $\sigma_1$ , and  $\tau_1$ . The reactive load coefficients are  $\rho_2$ ,  $\sigma_2$ , and  $\tau_2$ . These coefficients are tabulated in Table 2 [10], [20].

Table 1.  
Load category and exponent value [20]

Parameter	$\alpha$	$\beta$
Constant	0	0
Industrial	0.18	6.00
Residential	0.92	4.04
Commercial	1.5	3.40

Table 2.  
Weight coefficients of mixed actual load model

Actual load	$\rho$	$\sigma$	$\tau$
IRC [20]	$\rho_1 = \rho_2 = 0.45$	$\sigma_1 = \sigma_2 = 0.4$	$\sigma_1 = \sigma_2 = 0.15$
ICR [10]	$\rho_1 = \rho_2 = 0.5$	$\sigma_1 = \sigma_2 = 0.2$	$\sigma_1 = \sigma_2 = 0.3$
CRI	$\rho_1 = \rho_2 = 0.15$	$\sigma_1 = \sigma_2 = 0.35$	$\sigma_1 = \sigma_2 = 0.5$
CIR	$\rho_1 = \rho_2 = 0.35$	$\sigma_1 = \sigma_2 = 0.2$	$\sigma_1 = \sigma_2 = 0.45$
RCI	$\rho_1 = \rho_2 = 0.15$	$\sigma_1 = \sigma_2 = 0.55$	$\sigma_1 = \sigma_2 = 0.3$
RIC	$\rho_1 = \rho_2 = 0.3$	$\sigma_1 = \sigma_2 = 0.55$	$\sigma_1 = \sigma_2 = 0.15$

The mixed load model was simulated on six (6) models, where I represented the industrial load, R the resident load, and C the commercial load. For example, the CRI model indicated that commercial load consumed 50% of the real and reactive power of the total load demand. Therefore, the weights  $\rho_1$  and  $\rho_2$  were set to 0.50 and 0.50, respectively. Moreover, as the demand for residential expenses was 35% of the real and reactive power of the total load demand, the weights  $\sigma_1$  and  $\sigma_2$  were set to 0.35 and 0.35, respectively. As the industrial sectors required

15% of the active and reactive power of the total load demand,  $\tau_1$  and  $\tau_2$  were set to 0.15 and 0.15, respectively. The real load modeling results are presented in Figure 2.

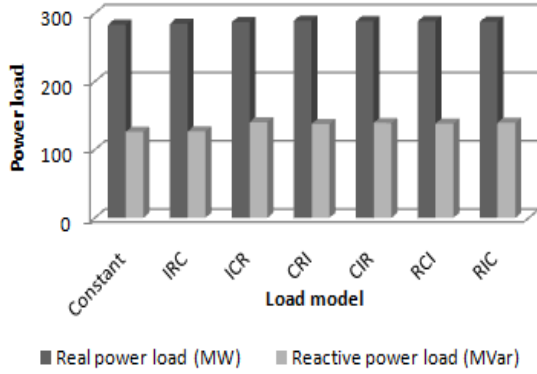


Figure 2. Actual load model

### B. The Maximum Loadability

The loadability determination for the distribution feeder should take system stability into account. This determination is reached by increasing the maximum load on the load bus while the system can still sufficiently handle the connected load. The maximum loading limit [21] is formulated in Eqn. (3):

$$g(x, \lambda) = g(x) + \lambda D \quad (3)$$

$$1 \leq h(x) \leq u$$

where  $\lambda$  is a loading parameter and  $g(x, \lambda)$  is a constraint function.  $D$  is a vector based on the percentage of the load shift.  $h(x)$  is an inequality constraint in the power system with the upper limit  $u$  and lower limit 1. The function  $g(x)$  is defined using the real power balance complying with power flow, as shown in Eqn. (4):

$$g(x) = P_{Gi} - P_{Li} = |V_i| \sum_{j=1}^n |V_j| \left[ G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j) \right] \quad (4)$$

where  $P_{Gi}$  and  $P_{Li}$  are the generating power and maximum load on bus  $i$ , respectively. The voltages on bus  $i$  and  $j$  are denoted by  $V_i$  and  $V_j$ , respectively.  $G_{ij}$  is the admittance of the connecting line between bus  $i$  and  $j$ .  $B_{ij}$  is the inductance of this connecting line. The voltage phase angles on bus  $i$  and bus  $j$  are denoted by  $\delta_i$  and  $\delta_j$ , respectively.

In this paper, the loading factors analysis using parameter  $\lambda$  was limited following Eqn. (5):

$$0 \leq \lambda_i \leq \lambda_{max} \quad (5)$$

where  $\lambda_{max}$  refers to the maximum load, which is identical to the critical loading value shown in Figure 3. The critical voltage point indicates the voltage stability value, which

itself is represented by a stable area boundary on the top of the P-V curve nose point.

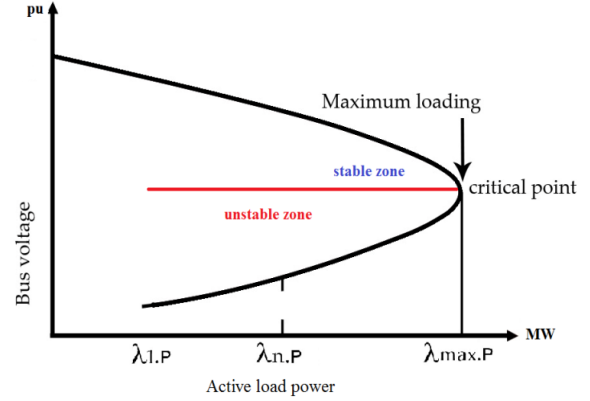


Figure 3. Loadability margin

Because the  $\lambda$  value is multiplied by  $P_{G0}$  and  $P_{L0}$ , which are respectively the generating power and load values for the initial conditions, the power flow will follow Eqns. (6) and (7):

$$P_{Gi} = \lambda_{max} P_{G0} \quad (6)$$

$$P_{Li} = \lambda_{max} P_{L0} \quad (7)$$

where  $P_{G1}$  and  $P_{L1}$  are the maximum generating and load values, respectively.

When the drop voltage is exceeding from tolerance limit, the load value is considered as maximum value or called kVA Margin to Maximum Loadability (KMML) [22]. Related to DG placement, this stability point was affected by connected DG capacity and load factor [23].

The increasing load, which is not accompanied by an adequate supply from the generator, will cause a voltage drop. This condition causes instability and failure of the work function of electronic equipment. It also has an impact by causing an economic loss, especially in industrial loads. In this research, bus stability is measured by continuation power flow (CPF).

The CPF method is superior to the voltage-collapse-proximity indicator (VCPI) method and the voltage-change index (VCI) [24], viewed from the perspective of computational time. The ranking of critical buses using CPF methodology is illustrated in Figure 4.

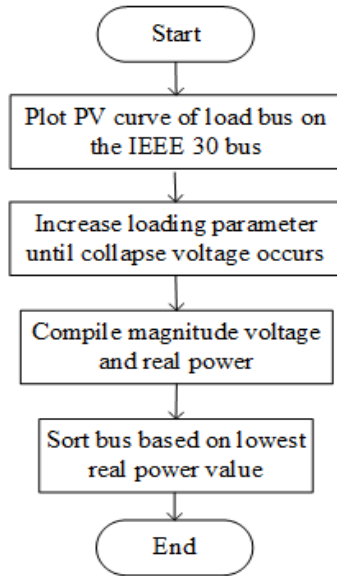


Figure 4. Critical bus ranking using CPF

### C. FA Optimization

The FA is included in the swarm artificial intelligence method. It was evolved by Xin-She Yang (Cambridge University) in 2008. The firefly attractiveness is controlled by its light intensity, related as a fitness function of the objective function [25]. The light intensity is formulated as Eq. (8):

$$I(r) = \frac{I_2}{r_2} I(r) = \frac{I_s}{r^2} \quad (8)$$

where  $I(r)$  is the light intensity at distance  $r$  and  $I_s$  is the source intensity. At certain distances with steady light absorption, the light intensity of  $I(r)$  differs according to the  $r$  distance in monotonic and exponentially, following Eq. (9):

$$I(r) = I_0 e^{-\gamma r} \quad (9)$$

where  $I_0$  is intensity for the initial light condition,  $\gamma$  is the coefficient of light absorption,  $r$  is the range among fireflies. The firefly attractiveness is matched to the light intensity that is visible by another firefly around it; the variation of attraction  $\beta$  can be specified for the distance  $r$  by Eq. (10):

$$\beta(r) = \beta_0 e^{-\gamma r} \quad (10)$$

where  $\beta_0$  is the attraction value if  $r = 0$ .

If there are two fireflies, namely  $i$  and  $j$ , then the range  $r$  can be analogous to the point at  $x_i$  and  $x_j$  so that it can be calculated by Eq. (11):

$$r_{ij} = \sqrt{\sum_{k=1}^d (x_{i,k} - x_{j,k})^2} = \|x_i - x_j\| \quad (11)$$

The displacement of fireflies which is influenced by the level of firefly attractive is expressed in Eqn. (12).

$$x_{i+1} = x_i + \beta_0 e^{-\gamma r} (x_i - x_j)^2 + \alpha(\text{rand} - 0.5) \quad (12)$$

where  $x_i$  shows the initial position of fireflies at location  $x$ , the second term of Eqn. (12) is related to the activeness of fireflies, while the third term is random which is influenced by value of  $\alpha$  as a random parameter. Rand is a random number produced from Gaussian distribution or other uniform distribution on a scale [0, 1].

The best fireflies are obtained on the last generation based on their brightness they have. In the next stage, the fitness of fireflies is updated by light intensity value of each firefly.

Table 3.  
Parameter of FA

Parameter	Weight
Number of fireflies	20
Iteration limit	30
DG unit	2
$\alpha$ (scaling)	0.25
$\beta$ (attractiveness)	0.2
$\gamma$ (absorption coefficient)	1

The brightest fireflies are used as the optimal solution in optimization process. In this article, the FA use previous research data parameters [26] which are presented in Table 3. The results and discussion of FA implementation will be discussed in the next section.

### D. FA Framework for Optimal DG

In this section, the FA is implemented to assign of DG size and location combination. The most widely used parameter to indicate the performance of an electric power system network are power loss and voltage drop. In this research, power loss minimization is a consideration factor for the best DG place and size determination, limited by the value of a certain voltage on each bus.

The DG optimum size and location search process of are carried out based on the flowchart shown in the Figure 5. The computation fitness value of each generated firefly pair is conducted through power flow procedure based on Newton Raphson method.

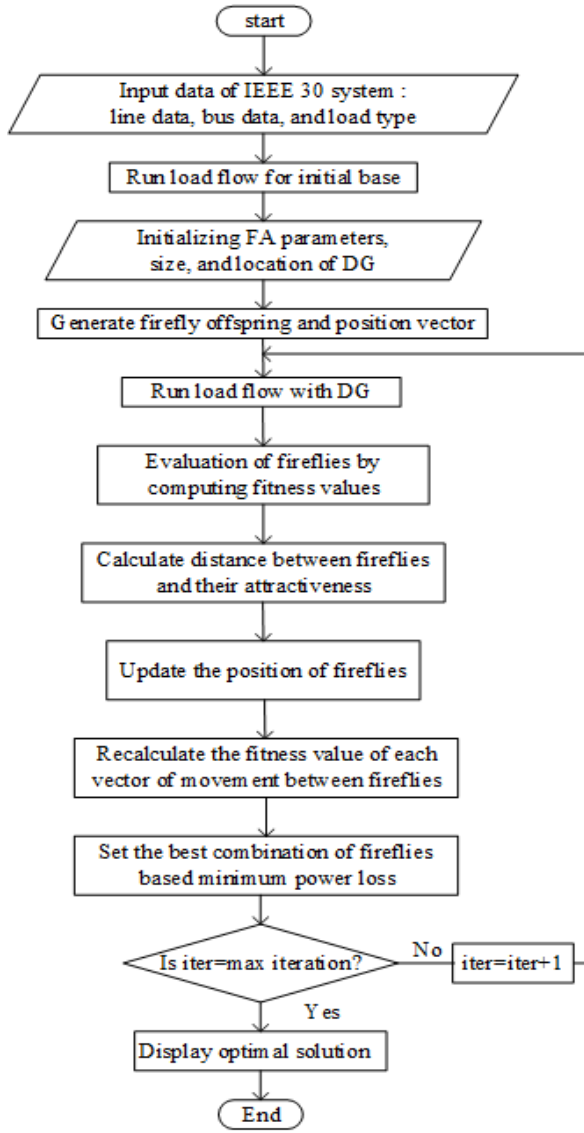


Figure 5. Flowchart of proposed method

The optimization method is done using single loop [27], which aims to get minimum value of network power loss active component. Mathematically, the aim is presented as objective function in Eqn. (13) but does not violate the constraint functions in Eqn. (14) and Eqn. (15).

$$F_{obj} = \min(P_{loss}) \quad (13)$$

Subject to:

$$P_{Gk-min} \leq P_{Gk} \leq P_{Gk-max} \quad (14)$$

$$1.05 pu \leq V_i \leq 0.95 pu \quad (15)$$

$P_{loss}$  is real power loss on a system [28] which expressed in Eq. (16).

$$P_{Loss} = \frac{r_{ij}}{V_i V_j} \left( \sum_{i=1}^N \sum_{j=1}^N \cos(\theta_i - \theta_j) (P_i P_j + Q_i Q_j) + \sin(\theta_i - \theta_j) (Q_i P_j - P_i Q_j) \right) \quad (16)$$

The symbols  $V$  and  $\delta$  are voltage and power angle value on bus  $i$  and  $j$ , respectively. The symbol of  $r_{ij}$  is resistance of connecting line bus

( $i-j$ );  $P$  and  $Q$  are active and reactive power at bus  $i$  and  $j$ , respectively; and  $N$  is number of system buses. The symbols  $i$  and  $j$  are coefficients on each variable that indicate two interconnected buses.

The constraint function is an unequal dependent variable consisting of DG output real power ( $P_{Gk}$ ) and load bus voltage ( $V_i$ ) to ensure the dependent variable within the tolerance limit and to prevent improper solutions.

### III. RESULTS AND DISCUSSION

The IEEE 30 bus represented in Figure 6 is an electric power system network plant in this study. The network has 283.4 MW and 126.2 MVar total loads. It is assumed as constant load. Figure 6 shows the simulation object benchmark in detail. The optimizing process starts with data initialization including generator, load, line, DG size, and alternative DG locations data.

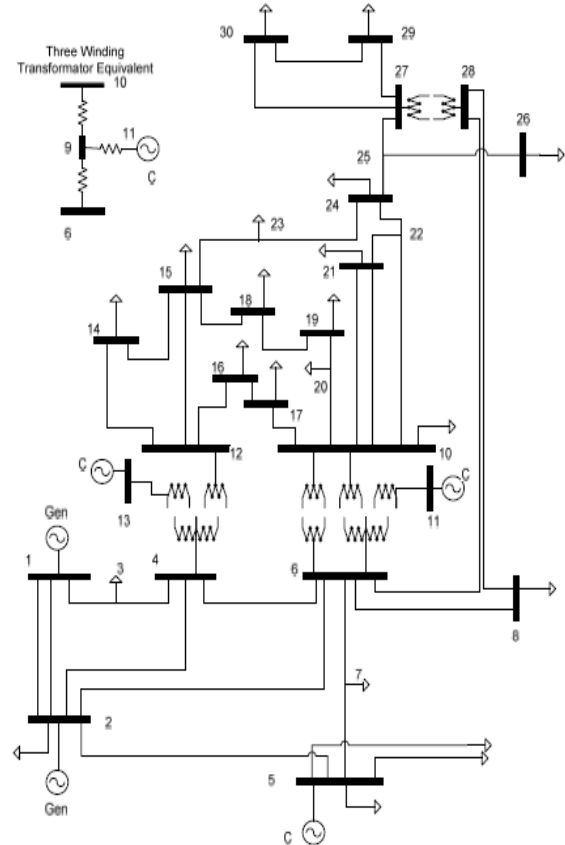


Figure 6. IEEE 30 bus representation

#### A. FA Based Optimal DG Placement

The initialization of firefly populations is carried out by generating arrays of DG sizes with a range of 0.01 MW to 10 MW. The same thing has also performed for DG location where retrieval of array data from alternative load bus. The load bus consists of 23 buses starting from Bus 7 to Bus 30.

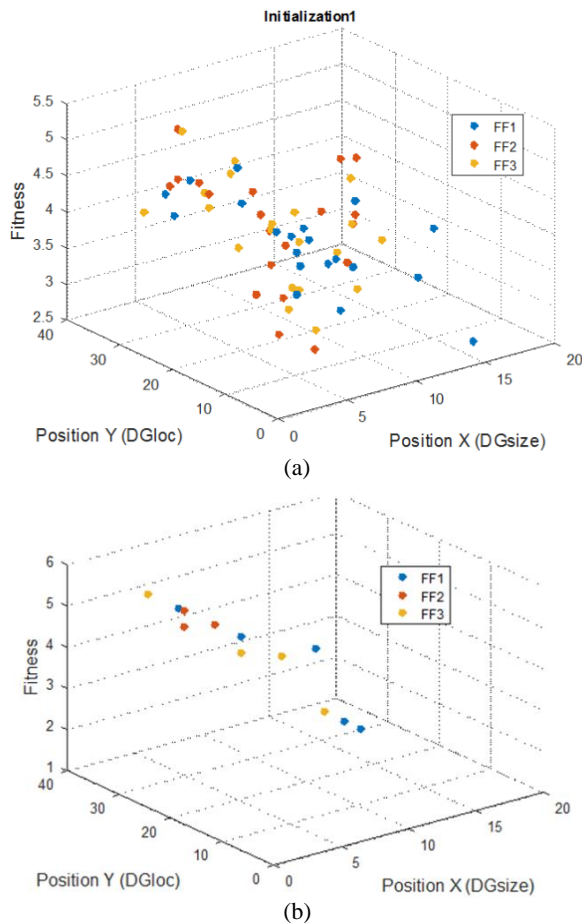


Figure 7. FA optimization stage: (a) initialization and (b) final convergence

During the initialization process, fireflies move randomly for universe searching as shown in Figure 7 (a). The evaluation of fitness value is measured in each movement vector between fireflies. The amount of fitness value will determine the movement direction of each firefly. The each firefly will change its position or move to movement vector which has the highest fitness value. The process will continue until the generation value limit is achieved.

When search process has reached the limit of generation value, the fitness value is evaluated for each combination of fireflies in last generation. The combination of fireflies represents a combination of DG. The combination with highest fitness value is elected as optimum value. This process is said to have converged as indicated in Figure 7 (b).

## B. Simulation Results

In this research, the assumption of DG power factor is unity. The optimization process is done by calculating power loss and voltage values. The obtaining results are provided in Table 4.

Table 4.  
DG placement for actual load models

Actual load model	Size (MW) and location of DG	$P_{loss}$ (MW)
IRC	8.12 ; 10 8.20 ; 29	16.695
ICR	8.06 ; 3 8.10 ; 30	17.024
CRI	8.10 ; 26 8.22 ; 30	17.170
CIR	8.31 ; 27 8.28 ; 30	16.931
RCI	8.13 ; 9 8.13 ; 26	17.094
RIC	8.13 ; 25 8.22 ; 26	17.081

Table 4 shows that each load model has different DG size and location pairs. This is due to different power injection requirements for reducing power loss as mapped in Figure 8.

For validation process, the FA will be compared with GA [10] and PSO [12] for constant load case. The FA method produces DG size and location which can reduce power loss by 12%, greater than two comparison methods. For more information, the proposed method validation is served in Table 5.

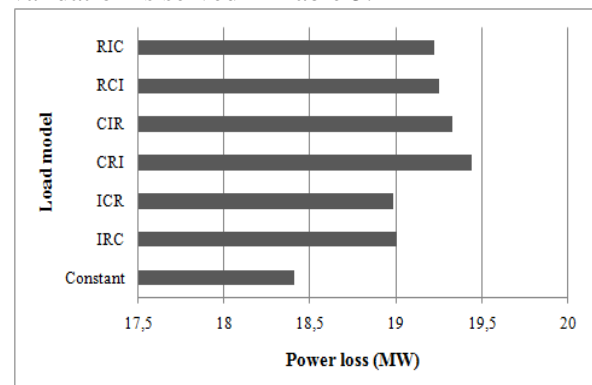


Figure 8. The power loss mapping for each load model

The power system network with industrial load, results 18.992 MW of power loss. Total power active load with ICR and IRC configurations are 287 MW and 284 MW, respectively. The integration of two DGs has an impact on power loss decreasing of 12.31% and 13.09% for combination of the ICR and the IRC load model, respectively.

Table 5.  
Validation of proposed method

Actual load model	Method	Size (MW) and location of DG	$P_{loss}^{total}$ (MW)
Constant	PSO [11]	13.578 ; 15	16.572
	GA [10]	15.30 ; 26	16.463
	Proposed	16.20 ; 14	16.214

(FA)

For the load model dominated by commercial consumers, it takes power loss of 19.38 MW on network without integrated DG. The active load of configured by CIR and CRI load models are 290 MW and 288 MW, respectively.

The penetration of two unit DGs has an influence on power loss reduction of 12.4% and 11.67%. The load dominated by 55% of resident consumers take 19.24 MW power losses for conditions without DG. The penetration of two unit DGs gives power loss decreasing effect of 11.2% and 11.13% for the combination of RCI and RIC loads, respectively.

The validation results of FA optimization technique resulted in a DG size and location pair had more significant influence on power loss alleviation compared to GA and PSO approaches.

### C. DG Integration Effect on System

#### Loadability

The critical loading conditions are determined to get the weakest bus from the network. The process is conducted by load power flow study with a critical loading value increasing to 80% with a minimum voltage indicator at 0.907 pu. When the load is increased to 90%, the critical voltage reaches 0.899 pu. Two scenarios are performed using the proposed method.

#### 1) Base Scenario

For this scenario, it refers to normal condition of IEEE 30 bus with CRI load model. This system serves 289.6 MW and 137.96 MVAR loads with 40.0 MW and 55.16 MVAR power plants distributed over six (6) buses.

Referring to the voltage collapse point, the results based on CPF display real power and voltage on P-Q bus. As shown in Figure 9, the PV curve shows the three weakest buses with a maximum reference point of 2.9 loading ( $\lambda$ ). The weak bus indication is also seen when the load escalates over a specific limit. The parameter repose in bus voltage which has decreased until it reaches a critical value.

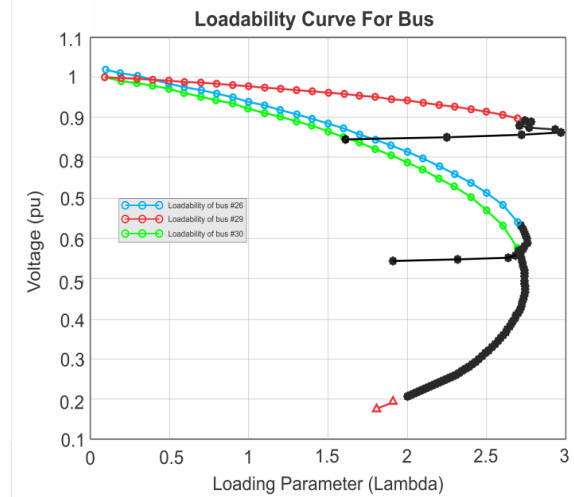


Figure 9. CPF result of IEEE 30-bus with CRI model

It can be explained by Figure 10, which fetches sample data on CRI load. When the load rises to 80%, the voltage experiences a critical point at 0.906 pu. If the load continues to be increased up to 90%, the voltage reaches a critical point at 0.89 pu.

#### 2) Extended System with DG

This scenario was performed to display the effect on the system loadability of power injection from DG. Using the same method as before, the results from the second scenario showed bus voltage profile in different loading parameter ( $\lambda$ ).

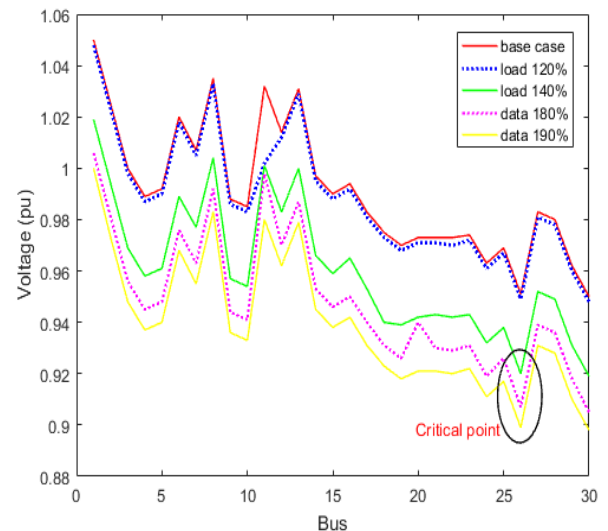


Figure 10. Voltage condition due to load increasing

The investigation of loadability is conducted by increasing the load on an integrated DG system. The actual CRI load model was chosen, to equalize the conditions in this scenario. Relating to the optimization results of the FA method, DG with 16.22MW total power was placed on bus 26 and bus 30. The additional load was carried out on bus 30 because it is the weakest bus on the IEEE 30 test bus system.

When compared to an initial condition of a loading capacity limit of 80%, the DG integration affects an increase in maximum loading capacity to 95%. An increase in loadability is followed by an increase of 11.6% in the minimum critical voltage (0.906pu under the base case).

The loadability is identified by a collapsing voltage value at a certain loading point. It is related to the system stability definition: the maintenance of a stability index of less than 1 (Index < 1) to be stable. In this research, the stability index uses SVSI [29]. From the loading investigation test results, the load level is increased every 10%, within the range 120%–190%, to give different stability index value. There is a trend of improving index value, as shown in Figure 11.

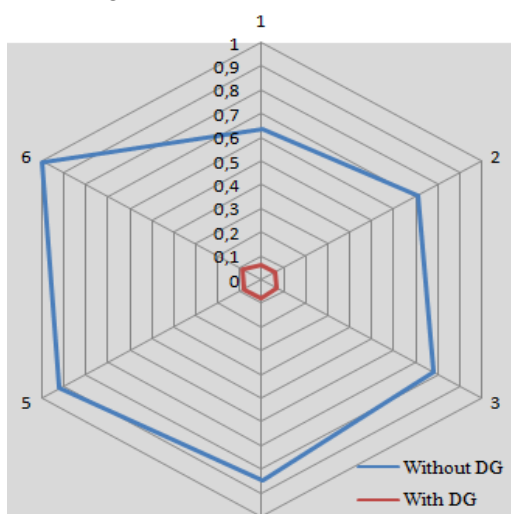


Figure 11. Improved stability index value

The stability index was corrected from 53.83%, at initial conditions, to 90.84% at maximum load level. This condition is linear with previous research [30] which placed DG on two buses. Using the optimal size and placement of DG on selected buses can decrease real power losses and rectify the voltage stability, as measured by the Voltage Stability Margin (VSM) indicator.

The case study results prove that DG integration in a power system has positive impact on both the loadability and the voltage stability limit.

#### IV. CONCLUSION

In this research, the influence of DG integration on power systems has been tested, with varying load models as representations of actual load. The proposed load model is the load variation of industrial, residential, and commercial sector consumers, with different loading percentages. There are six proposed load models: ICR, IRC, RCI, RIC, CRI, and CIR.

The optimal DG placement, using the FA algorithm, obtains DG size and location pairs on the IEEE 30 test bus system, with the six proposed load models. The DG placement is optimally able to reduce power loss by an average of 12.4% across the six load models. Using the CRI load model to investigate the integrated DG power system loading capacity caused the highest power loss. The results obtained indicate an increase in loading capacity from 15% (at basic condition) to 80%. The voltage stability is also a parameter indicator for this investigation.

For future research, the placement of multi-type DG should be analyzed based on FA. Further assessment is needed to analyze the influence of different DG types on power system loadability.

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