ISSN 2347 - 3983
Volume 8. No. 1.1, 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter0181.12020.pdf
https://doi.org/10.30534/ijeter/2020/0181.12020

Effect of DG Types and Penetration Level in Transmission System using Hybrid Optimization Technique for Loss Control

Sharifah A. Shaaya[1]**,Ismail Musirin**[2]**, Shahril I. Sulaiman**[3]**, Mohd H. Mansor**[4]**, Sharifah A. S.Mustaffa**[5]
[1,4,5]Department of Electrical Engineering, Universiti Tenaga Nasional, Kajang, 43000, Malaysia
shazwa@uniten.edu.my, mhelmi@uniten.edu.my, SharifahAzma@uniten.edu.my
[2,3]Faculty of Electrical Engineering, Universiti Teknologi MARA, Shah Alam, 40450, Malaysia
ismailbm@uitm.edu.my, shahril@uitm.edu.my

ABSTRACT

Loss in power system is a significant issue as it effects power system quality of service. Distributed Generation (DG) installation in power system is one of loss compensation of choice.DG installation in terms of DG type, size and location must be properly planned to avoid over-compensation or under-compensation.This paper analyses the impact of installing different DG types and their penetration level to control transmission power system loss. Ahybrid optimization techniqueknown as Immunized-Brainstorm-Evolutionary Programming (IBSEP) was used to determine the optimal DG sizes and location. It is important to examine the effect of installingdifferent DG typesso that related authoritiesare informed on the worthinessof the approach. Comprehensive results are embedded in this paper to demonstrate the effect of installing different DG types in transmission system towards system loss which would be beneficial to the power system operators.The results show that DGs with real power is better at minimizing the system loss. The lossis further reduced as the DG penetration level increases.

Key words: Distributed Generation, Real Power DG, Reactive Power DG, Loss Control, Penetration Level

1. INTRODUCTION

The current increasing demand in most power system network has led to voltage decrement. This phenomenon has been identified to be the cause for losses increment and monetary losses.Several options can be considered to alleviate and minimize losses phenomenon. One of the popular options is the installation of distributed generation (DG). DGhas been known to be having the ability to minimize loss of apower system, especially when their sizes and placements are carefully selected [1]–[3]. Power losses are very crucial in power system as they reduce the power transfer efficiency which can be translated to monetary loss to the power provider.

Numerous studies have beenconducted to minimize power system loss by placing DG in the transmission system[4]–[9]. These studies, though not as extensively as with the distribution system, concluded that transmission network loss can be minimized while the voltage was improved with the installation of optimally selected DG in terms of location and/or size.[10]–[12].

The importance of finding optimal DG size and/or location to fulfill the objective function, i.e. loss minimization encourages researchers to invent morerobust and reliable optimizationtechniques [13]–[16].The new techniques are commonly aim to avoid trapping solutions in local optima and to alleviate computational burden in the classical optimization techniques[17]. Example of classical optimization techniques are Evolutionary Programming (EP), Artificial Immune System (AIS) and Brainstorm Optimization (BSO). Introduced in 2011, BSOis an optimization technique thatreplicates human collective behaviour. Despite its ability to solve science and engineering problems, the K-means clustering technique approached by BSO causes high computational time[18].

In this paper, aIBSEP that incorporates AIS and BSO into the frame of EP was used to optimize the locations and sizes of multiple DGs in loss minimization. The DGs were installed in IEEE-30 Bus reliability test system (RTS) that resembles small transmission power system.

2. PROBLEM FORMULATION

The aim of this study was to investigate the effect of differentDG types installationatminimising transmission systemloss.The system loss with and withoutthe DG installation will be measured, for each DG type. Loss reduction percentage (LRP) due to DG installation will be calculated using equation ((1).

$$LRP = \frac{Loss_{No\ DG} - Loss_{DG}}{Loss_{No\ DG}} \times 100\ \% \qquad (1)$$

The following sections describe the objective function to be minimizedas well as the optimization constraints.

2.1 Objective Function

Theobjective function for this study is to minimize system loss, as mathematically represented by equation (2)

$$O.F. = Min \sum_{i=1}^{n} P_{loss,i} \qquad (2)$$

where n is the system bus number, and P_{loss} atline$i$ can be determined from equation(3) - (5),

$$P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j + P_iQ_j\right)\right] \qquad (3)$$

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos\left(\delta_i - \delta_j\right) \qquad (4)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin\left(\delta_i - \delta_j\right) \qquad (5)$$

where $r_{ij}$is the line resistance between bus i and bus j, V_i and V_j are the voltage magnitude, δ_i and δ_j are the voltage angles,$P_i$and P_j , are the active power whileQ_i and$Q_j$are the reactive power at bus i and j respectively.

The equality constraint on the power balanceas in equation (6) will be considered:

$$\sum_{i=1}^{n} P_i = P_{demand} + P_{loss} \qquad (6)$$

where P_{demand}represents the system load demand.

The inequality constraints as in equation (7)are also considered:

$$P_{i,min} \leq P_i \leq P_{i,max} \qquad (7)$$

where $P_{i,min}$ and $P_{i,max}$ are minimumreal power output and maximum real power output of i^{th} generator, respectively.

2.2 Penetration Level

Penetration level is one of the important criteria in DG studies. Once the optimal DG sizes are determined, the penetration level of installed DG to the network can be calculated using equation (8).

$$\frac{TotalSize_{DG}}{Load_{Total}} \times 100\% \qquad (8)$$

$TotalSize_{DG}$ is calculated by summing all DG sizes in MW for Type-1 and Type-3 DG, and in MVar for Type-2 DG. $Load_{Total}$ is total load demand determined from load flow without DG installation. Total active-power load demand will be used to calculate the penetration level of Type-1 and Type-3 DGs while total reactive-power load demand will be used with Type-2 DGs.

2.3 DG Type

DGs are categorized according to their ability to deliver real power or reactive power, or both. There are four categoriesof DG in terms of power delivery as defined in Table 1[19].

P_{dg} represents real power of DG and Q_{dg} represents DGs reactive power. Value 1 in column P_{dg} and Q_{dg} indicates that the DG is able to deliver real power and reactive power, respectively. Value 0 indicates that the power is not delivered, while value -1 indicates that that DG absorbs that power.

This study compares the effect of installing single Type-1, Type-2 and Type-3 DG in controlling the transmission system loss. The DG units will be increased to two and three units so that the effect of DG penetration level to transmission system can be investigated. The real power for each Type-1 DG is limited to 50MW, following the maximum PV output suggested by reference[20]. The apparent power *S*, for each Type-1 DG would then be limited to 50MVA, based on equation (10).

$$S = \sqrt{P^2 + Q^2} \qquad (9)$$

where *S* is the apparent power, in VA, *P* is the real power, in W and *Q* is the reactive power, in VAR of the DG. For fair comparison, the maximum apparent power of other DG typeswere also set to 50MVA each.

Table1: Types of DGs and their power delivery ability

Type of DG	Description	P_{dg}	Q_{dg}
Type-1	Deliver only real power E.g.: photovoltaic and fuel cells.	1	0
Type-2	Deliver only reactive power E.g.: DGs based on synchronous compensator.	0	1
Type-3	Deliver real power and reactive power E.g.: Cogeneration and gas turbine.	1	1
Type-4	Deliver real power but absorb reactive power. E.g.: Induction generators used in wind farms.	1	-1

3. PROPOSED METHODOLOGY

In this study, optimal DGssizes are placed at optimal load buses of IEEE-30 RTS to minimize system loss while systemreactive demand increases.These optimal DG sizes and location were determined using IBSEP optimization technique. The following section explains the IBSEP technique.

3.1 Immunized-Brainstorm-Evolutionary Programming (IBSEP)Technique

Figure 1 shows the IBSEP flowchart to determine the optimal DGlocation and size.The steps below briefly explain the algorithm:

Step 1: Initialization: Parameters of IBSEP technique likethe population size *k*, the clusters amount*l* and few constants are defined. The location, X_n and size, S_n are randomly generated for each *n* DG.

Step 2: Fitness Calculation: The system loss with DG installation will be inspected. Individuals with good fitness are cloned to increase the population size, creating broader choices among the individuals. Theyare then distributed to few clusters.

Step 3: Mutation: Individuals of a cluster is to be mutated using Gaussian mutation operator to produce offspring. The offspring fitness will be calculated.

Step 4: Combination Process: The parents and the offspring then compete where*n*top individuals will be progressed to the next cycle.

Step 5: Convergence Test: A convergence test that calculate the deviationof the individuals fitness values is conducted based on equation (9),

$$Loss_{max} - Loss_{min} \leq 0.00001 \qquad (10)$$

Step 2 until Step 5 are to be repeated if this condition is false.

3.2 Weak bus identification

This subsection explains the algorithm to determine the weak buses of the test system. A maximum loadability testis done by increasing the reactive load ofa load bus. The maximum load the system can take is recorded. The process is repeated with other buses.The maximum loadrecorded are then sorted in ascending order.Weak buses are identified as the top buses from the list.

4. RESULTS AND DISCUSSION

In this study, reactive load $Q_d$was increased from 0MVar to 30MVarat weak Bus-30. At the same time, the unit of DGs installed was increased from 1, 2, and 3 units, for each DG type.

Table 2 shows the system losses after single DG of each type wasinstalled while reactive load Q_{d30} increases. The system loss without DG when Q_{d30}varies at 0, 10, 20 and 30 MVar are 17.56 MW, 18.11 MW, 19.55 MW and 23.44 MW respectively.

From Table 2, it can be seen that single DG of Type-1 manages to reduce system loss the most when Q_{d30} increases from 0MVar to 20MVar as indicated by Loss Reduction Percentage (LRP) values in bold. At Q_{d30}=30MVar, Type-3 DG records the highest LRP of 37.40%.

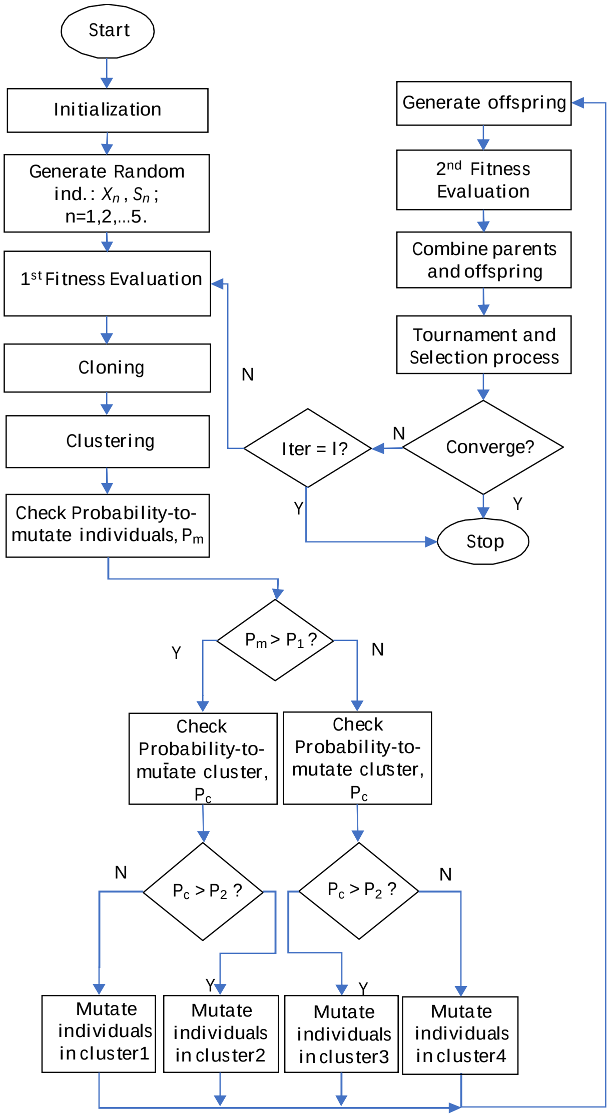

Figure 1: Flowchart for optimal DG location and sizes using IBSEP technique.

Table 2: IEEE-30 RTS Loss and LRP with Single Installation of Different DG Types

Q_{d30} (MVar)	Loss (MW)			LRP (%)		
	T1	T2	T3	T1	T2	T3
0	11.54	17.44	13.94	**34.30**	0.70	20.66
10	11.98	17.55	14.36	**33.86**	3.09	20.73
20	13.35	17.85	14.71	**31.73**	8.69	24.79
30	16.79	17.59	14.68	28.36	24.98	**37.40**

T1, T2 and T3 are Type-1, Type-2 and Type-3 DG respectively

Table 3 and Table 4 tabulate the system losses and LRP when two and three DGs of different type were installed in IEEE-30 RTS, respectively. From Table 2, $2T_1$ indicates two DGs of Type-1, while $2T_2$ indicates two DGs of Type-2 and $2T_3$indicates two DGs of Type-3. Whereas, $3T_1$, $3T_2$ and $3T_3$ in Table 4 represents three DGs of Type-1, Type-2 and Type-3 respectively. Again, Type-1 DGs show best performance in reducing the loss as Q_{d30} increases from 0MVar to 20MVar as shown by bold LRP. As Q_{d30} increases, LRP by Type-1 DGs decreases until the highest LRP is recorded by Type-3 DGs when Q_{d30} = 30MVar.

Table 3:IEEE-30 RTS Loss and LRP with Two Different Types DGs

Q_{d30}	Loss (MW)			LRP (%)		
(MVar)	2T1	2T2	2T3	2T1	2T2	2T3
0	9.32	17.40	10.98	**46.96**	0.95	37.47
10	10.33	17.52	10.92	**42.95**	3.27	39.71
20	11.62	17.60	12.18	**40.55**	9.98	37.69
30	14.79	17.62	12.94	36.91	24.85	**44.78**

T1, T2 and T3 are Type-1, Type-2 and Type-3 DG respectively

Table 4: IEEE-30 RTS Loss and LRP with Three Different TypesDGs

Q_{d30} (Mvar)	Loss (MW)			LRP (%)		
	3T1	3T2	3T3	3T1	3T2	3T3
0	7.92	17.39	9.54	**54.93**	1.01	45.69
10	8.74	17.50	9.89	**51.75**	3.36	45.37
20	10.04	17.62	11.09	**48.64**	9.87	43.28
30	13.14	17.83	11.27	43.95	23.93	**51.94**

T1, T2 and T3 are Type-1, Type-2 and Type-3 DG respectively

The optimal locations and sizes of these DGs are tabulated in Table 5, Table 6and Table 7for single, two and three DG units respectively. Q_{DGT1}, P_{DGT2},Q_{DG2T1}, P_{DG2T2},Q_{DG3T1} and P_{DG3T2} are 0 at all time. At Q_{d30}=30MVar, the optimal Type-3 is at Bus-30 with optimal P_{dg} and Q_{dg} sizes of 33.4MW and 29.8MVar respectively as highlighted in Table 5.

Table 5: Optimal Single DG Location and Sizes

Q_{d30}	Loc (Bus)			Size			
	T1	T2	T3	$P_{DG\ T1}$	$Q_{DG\ T2}$	$P_{DG\ T3}$	$Q_{DG\ T3}$
0	7	4	23	50.0	38.1	34.7	12.8
10	7	30	23	50.0	12.3	34.7	12.8
20	7	30	30	50.0	12.3	33.4	29.8
30	7	30	**30**	50.0	36.1	**33.4**	**29.8**

Unit for P_{DG} is MW. Unit for Q_{DG} is MVar.

Whereas, Bus-12 and Bus-30 are the optimal location for two Type-3 DGs with capacity of 28.2MW and 5.7MVar as well as 30.3MW and 17.2MVar respectively when Q_{d30}=30MVar as highlighted in Table 6.

At the same loading of 30MVar, Bus-30 is still one of the optimal bus for DG installation, along with Bus-19 and Bus-25 as highlighted in Table 7. The optimal DG sizes are 34.1MW with 19.0MVar, 1.9MW with 6.6MVar and 26.8MWwith 30.5MVar for the DGs installed at Bus-19, 25 and 30, respectively.

Table 6: Optimal Two DG Locations and Sizes

Q_{d30} (Mvar)	Loc (Bus)			Size			
	2T1	2T2	2T3	P_{DG} 2T1	Q_{DG} 2T2	P_{DG} 2T3	Q_{DG} 2T3
0	19	4	9	38.6	26.0	32.4	17.4
	28	24	27	48.6	11.0	33.3	16.2
10	7	25	6	50.0	6.8	33.7	4.7
	25	30	24	18.3	12.2	33.1	6.0
20	7	10	6	50.0	2.9	33.7	4.7
	25	30	24	18.3	27.1	33.1	6.0
30	7	10	**12**	50.0	2.9	**28.2**	**5.7**
	25	30	**30**	18.3	27.1	**30.3**	**17.2**

Unit for P_{DG} is MW. Unit for Q_{DG} is MVar.

Table 7: Optimal Three DG Locations and Sizes

Q_{d30} (Mvar)	Loc (Bus)			Size			
	3T1	3T2	3T3	P_{DG} 3T1	Q_{DG} 3T2	P_{DG} 3T3	Q_{DG} 3T3
0	4	3	6	32.7	18.8	30.2	17.6
	15	19	20	39.0	7.6	16.2	3.6
	22	25	28	45.2	2.6	31.4	10.2
10	7	12	6	34.0	30.0	30.2	17.6
	14	25	20	40.5	6.8	16.2	3.6
	28	30	28	32.6	12.2	31.4	10.2
20	7	3	6	34.0	40.4	28.5	9.9
	14	10	15	40.5	26.1	24.1	26.2
	28	30	29	32.6	29.2	24.1	31.9
30	7	15	**19**	34.0	18.4	**34.1**	**19.0**
	14	25	**25**	40.5	8.1	**1.9**	**6.6**
	28	30	**30**	32.6	43.2	**26.8**	**30.5**

Unit for P_{DG} is MW. Unit for Q_{DG} is MVar.

To investigate the effect of DG penetration level, the system load demand was determined from load flowas Q_{d30} increases and tabulated in Table8.

Table 8:Optimal Three DG **Locations and Sizes**

Q_{d30} (Mvar)	$Load_{Total}$	
	Pd (MW)	Q_d (Mvar)
0	283.4	124.3
10	283.4	134.3
20	283.4	144.3
30	283.4	154.3

Using equation **(8**) and DG sizes from Table 5until Table 7, the DG penetration level is calculated and shown in Table 9. From Table 9, it can be seen that for Type-1 DG, the penetration level increases from 17.6% to 37.8% as the number of DG increases at Q_{d30} = 20 MVar. This shows that as penetration level of DG increases, so does the LRP. It is also obvious that the penetration level of Type-1 DG is always higher than Type-3 DG.

Table 9: DG Penetration Level

DG Type	DG Amt. (Unit)	Penetration Level (%)			
		Q_{d30} = 0	Q_{d30} = 10	Q_{d30}= 20	Q_{d30}= 30
T1	1	17.6	17.6	**17.6**	17.6
	2	30.8	24.1	**24.1**	24.1
	3	41.2	37.8	**37.8**	37.8
T2	1	30.7	9.2	8.5	23.4
	2	29.8	49.8	20.8	19.4
	3	23.3	36.5	66.3	45.2
T3	1	12.2	12.2	11.8	11.8
	2	23.2	23.6	23.6	20.6
	3	27.5	27.5	27.1	22.2

However, if we relate to the LRP of these Type-1 and Type-3 DGs as shown in Table 2to Table 4, we can see that higher penetration level of DGs with real power does not always guarantee that it will minimize the system loss the most. As more reactive load is added to a weak bus of a transmission system, the reactive power provided by Type-3 DGs could have conditioned the load demand, thus supporting the network better than Type-1 and Type-2 DGs.

5. CONCLUSION

This paper presented the effect of installingDGs of different types and its penetration level in transmission system to minimize system loss. In this study, the application of IBSEP managed to search the optimal locations and sizing of DGs with reactive load varied.

It can be concluded that as reactive load at a weak bus increases, DGs that provide real power are able to minimize system loss more than the DGs that provide only reactive power. LRP also increases when the number of DGs, or the DG penetration level increases. However, as the weak bus is heavily loaded, DGs with the ability to provide both real and reactive power would be a better choice to minimize transmission system loss.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Research Management (RMC) UiTM Shah Alam, Selangor, Malaysia and the Ministry of Education, Malaysia (MOE) for the financial support of this research. This research is supported by MOE under Fundamental Research Grant Scheme (FRGS) with project code:600-IRMI/FRGS 5/3 (082/2019).

REFERENCES

[1] P. Kayal and C. K. Chanda, “Placement of wind and solar based DGs in distribution system for power loss minimization and voltage stability improvement,” *International Journal of Electrical Power & Energy Systems*, vol. 53, pp. 795–809, Dec. 2013.

[2] U. Sultana, A. B. Khairuddin, M. M. Aman, A. S. Mokhtar, and N. Zareen, “A review of optimum DG placement based on minimization of power losses and voltage stability enhancement of distribution system,” *Renewable and Sustainable Energy Reviews*, vol. 63, pp. 363–378, 2016.

[3] B. Poornazaryan, P. Karimyan, G. B. Gharehpetian, and M. Abedi, “Optimal allocation and sizing of DG units considering voltage stability, losses and load variations,” *International Journal of Electrical Power & Energy Systems*, vol. 79, pp. 42–52, Jul. 2016.

[4] D. Q. Hung, N. Mithulananthan, and R. C. Bansal, “Integration of PV and BES units in commercial distribution systems considering energy loss and voltage stability,” *Applied Energy*, vol. 113, pp. 1162–1170, Jan. 2014.

[5] N. Ameir Ahmad, I. Musirin, and S. I. Sulaiman, “Loss minimization of distribution system with photovoltaic injection using Swarm evolutionary programming,” *Proceedings of the 2013 IEEE 7th International Power Engineering and Optimization Conference, PEOCO 2013*, no. June, pp. 752–757, 2013.

[6] V. Mendez, J. Rivier, and T. Gomez, “Assessment of Energy Distribution Losses for Increasing Penetration of Distributed Generation,” *IEEE Transactions on Power Systems*, vol. 21, no. 2, pp. 533–540, 2006.

[7] M. F. Nadeem, T. N. Malik, A. R. Imtiaz, and G. Ali, “Simultaneous placement and sizing of multi-DG units in distribution system using IGSA,” in *2018 International Conference on Computing, Mathematics and Engineering Technologies: Invent, Innovate and Integrate for Socioeconomic Development, iCoMET 2018 - Proceedings*, 2018.

[8] N. Z. M. Ali, I. Musirin, S. I. Suliman, N. R. Hamzah, and Z. Zakaria, “Effect of multi-DG installation to loss reduction in distribution system,” *Journal of Electrical Systems*, vol. 12, no. 1, pp. 187–196, 2016.

[9] P. Chiradeja, S. Yoomak, and A. Ngaopitakkul, “Optimal Allocation of Multi-DG on Distribution System Reliability and Power Losses Using Differential Evolution Algorithm,” in *Energy Procedia*, 2017.

[10] M. H. Mansor, I. Musirin, M. M. Othman, S. A. Shaaya, and S. A. Syed Mustaffa, “Application of immune log-normal evolutionary programming in distributed generation installation,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 6, no. 3, 2017.

[11] M. K. Mohamad Zamani,et al., “Active and reactive power scheduling optimization using firefly algorithm to improve voltage stability under load demand variation,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 9, no. 2, 2018.

[12] S. A. Shaaya, I. Musirin, S. I. Sulaiman, and M. H. Mansor, “Immunized-evolutionary algorithm based technique for loss control in transmission system with multi-load increment,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 6, no. 3, 2017.

[13] J. Soares, M. Silva, T. Sousa, Z. Vale, and H. Morais, “Distributed energy resource short-term scheduling using Signaled Particle Swarm Optimization,” *Energy*, vol. 42, no. 1, pp. 466–476, 2012.

[14] Z. M. Yasin, T. K. A. Rahman, and Z. Zakaria., “Multiobjective Quantum-inspired Evolutionary Programming for Optimal Location and Sizing of Distributed Generation,” *2012 IEEE Conf Sustain Util Dev Eng Technol STUDENT 2012 – Conf Bookl*, pp. 233–238, 2012.

[15] G. Yang-yang, C. Zhi-yuan, and S. Li-yong, “Optimal placement for hybrid energy in micro-grid,” *2016 IEEE International Conference on Power System Technology (POWERCON)*, vol. 3, pp. 1–8, 2016.

[16] K. Muthukumar and S. Jayalalitha, “Optimal placement and sizing of distributed generators and shunt capacitors for power loss minimization in radial distribution networks using hybrid heuristic search optimization technique,” *International Journal of Electrical Power & Energy Systems*, vol. 78, pp. 299–319, Jun. 2016.

[17] I. Rahman and J. Mohamad-saleh, “Hybrid bio-Inspired computational intelligence techniques for solving power system optimization problems : A comprehensive survey,” *Applied Soft Computing Journal*, vol. 69, pp. 72–130, 2018. https://doi.org/10.1016/j.asoc.2018.04.051

[18] Z. Song, J. Peng, C. Li, and P. X. Liu, “A Simple Brain Storm Optimization Algorithm with a Periodic Quantum Learning Strategy,” *IEEE Access*, vol. 6, pp. 19968–19983, 2017.

[19] R. P. Payasi, A. K. Singh, and D. Singh, “Optimal Location and Size of Different Type of Distributed Generation with Voltage Step Constraint,” pp. 341–357, 2013.

[20] A. W. H. Sie, I. Z. Abidin, and H. Hashim, “A methodology to determine suitable placement of solar photovoltaic sources in the transmission system taking into account Voltage Stability Index (VSI),” in *Conference Proceeding - 2014 IEEE International Conference on Power and Energy, PECon 2014,* 2014, pp. 226–230.