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Optimal Distributed Generation (DG) Allocation for Losses Reduction Using Improved Particle Swarm Optimization (IPSO) Method

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ABSTRACT

The optimal aloccation of Distributed Generation (DG) was most important aspect of DG connected to electrical network scheme development. The methods to determine optimal allocation of DG like SGA dan PSO had weakness. The weakness was a large possibility to be trapped in local optimum solutions. Inertia weight (w) adding to PSO algorithm was a way to overcome the weakness. The developing method knew as Improved Particle Swarm Optimization (IPSO). This research used IPSO method for optimal allocation of DG. The optimization was conducted to obtain minimum active power losses reduction with acceptable voltage profile. The method was implemented and tested on IEEE 30 Bus System. The comparison of losses reduction after DG installation showed that IPSO method generated more optimal solution than SGA and PSO methods. The voltage profile after DG installation using IPSO method within standar voltage limit 0.95 - 1.1 pu.
Keywords: Optimization, distributed generation, losses reduction, Improved Particle Swarm Optimization

INTRODUCTION

Distributed Generation (DG) was defined by The Electric Power Research Institute (EPRI) as a power plant with capacity of several kW to 50 MW [1].The DG is a generation system that will play important role in the future. The interconnection planning of DG to electrical network must consider a number of factors. The factors included DG technology; capacity of DG unit; location of DG connected and network connection type [2], [3].

The DG was connected to network could provide a number of benefits. The benefits were active power losses reduction, energy undelivered costs reduction, preventing or delaying network expansion [3]. Other benefits were peak load operating costs reduction, improved voltage profile and improved load factor network [4]. In addition to provide benefits, DG could also have negative impacts on network. The impacts were frequency deviation, voltage deviation and harmonics on network [5]. The increasing of power losses was other effect that might be occurred [2], [3]. Optimum allocation of DG had a correlation with the benefits or negative impacts.

The methods were used in the optimization of DG allocation can be divided into analytical methods, computer programming methods and artificial intelligence methods [6]. The artificial intelligence method that using in the previous researches included Genetic Algorithm (GA) [2], [5], [7] and Particle Swarm Optimization (PSO) [8]. The relationship between optimal of DG allocation and network power losses and voltage profile had been studied by some researchers. Borges and Falcao (2006) studied the optimal allocation of distributed generation for reliability, losses reduction and voltage improvement using GA. El-Ela et al (2010) used GA to maximize optimal benefit of DG that was connected to the network. The objectives of research included power losses reduction and voltage profile improvement. Beromi et al (2007) discussed about power losses reduction and voltage profile improvement through optimal DG allocation using GA. Beromi et al (2008) conducted an optimization of DG capacity and location to get power losses reduction, improvement of voltage profile and reduction of harmonic distortion using PSO.

SGA and PSO method was identified had a weakness. Both of methods had a great possibility to get stuck in local optimum solutions. This means that the solution was resulted by the methods were not necessarily the most optimal solution. The application of more advanced artificial intelligence method was a solution to overcome the problem. This research proposed Improved Particle Swarm Optimization (IPSO) method for optimal allocation of DG. The IPSO method was an accomplishment of PSO method with weight inertia factor adding on PSO algorithm.

The objective of this research was active power losses reduction in acceptable voltage profile (0.95 – 1.1 pu). The proposed method was implemented and tested on IEEE 30 Bus Test System. The implementation of IPSO method in this research was expected to minimize the local optimum solution occurrence. The simulation results comparison of IPSO, PSO SGA method could present the capability of this proposed method.

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MATERIALS AND METHODS

Optimization of multi-type distributed generation (DG) on IEEE 30 bus system

This research used multi-type DG. The multi-type DG were:

1. DG injecting only active power. In this research, the DG was referred to DG type 1.
2. DG injecting both active and reactive power. In this research, the DG was referred to DG type 2
2. DG injecting active power and absorbing reactive power. In this research, the DG was referred to DG type 3.

The each DG unit had 12 MW maximum active power capacities. The DG type 2 and type 3 had 3 MVAr maximum reactive power capacities. The optimization conducted on four DG unit for each type. This optimization research used bus data and line data of IEEE 30 bus system [9]. From 24 bus loads of IEEE 30 bus, DG could be placed on 18 bus. The buses were classified as distribution bus with voltage 33 kV. The number of buses was 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29 and 30. The initial active power losses of system were 17.9773 MW.

Proposed of optimization method

Optimization procedure using IPSO method was described as follows:

1. Individu position and velocity initialization

Initialization was performed on a set of individual. The set of individual was a group or population that generating randomly. Individual structures in this research was consisted of a set of elements. The element was included of DG active power capacity, DG reactive power capacity and DG location. Thus, the position of individual i at iteration 0 was represented by:

$$X_i^0 = (P_{i1},...,P_{im}),(Q_{i1},...,Q_{im}),(L_{i1},...,L_{im}) \quad (1)$$

With

P = active power capacity of DG

Q = reactive power capacity of DG

L = location of DG

With individual i velocity was:

$$V_i^0 = (v_{i1},...,v_{in}) \quad (2)$$

Velocity changing on PSO algorithm consisted of three parts, namely social part, cognitive part and momentum part. The third part determined the balance between global and local search capabilities [10]. Social part of standard PSO algorithm could be developed with inertia weight parameter addition. The concept of inertia weight (w) was developed by Shi and Eberhart in 1998 to be a good control parameter of the searching scope. The concept was motivated to reduce Vmax [11].

Inertia weight parameter (w) was obtained using equation (3).

$$w = w_{max} - \frac{w_{max} - w_{min}}{Iter_{max}} xIter \quad (3)$$

The dynamic equation of PSO with inertia weight (w) became:

$$V_{id} = \omega V_{id} + c_1 rand_1 (P_{id} - X_{id}) + c_2 rand_2 (P_{gd} - X_{id}) \quad (4)$$

$$X_{id} = X_{id} + V_{id} \quad (5)$$

2. Optimization of fitness evaluation at d variable on each particle

Each particle was evaluated using objective function as showed in equation (6).

Minimization:

$$F = \sum_{i=1}^{N_B} P_{loss-i}, i = 1,,2,3...N_B \quad (6)$$

The objective function was limited by voltage constraints as equation as showed in equation (7):

$$V_{i\min} \le V_i \le V_{i\max}, \quad (7)$$

3. The fitness evaluation of particle was compared with its Pbest. If there was a better value than its Pbest value, Pbest set to equal with the value. The Pi had same location with existing particle, Xi in d dimensional space.

4. Pbest of each individu at k+1 iteration, was modified by equation (8) and (9):

$$Pbest_i^{k+1} = X_i^{k+1} \ if \ TC_i^{k+1} < TC_i^k \quad (8)$$

$$Pbest_i^{k+1} = Pbest_i^k \ if \ TC_i^{k+1} < TC_i^k. \quad (9)$$

with TC_i was objective function evaluation at individual position 1. Gbest at k+1 iteration was set as best position that had been evaluated. Likewise with $Pbest_i^{k+1}$

4. The particle identification in environment with the best result.
5. Velocity and position particle updated.
6. Returned to step 2 until the criteria was considered. Usually stopped at enough good fitness value or until reached maximum number of iterations.The flow chart of optimization method was shown in figure 1.

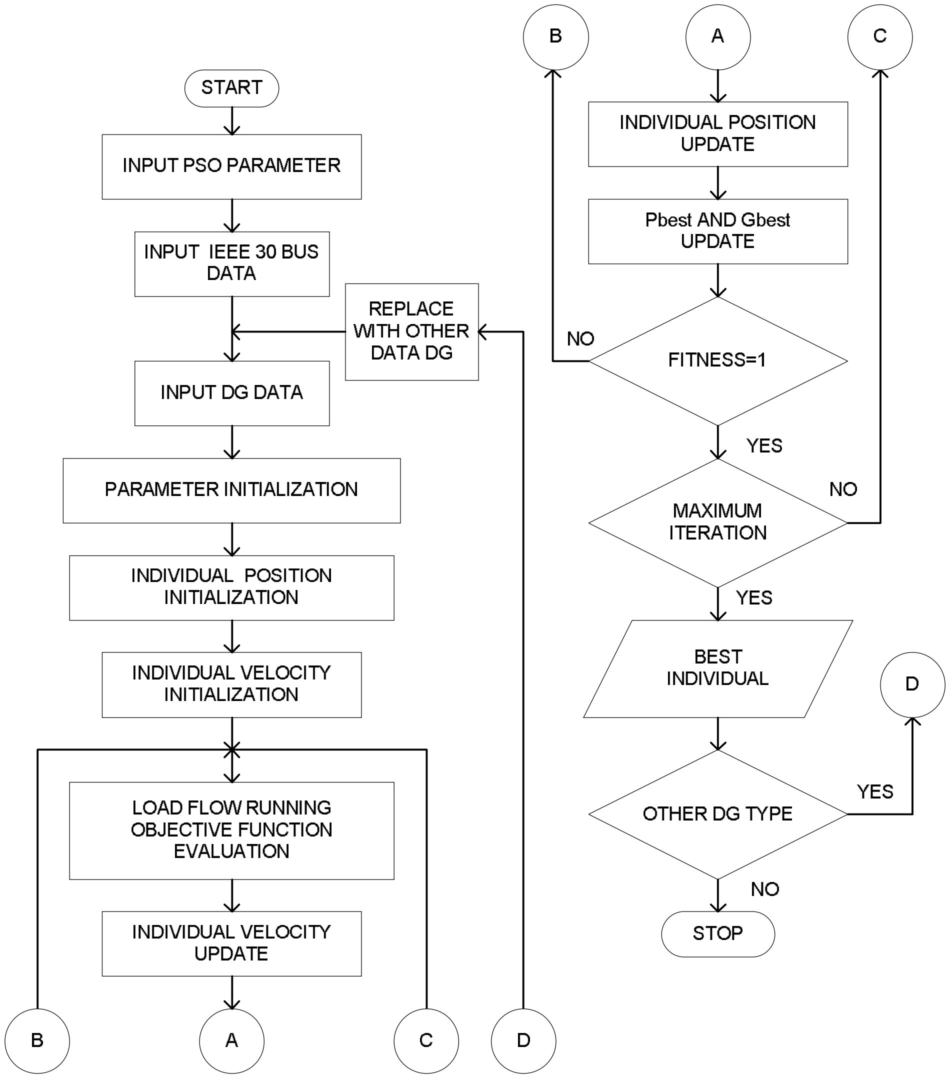


Figure 1: The optimization using IPSO method flow chart

RESULTS AND DISCUSSION

Table 1 presented the comparison of optimal DG type 1 allocation using IPSO, PSO and SGA methods. The simulation results for DG type 2 were shown in table 2. While table 3 showed the simulation results for DG type 3.

Table 1. Optimal DG Type 1 Allocation Using IPSO, PSO and SGA Method

IPSO METHOD			PSO METHOD			SGA METHOD		
Optimum Allocation		Losses MW	Optimum Allocation		Losses MW	Optimum Allocation		Losses MW
Bus No	Size MW+jMVAr		Bus No	Size MW+jMVAr		Bus No	Size MW+jMVAr	
10	11.625 +j0	12.1851	10	11.694+j0	12.2622	10	11.472+j0	12.3919
10	11.956+j0		15	11.391+j0		10	11.904+j0	
22	11.995+j0		20	11.378+j0		19	11.052+j0	
30	11.986+j0		30	10.577+j0		24	11.772+j0	
Total	47.562+j0		Total	45.04+j0		Total	46.6+j0	

Table 2. Optimal DG Type 2 Allocation Using IPSO, PSO and SGA Method

IPSO METHOD			PSO METHOD			SGA METHOD		
Optimum Allocation		Losses MW	Optimum Allocation		Losses MW	Optimum Allocation		Losses MW
Bus No	Size MW+jMVAr		Bus No	Size MW+jMVAr		Bus No	Size MW+jMVAr	
10	11.830+j0.001	11.9450	10	11.474+j2.159	12.1056	10	11.364+j1.219	12.2258
21	11.433+j3.000		17	11.981+j0.919		23	11.472+j1.168	
24	11.739+j3.000		20	11.670+j2.305		24	11.916+j2.037	
30	11.995+j0.001		30	11.349+j3.000		30	9.816+j1.468	
Total	46.997+j6.002		Total	46.474+j8.383		Total	44.568+j5.892	

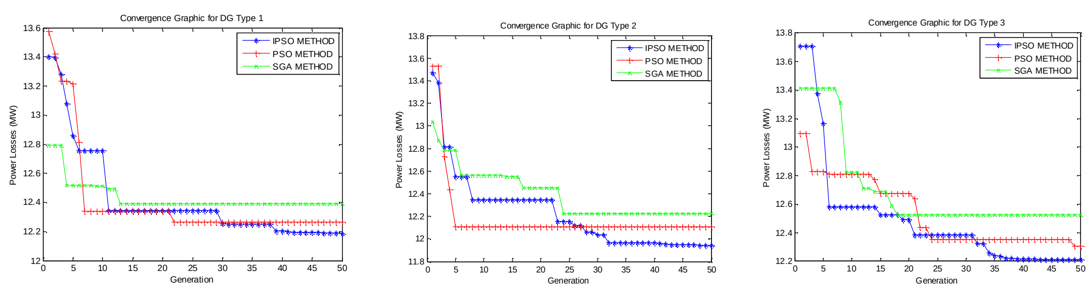
Table 3. Optimal DG Type 3 Allocation Using IPSO, PSO and SGA Method

IPSO METHOD			PSO METHOD			SGA METHOD		
Optimum Allocation		Losses MW	Optimum Allocation		Losses MW	Optimum Allocation		Losses MW
Bus No	Size MW-jMVAr		Bus No	Size MW-jMVAr		Bus No	Size MW-jMVAr	
10	12.000 -j0.526	12.2099	10	11.885-j0.797	12.3044	10	9.384-j0.088	12.5265
19	10.861-j3.000		18	10.881-j3.000		18	11.112-j0.715	
22	11.917-j2.837		20	11.563-j0.899		22	11.748 -j0.589	
30	11.956-j0.526		30	11.350 -j0.383		30	10.008-j0.487	
Total	46.734-j6.889		Total	45.679-j5.079		Total	42.252-j1.879	

Table 1, 2 and 3 showed that IPSO method generated the smallest active power losses compared with two other methods. For DG type 1, IPSO method generated 12.1851 MW losses. The PSO and SGA methods generated 12.2622 and 12.3919 MW losses, respectively. The IPSO method generated 11.9450 MW losses for DG type 2. The PSO and SGA method generated 12.1056 and 12.2258 MW losses, respectively. For DG type 3, The IPSO method generated 12.2099 MW losses while PSO and SGA were 12.3044 and 12.5265 MW, respectively.

Table 4. Losses Reduction Before and After DG Installation

DG Type	Losses Without DG (MW)	IPSO Method Losses		PSO Method Losses		SGA Method Losses	
		Reduction (MW)	Reduction (%)	Reduction (MW)	Reduction (%)	Reduction (MW)	Reduction (%)
Type 1	17.9773	5.7922	32.22	5.7150	31.79	5.5853	31.07
Type 2		6.0323	33.56	5.8717	32.66	5.7515	31.99
Type 3		5.7674	32.08	5.6729	31.56	5.4509	30.32



(a) DG Type 1 (b) DG Type 2 (c) DG Type 3

Figure 2: The Convergence Graphic Comparison of IPSO, PSO and SGA Methods

Table 4 showed the active power losses reduction before and after DG installation. The table showed that IPSO method generated the highest active power losses reduction compared to the other two methods. The IPSO method generated 32.22 % losses reduction for DG type 1. The PSO and SGA method generated 31.79 % and 31.07 % losses reduction, respectively. For DG type 2, IPSO method generated 33,56 % losses reduction while PSO and SGA were 32.66 % and 31.99 % losses reduction, respectively. For DG type 3, IPSO method generated 32.08 % losses reduction. The PSO and SGA method generated 31.56 % and 30.32 % losses reduction, respectively.

Figure 2 showed convergence graphic comparison of optimization program using IPSO, PSO and SGA method for DG type 1, DG type 2 and DG type 3. The graphics showed the relationship between convergence value of active power losses and number of generation or iterations was required to obtain optimal solution. The IPSO graphic convergence generated the smallest active power losses comparing to two other methods. However, it needed more iteration to convergence. Optimal solution for all simulation obtained before 40th iteration from maximum 50 iterations. Table 5 showed the comparison number of iterations to convergence for IPSO, PSO and SGA method.

Table 5. The Number of Iteration to Convergence for IPSO, PSO and SGA Method

DG Type	Number of Iterations		
	IPSO	PSO	SGA
Type 1	39	21	13
Type 2	32	5	24
Type 3	37	24	14

Table 6. The Voltage Profile Comparation between IPSO, PSO and SGA Methods

Bus No	VOLTAGE WITHOUT DG (pu)	VOLTAGE WITH DG TYPE 1 (pu)			VOLTAGE WITH DG TYPE 2 (pu)			VOLTAGE WITH DG TYPE 3 (pu)		
		IPSO	PSO	SGA	IPSO	PSO	SGA	IPSO	PSO	SGA
1	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060
2	1.033	1.043	1.043	1.043	1.043	1.043	1.043	1.043	1.043	1.043
3	1.013	1.024	1.024	1.024	1.025	1.025	1.025	1.023	1.024	1.024
4	1.003	1.016	1.016	1.016	1.016	1.017	1.016	1.015	1.015	1.015
5	1.000	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010
6	1.000	1.014	1.014	1.014	1.015	1.015	1.014	1.013	1.013	1.013
7	0.992	1.005	1.004	1.005	1.005	1.005	1.005	1.004	1.004	1.004
8	1.000	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010
9	1.030	1.045	1.044	1.045	1.047	1.048	1.046	1.041	1.042	1.043
10	1.013	1.030	1.027	1.030	1.034	1.035	1.031	1.022	1.024	1.027
11	1.072	1.082	1.082	1.082	1.082	1.082	1.082	1.082	1.082	1.082
12	1.045	1.051	1.053	1.052	1.054	1.054	1.055	1.049	1.050	1.051
13	1.071	1.071	1.071	1.071	1.071	1.071	1.071	1.071	1.071	1.071
14	1.028	1.034	1.038	1.036	1.038	1.039	1.040	1.031	1.033	1.035
15	1.020	1.030	1.036	1.033	1.035	1.036	1.038	1.027	1.030	1.032
16	1.025	1.035	1.035	1.036	1.038	1.041	1.038	1.031	1.032	1.034
17	1.011	1.026	1.024	1.026	1.030	1.035	1.028	1.019	1.021	1.023
18	1.005	1.017	1.025	1.025	1.022	1.029	1.023	1.015	1.022	1.024
19	1.000	1.013	1.021	1.023	1.018	1.028	1.018	1.011	1.017	1.017
20	1.002	1.017	1.024	1.024	1.021	1.033	1.020	1.013	1.020	1.018
21	1.001	1.019	1.015	1.019	1.027	1.023	1.021	1.011	1.012	1.016
22	1.001	1.021	1.016	1.020	1.028	1.024	1.023	1.012	1.012	1.018
23	1.004	1.017	1.020	1.021	1.027	1.022	1.037	1.012	1.014	1.017
24	0.991	1.008	1.007	1.014	1.025	1.013	1.026	1.000	1.003	1.006
25	0.994	1.013	1.012	1.010	1.024	1.022	1.026	1.004	1.009	1.010
26	0.976	0.995	0.994	0.992	1.006	1.004	1.008	0.986	0.991	0.993
27	1.005	1.025	1.024	1.017	1.031	1.035	1.034	1.015	1.022	1.022
28	0.998	1.014	1.013	1.012	1.015	1.015	1.015	1.012	1.013	1.013
29	0.985	1.017	1.015	0.997	1.023	1.032	1.026	1.003	1.012	1.011
30	0.973	1.017	1.014	0.986	1.024	1.037	1.027	1.000	1.011	1.009
Average		1.0260	1.0264	1.0251	1.0305	1.0314	1.0301	1.0215	1.0241	1.0250

Table 6 showed the voltage values before and after DG installation using IPSO, PSO and SGA methods. For DG type 1, IPSO method generated the highest average voltage was 1.0260 pu. PSO and SGA method generated 1.0264 and 1.0251 pu, respectively. For DG type 2, IPSO , PSO and SGA method generated average voltage 1.0305, 1.0314 and 1.0301 pu, respectively. For DG type 3, IPSO, PSO and SGA methods generated average voltage 1.0215, 1.0241 and 1.0250 pu respectively.

Figure 3 showed the IEEE 30 Bus System voltage profile before and after DG type 1 installation using IPSO, PSO and SGA method. The result for DG type was shown in figure 4. Figure 5 showed the result for DG type 3. The all of figures showed that the all of bus voltage still remained at 0.95-1.1 pu value.

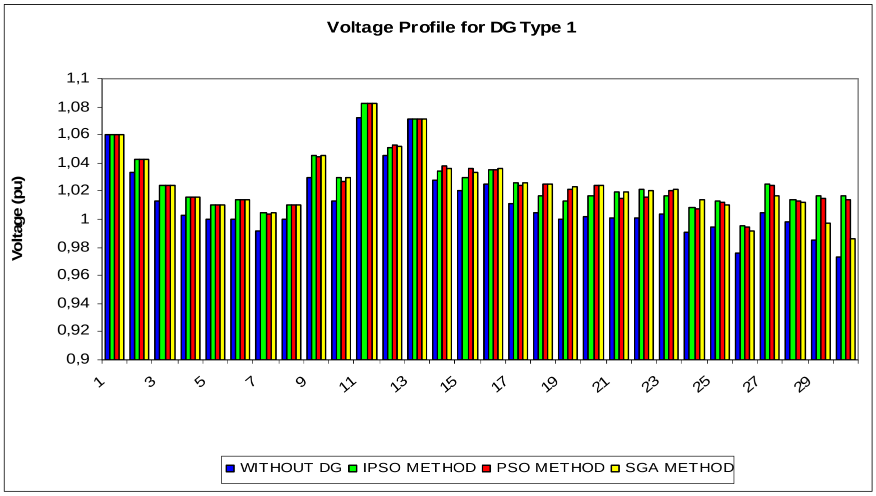


Figure 3: Voltage before and after DG type 1 installation

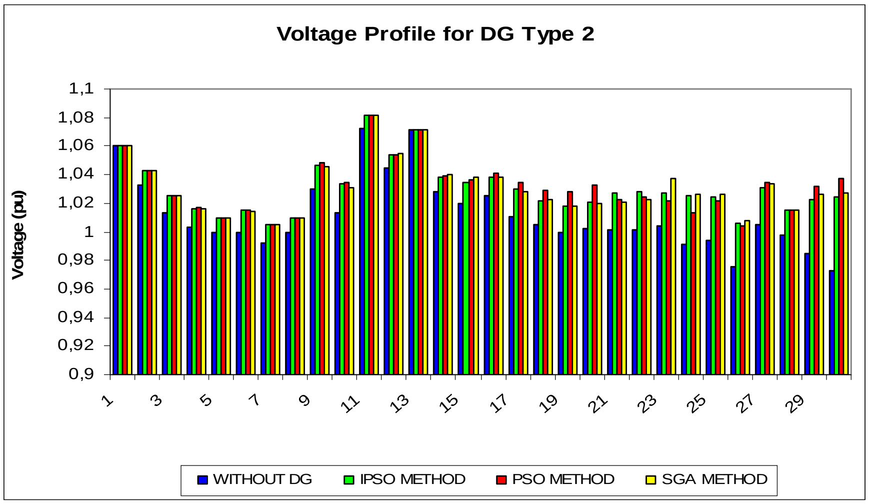


Figure 4: Voltage profile before and after DG type 2 installation

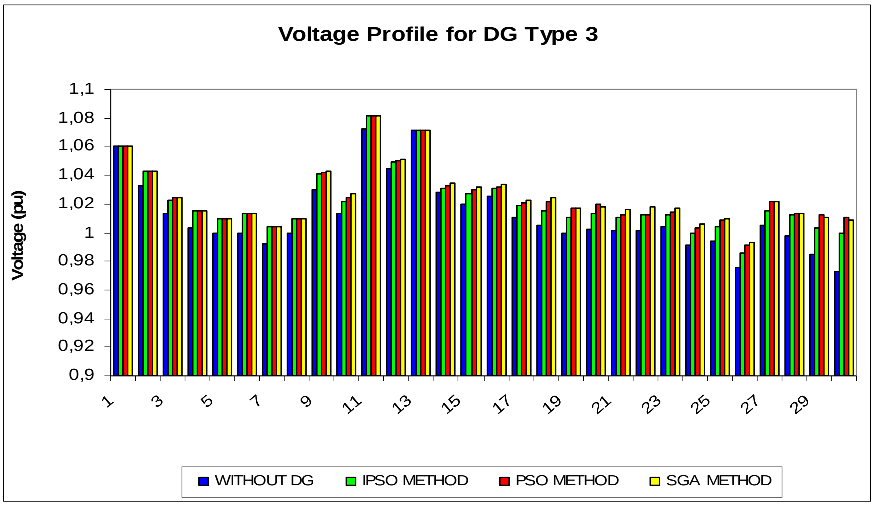


Figure 5: Voltage profile before and after DG type 3 installation

The simulation result presented that after all type DG installation, the active power losses were reduced and voltage profile was improved. This results were obtaned using IPSO, PSO and SGA methods. The IPSO method generated more optimal solution than PSO and SGA method base on the losses reduction parameter. The IPSO method generated the highest losses reduction compared to two other methods. However, the IPSO method needed more iterations number to convergence compared to PSO and SGA method.

The IPSO method showed unconsistent results for voltage profile parameter. For DG type 1 and 3, IPSO method generated the smallest average voltage compared to two other methods. But, the IPSO method generated higher average voltage than SGA method but lower than PSO method for DG type 2.

The comparison between each method needed some requirements that must be met. The comparison should be made head to head in same conditions. The conditions were research plant that used, number of DG, active power of DG capacity, reactive power of DG capacity and optimization objective. The comparison must be confirmed in convergence graphic. The convergence graphic could show the method capability to obtain the optimization value within determined iterations limit.

The paper that comparing the advantages of IPSO method than PSO and SGA for DG optimal allocation had not been obtained so far. The comparison between SGA and PSO method could use two papers were written by Beromi et al. Beromi et al (2007) conducted their research using SGA method. The other research used PSO method [8]. Both of researches used two unit of DG type injecting active and reactive power. Thus, the two research would be compared with simulation results using DG type 2 in this research. The comparisons were presented in the table 7.

The both of Beromi et al researches conducted on same research plant. The plant was Tehran Distribution Network 13 Bus. Their researches were different in objective parameter. But, the difference could be neglible for comparison usefulness. The losses reduction and voltage profile using two methods were compared each other. After DG installation, the losses reduced to 92.9 kW using SGA method. The work conducted by PSO method, generated 172.38 kW losses reduction. Thus, the PSO method generated higher reduction of losses than SGA method. For voltage profile, SGA method generated 0.99 pu average voltage. The PSO method generated 0. 976 pu average voltage. This means, the PSO method generated lower average voltage than SGA method. The graphic convergence of optimization program was not presented in two researches. It caused the comparison about number of iterations to convergence had not been obtained. Finally, Beromi et al (2008) in their research made a conclusion that the PSO method was better than SGA in terms of solution and number of iterations.

The reduction of losses and the improvement of voltage profile as result of this research were similar with the work of Beromi et al (2007) and Beromi et al (2008). In this research, only the losses reduction were considered to judge the capabilty of IPSO, PSO and SGA methods. From the result for DG type 1, 2 and 3, the highest of active power losses reduction were generated by IPSO method. Finally, this research made a conclusion that IPSO method generated more optimal solution compared to PSO and SGA method.

Table 7. The Research Comparison Using SGA, PSO and IPSO Methods

No	Parameter	Research by Beromi et al		Research by Yusran et al		
		Method		Method		
		SGA	PSO	SGA	PSO	IPSO
1	Research Plant	Tehran Distribution Network 13 Bus		IEEE 30 Bus		
2	DG Unit	2		4		
3	Active Power Capacity	Fix 1600 kW	At Range 500 – 1500 kW	At Range 0 – 12 MW		
4	Reactive Power Capacity	Fix 0.01 kVAr	At Range -50 to 500 kVAr	0.001 – 3 MVAr		
5	Objective of Optimization	Losses reduction Voltage profile improvement	Losses reduction Voltage profile improvement THD reduction	Losses reduction in acceptable voltage profile		
6	Losses Result	Reduced 92.9 kW	Reduced 172.38 kW	Reduced 31.99 %	Reduced 32.66 %	Reduced 33.56 %
7	Voltage Profile Result	Increased 0.99 pu	Increased 0.976 pu	Increased 1.0301 pu	Increased 1.0314 pu	Increased 1.0305 pu
8	Iterations Number	Not Available	Not Available	25	5	40
9	Method Comparison Result	PSO method better than SGA method on solution quality and number of iterations		The method rank based on losses result 1. IPSO 2. PSO 3. SGA		

CONCLUSION

A method based on IPSO method was proposed in this optimal DG allocation research. Optimization program implemented and tested on IEEE 30 Bus Sytem. In this research, the IPSO method was conducted succesfully to obtain optimal solution. The IPSO generated more optimal solution than PSO and SGA methods using active power losses reduction parameter. The highest power losses reduction was generated by IPSO method. However, IPSO method needed more iterations to convergence compared to two other methods. The voltage profile after DG installation using IPSO method within standar voltage limit 0.95 - 1.1 pu.

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