OPTIMAL MULTIPLE DISTRIBUTION GENERATION PLACEMENT IN MICROGRID SYSTEM

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1. Introduction

Microgrid (MG), a system of multiple distributed generations (DG) to serve loads, can reduce the system loss and improve system reliability.

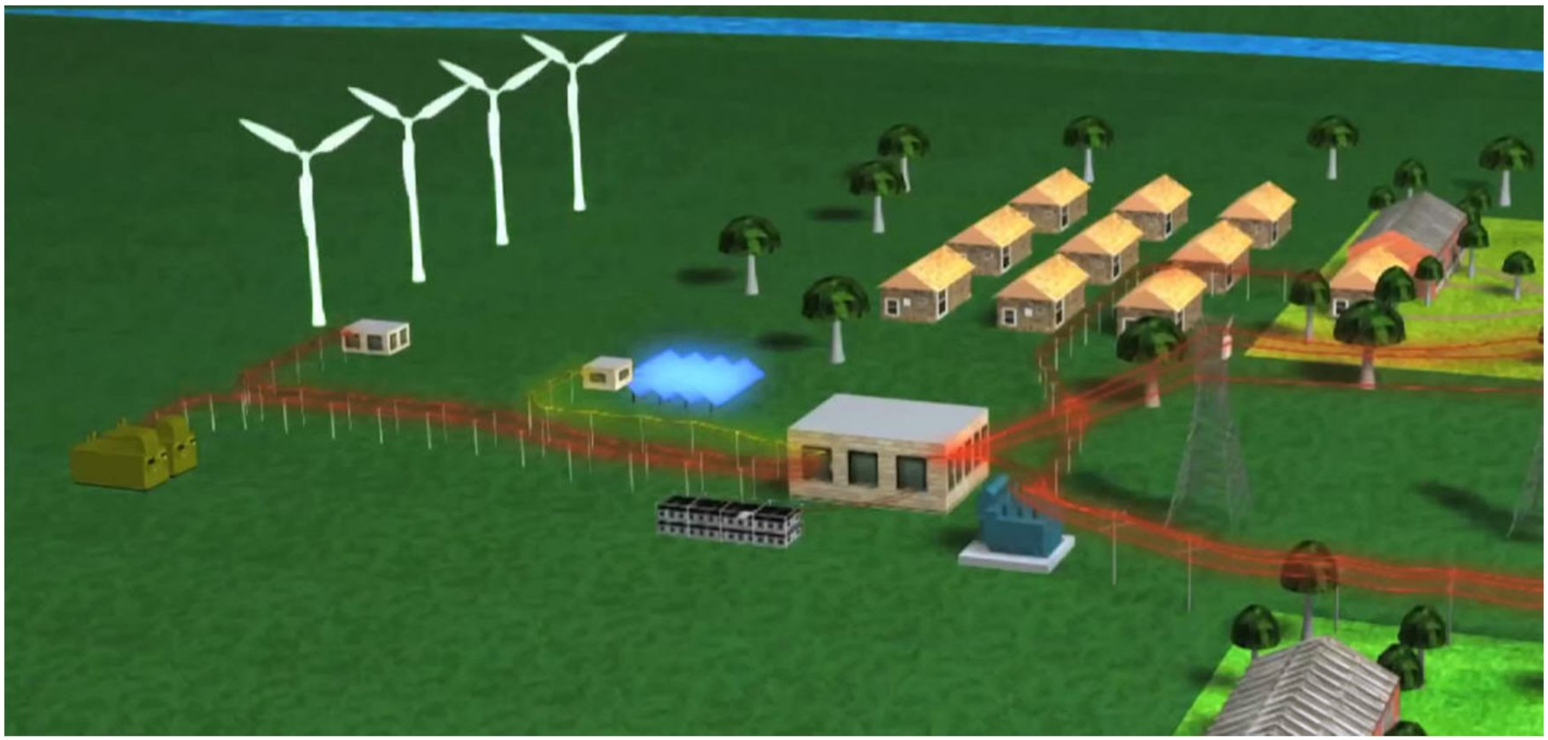


Figure 1.1 Microgrids

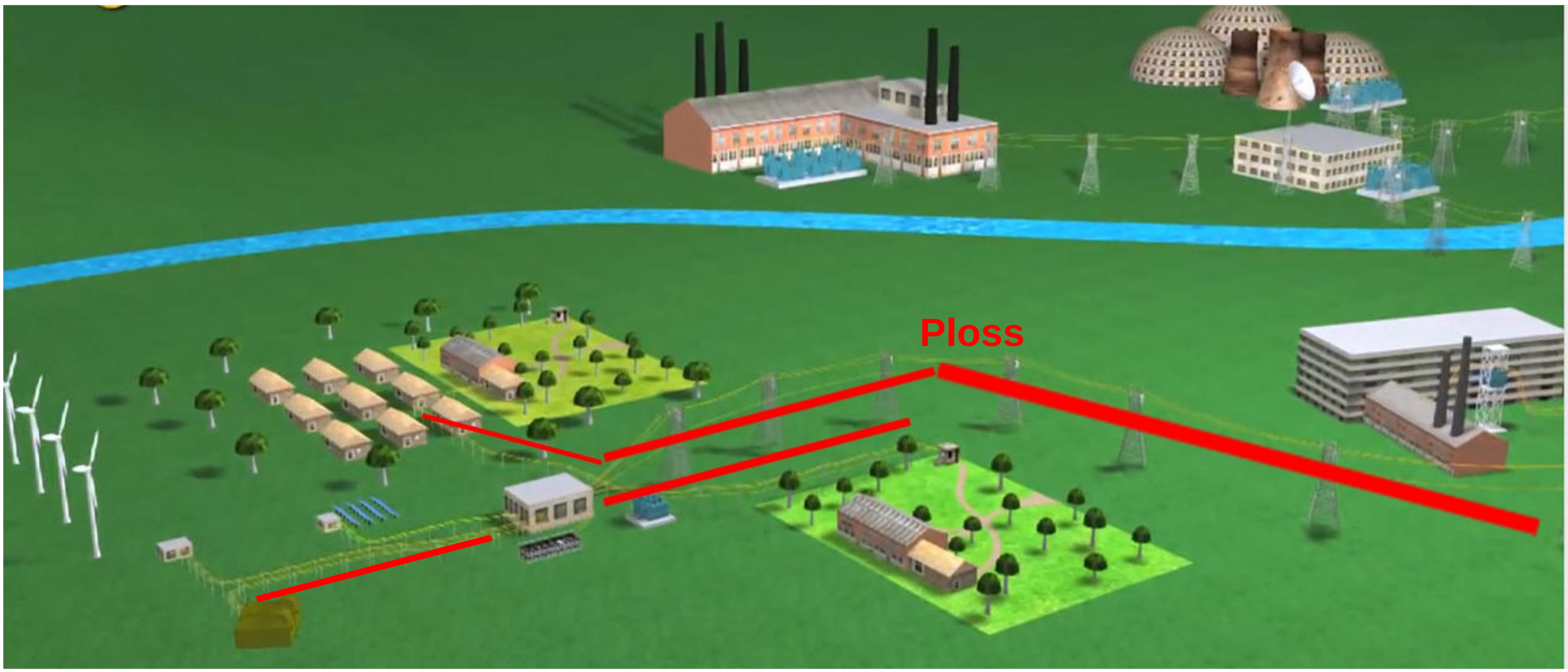
1. Introduction

In this thesis, there are 2 contributions as:

- For optimal multiple DG placement by improved reinitialized social structures PSO (IRS-PSO) to minimize the total real power loss, MG with four different types of DG is introduced.
- The IRS-PSO is developed to solve optimal multiple DG placement by adding reinitialized particles to escape from local optimum in the process of velocity updating when particle velocity is not within limit.

2. Research objective

To determine optimal location and size of multiple distributed generations by IRS-PSO for minimizing the total real power loss in a MG system.



3. Optimal multiple DG placement in MG

3.1 Literature reviews

Optimal distributed generation (DG) placement, a mixed integer nonlinear programming problem, has been solved by various methods including repetitive load flow, genetic algorithm (GA), and traditional basic particle swarm (BPSO) in refs. (Mahat P., 2006), (Mithulanthan N., 2004), and (Kuersuk W., 2006) to minimize the total real power loss in a MG system. However, the problem of all methods is premature convergence because of local traps.

3.1 Literature reviews (continuous)

In this chapter, The total real power loss calculated by Backward-Forward sweep method, is minimized by Improved reinitialized social structures PSO (IRS-PSO) determining the optimal multiple DGs placement in the MG system. Its solutions are compared to BPSO, Adaptive weight PSO (APSO), and Global best, local, Neighbor - PSO (GLN-PSO).

3.2 Objective function

Minimize P_{loss} (3.1)

P, Location

$$P_{loss} = \sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij}(P_i P_j + Q_i Q_j) + B_{ij}(Q_i P_j - P_i Q_j) \tag{3.2}$$

where, P_i and P_j are the real power injection at bus i and j. Q_i and Q_j are the reactive power injection at bus i and j. A_{ij} and B_{ij} are distribution coefficients which are discussed as following

$$A_{ij} = \frac{R_{ij} \cos(\delta_i - \delta_j)}{V_i V_j} \tag{3.3}$$

$$B_{ij} = \frac{R_{ij} \sin(\delta_i - \delta_j)}{V_i V_j} \tag{3.4}$$

where, R_{ij} is the distribution resistance between bus i and j. V_i and V_j are the voltage at bus i and j. δ_i and δ_j are the voltage angle at bus i and j.

3.2 Objective function (continue)

Subject to:

(a) Power balance constraint

$$\sum_{i} P_{DG,i} = \sum_{i} P_{D,i} + P_{loss} \tag{3.5}$$

where, $P_{DG,i}$ and $P_{D,i}$ are the DG and demand power at bus i.

(b) Voltage limits

$$|V_i|^{\min} \le |V_i| \le |V_i|^{\max} \tag{3.6}$$

where, $|V_i|^{\min}$ and $|V_i|^{\max}$ are the minimum and maximum voltage at bus i.

(c) Real power generation limits

$$P_{DG,i}^{\min} \le P_{DG,i} \le P_{DG,i}^{\max} \tag{3.7}$$

where, $P_{DG,i}^{\min}$ and $P_{DG,i}^{\max}$ is the minimum and maximum DG real power at bus i.

(d) Reactive power generation limits

$$Q_{DG,i}^{min} \leq Q_{DG,i} \leq Q_{DG,i}^{max} \tag{3.8}$$

where, $Q_{DG,i}^{min}$ and $Q_{DG,i}^{max}$ is the minimum and maximum DG reactive power at bus i .

Microgrid models

Type 1 - MG with DG supplying real power only

$$P_i = P_{DG,i} - P_{D,i} \tag{3.9}$$

Type 2 - MG with DG supplying reactive power only

$$Q_i = Q_{DG,i} - Q_{D,i} \tag{3.10}$$

DG like synchronous condenser will provide reactive power to improve the voltage profile.

Type3 - MG with DG supplying real and consuming reactive power

$$Q_{DG,i} = -(0.5 + 0.04P_{DG,i}^2) \qquad (3.11)$$

The real power loss can be given as follows;

$$P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n}\begin{bmatrix} A_{ij}[(P_{DG,i} - P_{D,i})P_j + (-0.5 - 0.04P_{DG,i}^2 - Q_{D,i})Q_j] \\ +B_{ij}[(-0.5 - 0.04P_{DG,i}^2 - Q_{D,i})P_j - (P_{DG,i} - P_{D,i})Q_j] \end{bmatrix} \qquad (3.12)$$

Type 4 - MG with DG regulating the bus voltage

In this type, DG supplying real power injection by the DG will require reactive power to support the bus voltage.

Type 5 - MG with four different types of DGs

Photovoltaic, synchronous condenser, wind generation, and biomass generator representing each type of DG are considered.




Practical swarm optimization (PSO)

- PSO is a population based search method with position of particle is representing solution and swarm of particles as searching agent. This idea is similar to bird flocks searching for food.
- Bird = a particle
- Food = a solution

3.3 Optimal multiple DG placement by Improved reinitialized social structures PSO (IRS-PSO)

- The IRS-PSO is used for optimal DG placement. Initially, the particles represent DG sizes and locations which will be randomly initialized at the first iteration and reinitialize at every certain number of iterations. Reinitializing is used to escape from local optimum by totally randoming particles except *gbest*.

- The velocity and particle position equations of IRS-PSO are (3.18) and (3.19). The IRS-PSO velocity includes an inertia term, a cognitive term *pbest*, and three social terms including *gbest*, *lbest*, and *nbest*.

$$v_{i,d}^{k+1} = w^k v_{i,d}^k + C_p R_1 (pbest_{i,d}^k - x_{i,d}^k) + C_g R_2 (gbest_d^k - x_{i,d}^k) + C_l R_3 (lbest_{i,d}^k - x_{i,d}^k) + C_n R_4 (nbest_{i,d}^k - x_{i,d}^k) \quad (3.18)$$

where, C_p, C_g, C_l, and C_n are the personal, global best, local, and near neighbor acceleration. R_1, R_2, R_3, and R_4 are random numbers in the range [0,1]. $pbest_{i,d}^k, gbest_d^k$, $lbest_{i,d}^k$, and $nbest_d^k$ are the personal, global best, local, and near neighbor of dimension d at iteration k.

Particle positions are updated by

$$x_{i,d}^{k+1} = x_{i,d}^k + v_{i,d}^{k+1} \quad (3.19)$$

- For optimal multiple DGs placement by IRS-PSO, the procedure can be described in 10 steps as follows.

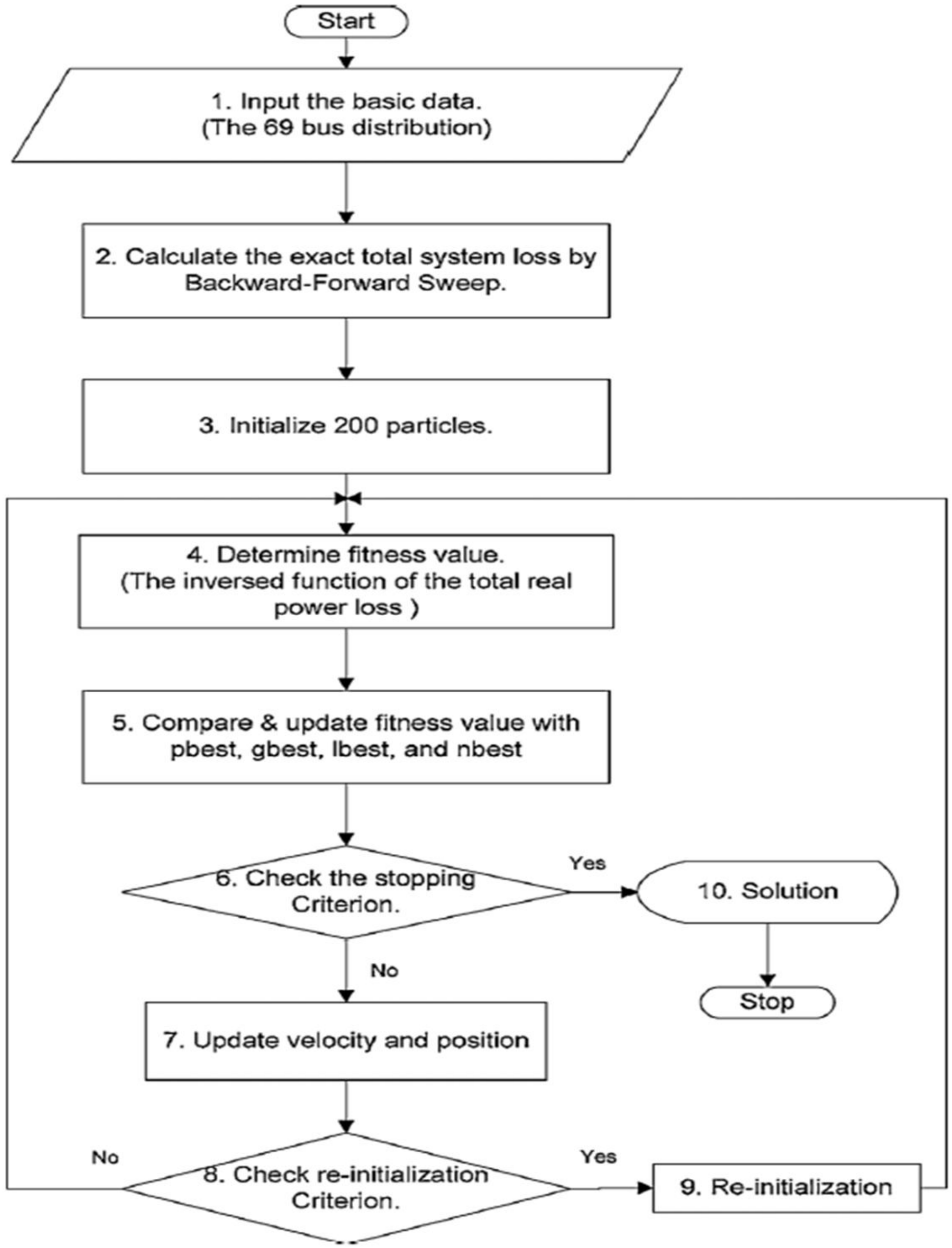


Figure 3.1 The flowchart of IRS-PSO for optimal multiple DGs placement

3.4 The test system

- A MG distribution system (22 kV) is used as a test system. The 69 radial bus distribution MG system has a total load of 3.80 MW and 2.69 MVAR (Baran ME, 1989). The single line diagram of the test system is shown in Figure 3.2. When multiple small DGs are optimally placed, the bus voltage limits are set to 0.90 and 0.98 per unit. For the minimum and maximum sizes of DG, real power generation limits are set to 0.05 and 5 MW, and reactive power generation limits are set to 0.05 and 5 MVAR.

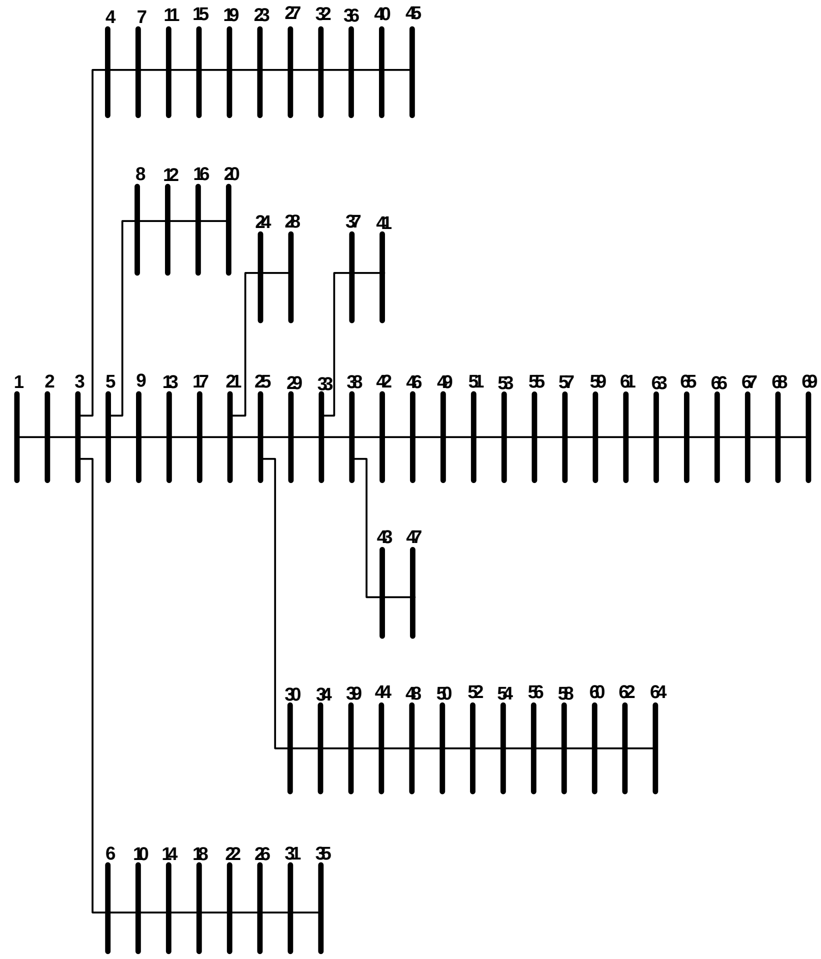


Figure 3.2 The single line of the test system

4. Numerical results

- Tables 1 – 4 show optimal DG locations and sizes minimizing real power loss in 69 bus distribution system. The maximum number of DG is set to 3. The decrease in total real power loss will depend on the location and size of DG. As shown in Tables 1 – 4, IRS-PSO total real power losses are less than repetitive load flow for each type of one DG. In Table 3.4, IRS-PSO total losses are less than BPSO, APSO, and GLN-PSO of three DGs. Moreover, MG type 4 gives the minimum loss since it can supply real and reactive power. IRS-PSO in MG type 4 can reduce loss by 97.25%.

- In Table 5 (MG type 5), different DG types are considered in MG. There are three combinations of DG types 1 and 2, types 1 – 3, and types 1 – 4. Apparently, the IRS-PSO is the best method for optimal placement because of minimum real power loss. Moreover, IRS-PSO total losses are less than BPSO, APSO, and GLN-PSO of three and four DGs.

Table I. Optimal DG placement in MG with DG supplying real power only.

Method	Bus no.	DG size (MW)	Bus no.	DG size (MW)	Bus no.	DG size (MW)	Ploss (kW)	Qloss (kVAR)	Loss reduction %	
									Real	Reactive
	The original power loss in the 69 bus system						230.1962	104.4490		
IRS-PSO	56	1.8739					84.7804	41.2841	63.17	60.47
	56	1.7799	55	0.5342			73.0659	36.6217	68.26	64.94
	56	1.7147	55	0.3761	33	0.5304	70.7626	35.6308	69.26	65.90

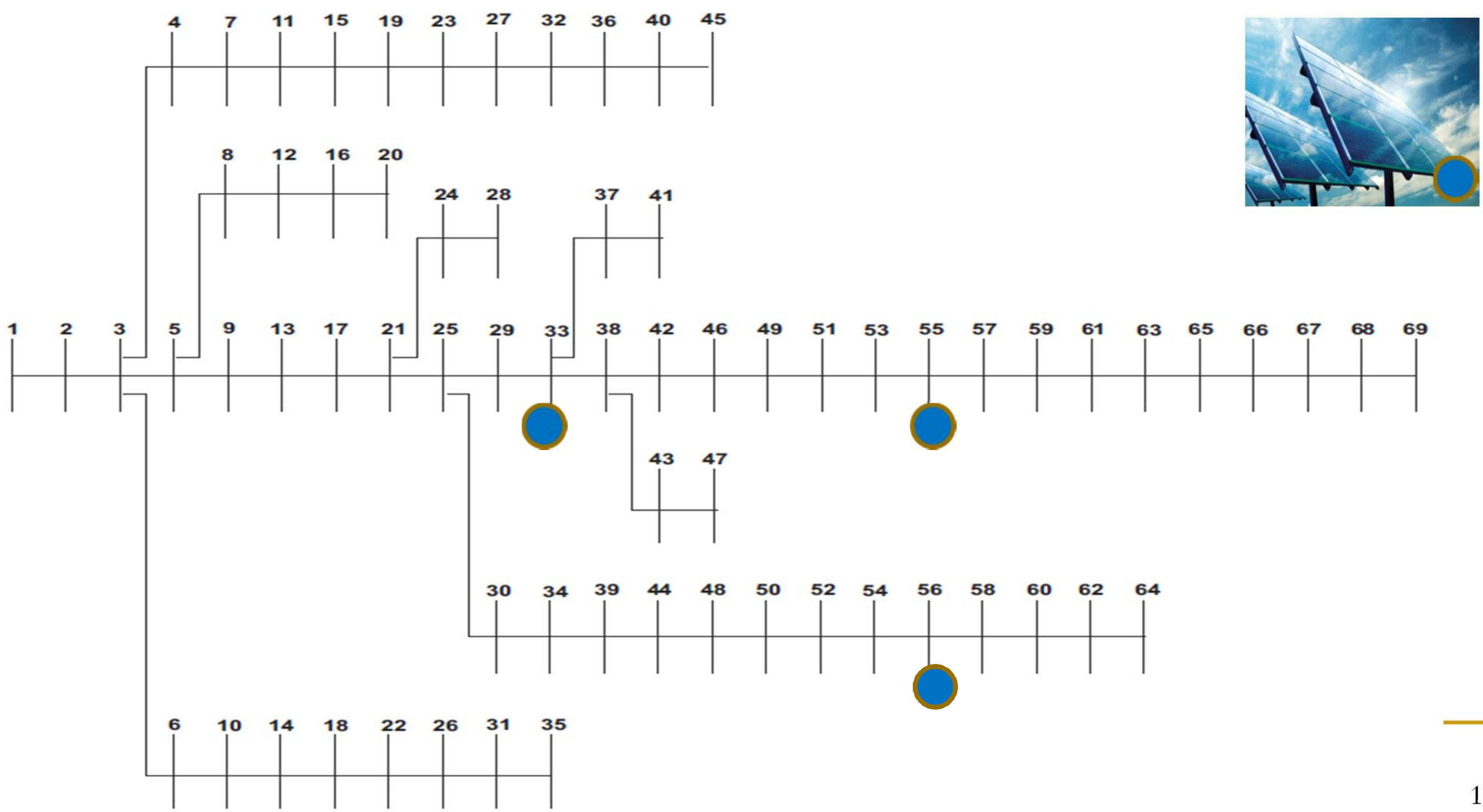


Table II. Optimal DG placement in MG with DG supplying reactive power only.

Method	Bus no.	DG size (MVAR)	Bus no.	DG size (MVAR)	Bus no.	DG size (MVAR)	Ploss (kW)	Qloss (kVAR)	Loss reduction %	
									Real	Reactive
	The original power loss in the 69 bus system						230.1962	104.4490		
IRS-PSO	56	1.3306					155.3349	71.9856	32.52	31.08
	56	1.2683	38	0.5464			149.8574	64.6481	34.90	33.32
	56	1.2025	61	0.2332	33	0.3707	148.3845	69.1487	35.54	33.80

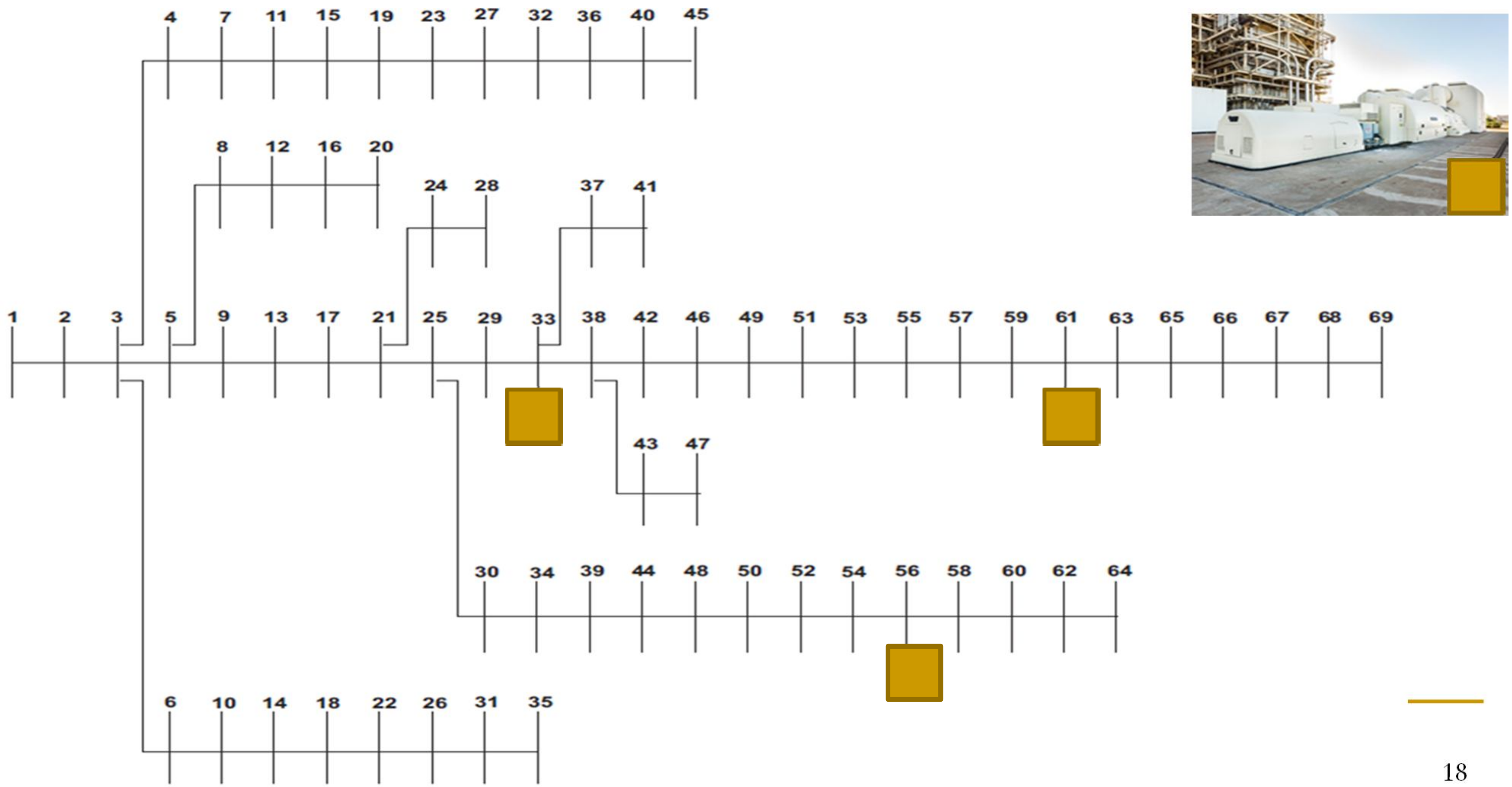


Table III. Optimal DG placement in MG with DG supplying real power and consuming reactive power.

Method	Bus no.	DG size (MVA)	Bus no.	DG size (MVA)	Bus no.	DG size (MVA)	Ploss (kW)	Qloss (kVAR)	Loss reduction %	
									Real	Reactive
	The original power loss in the 69 bus system						230.1962	104.4490		
IRS-PSO	56	1.6928					103.0616	49.3193	55.23	52.78
	56	1.5898	51	0.4800			92.2203	45.4009	59.94	56.53
	56	1.5114	49	0.4647	25	0.7130	91.5060	44.5127	60.25	57.38

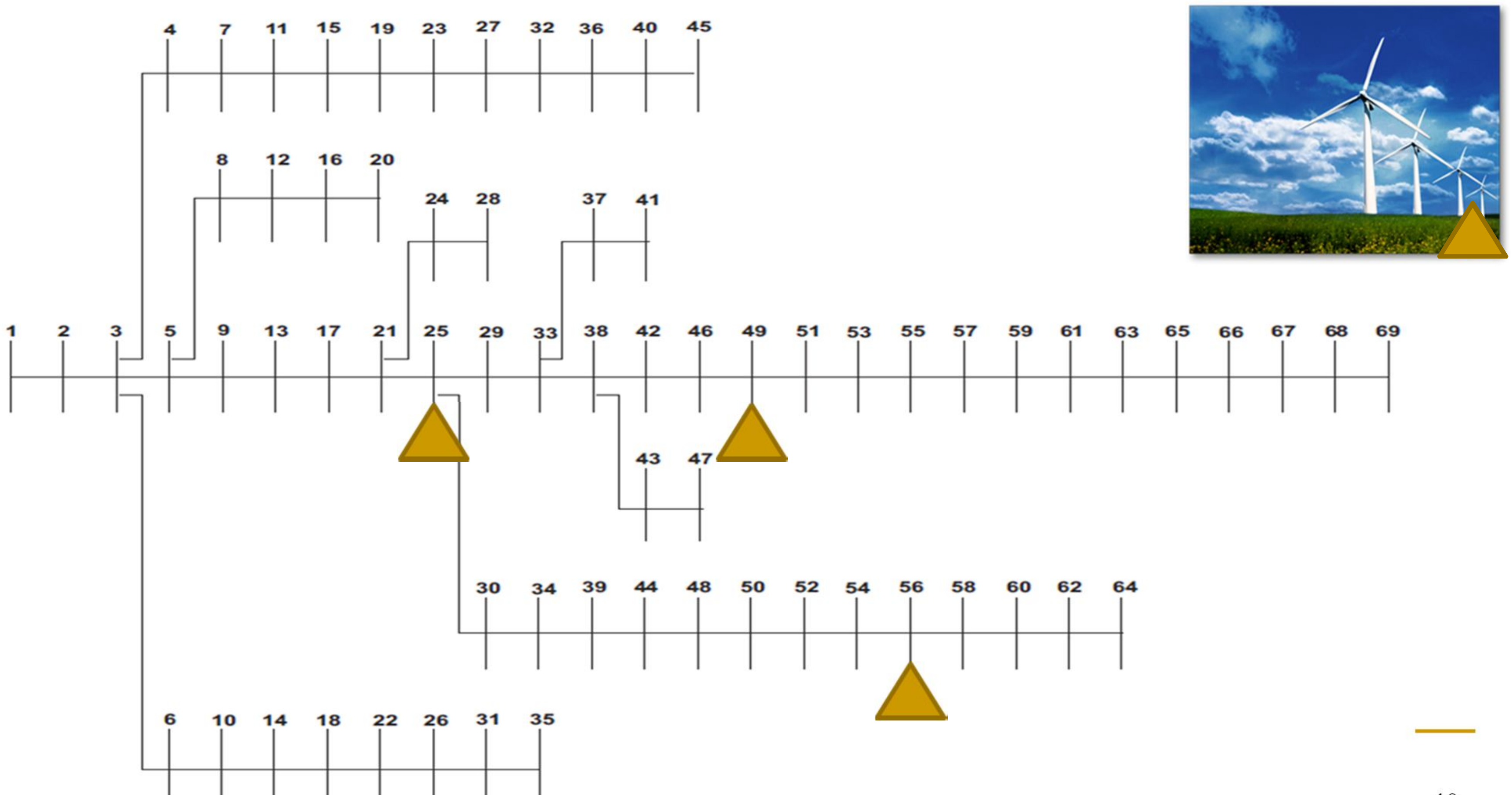


Table IV. Optimal DG placement in MG with DG regulating bus voltage.

Method	Bus no.	DG size (MW) (MVAR)	Bus no.	DG size (MW) (MVAR)	Bus no.	DG size (MW) (MVAR)	Ploss (kW)	Qloss (kVAR)	Loss reduction % Real	Loss reduction % Reactive
	The original power loss in the 69 bus system						230.1962	104.4490		
IRS-PSO	56	1.8282 1.3004					23.5123	14.6156	89.79	86.01
	56	1.7356 1.2371	53	0.5203 0.3529			7.5875	8.3307	96.70	92.02
	56	1.7758 1.2587	49	0.5472 0.3228	16	0.6502 1.1604	6.3153	4.8646	97.25	95.34

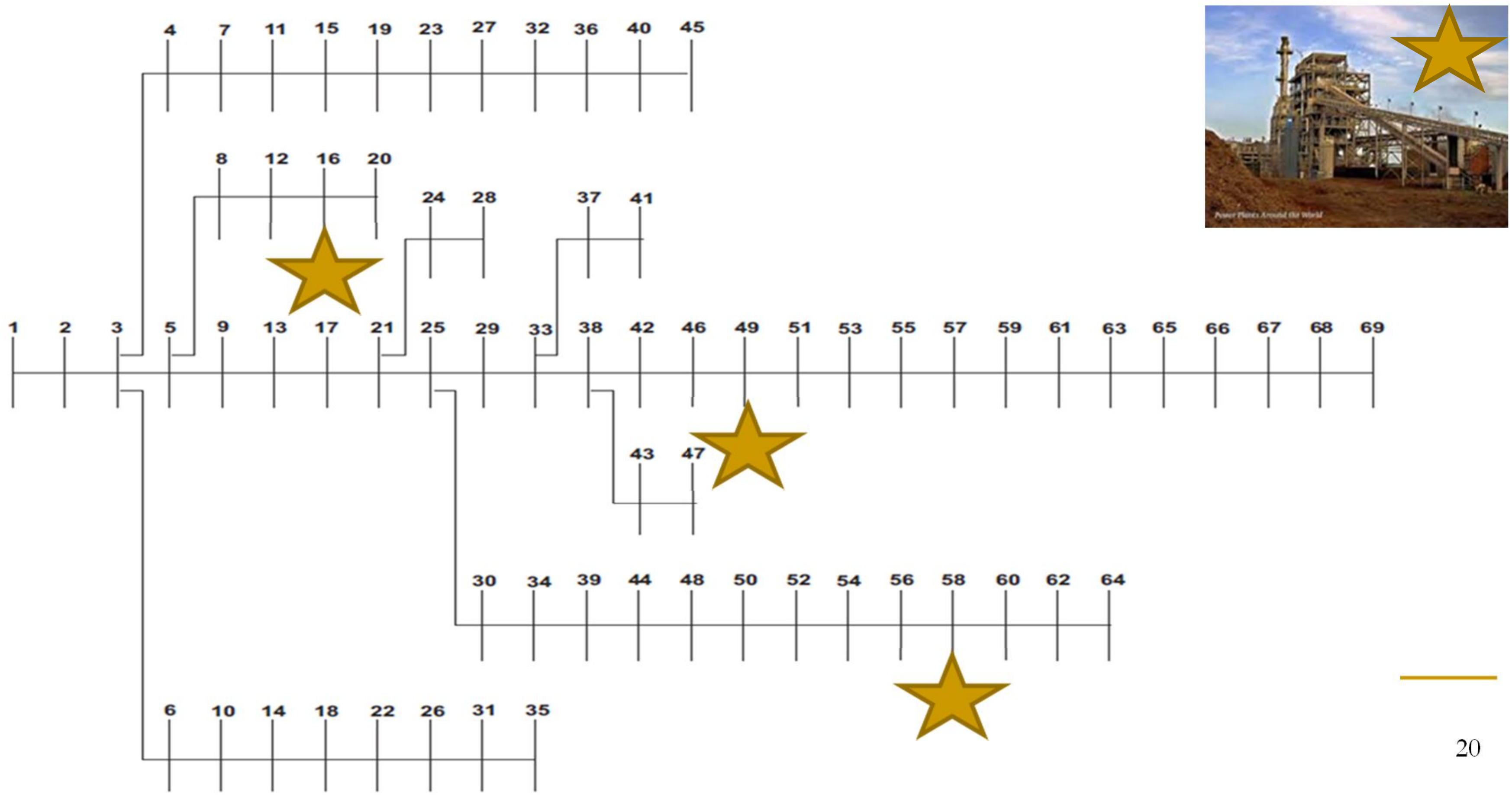


Table V. Optimal DG placement with four different types of DGs in MG.

Method	Type 1		Type 2		Type 3		Type 4			Ploss (kW)	Qloss (kVAR)
	Bus no.	DG size (MW)	Bus no.	DG size (MVAR)	Bus no.	DG size (MVA)	Bus no.	DG size (MW)	DG size (kVAR)		
	The original power loss in the 69 bus system									230.1962	104.4490
IRS-PSO	56	1.8281	56	1.2992						23.5123	14.6170
	38	0.9150	58	1.4486	56	1.5476				15.0527	11.0977
	67	0.1741	42	0.4869	33	0.8735	56	1.5033	1.4313	9.6187	8.7658

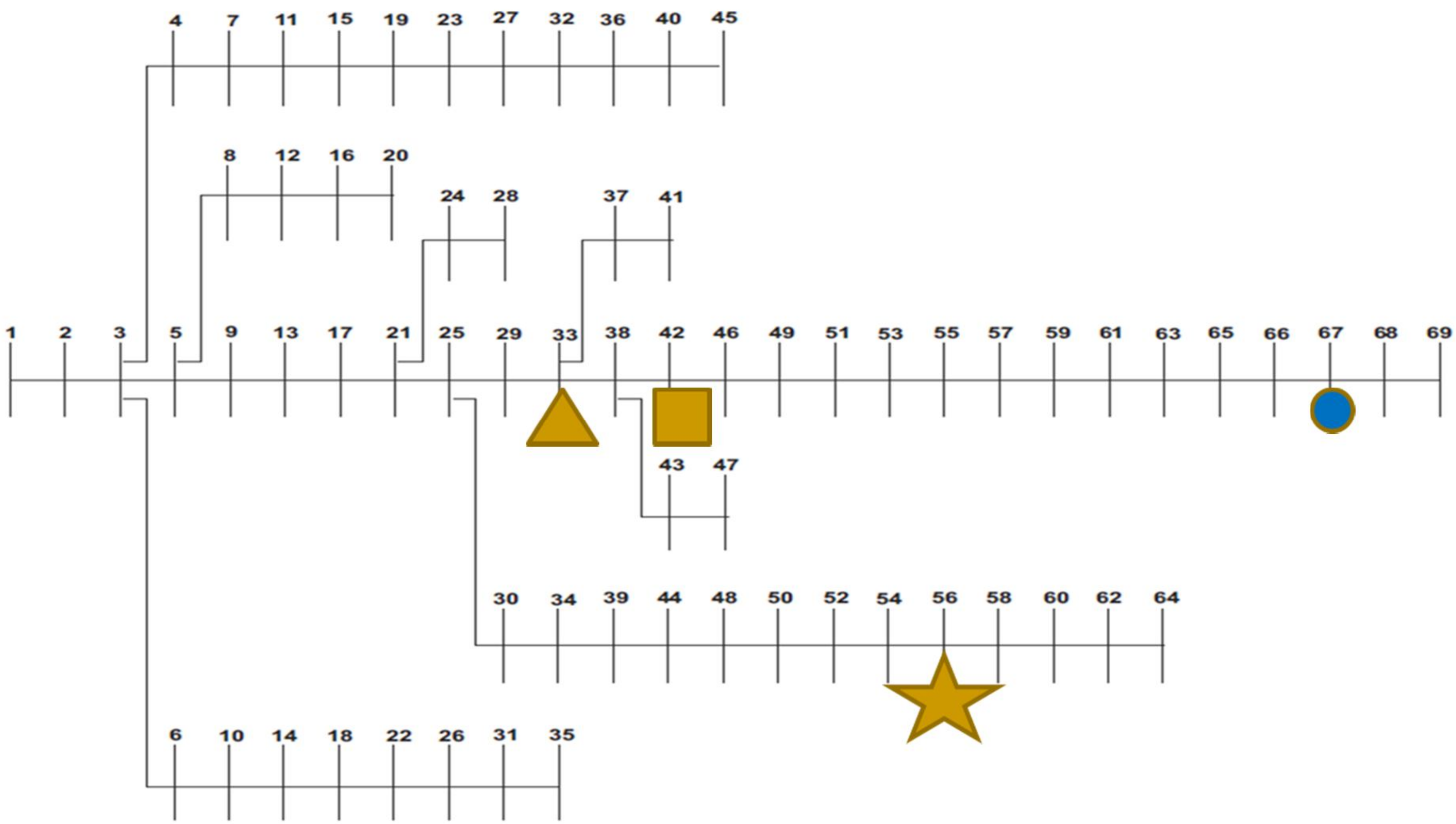
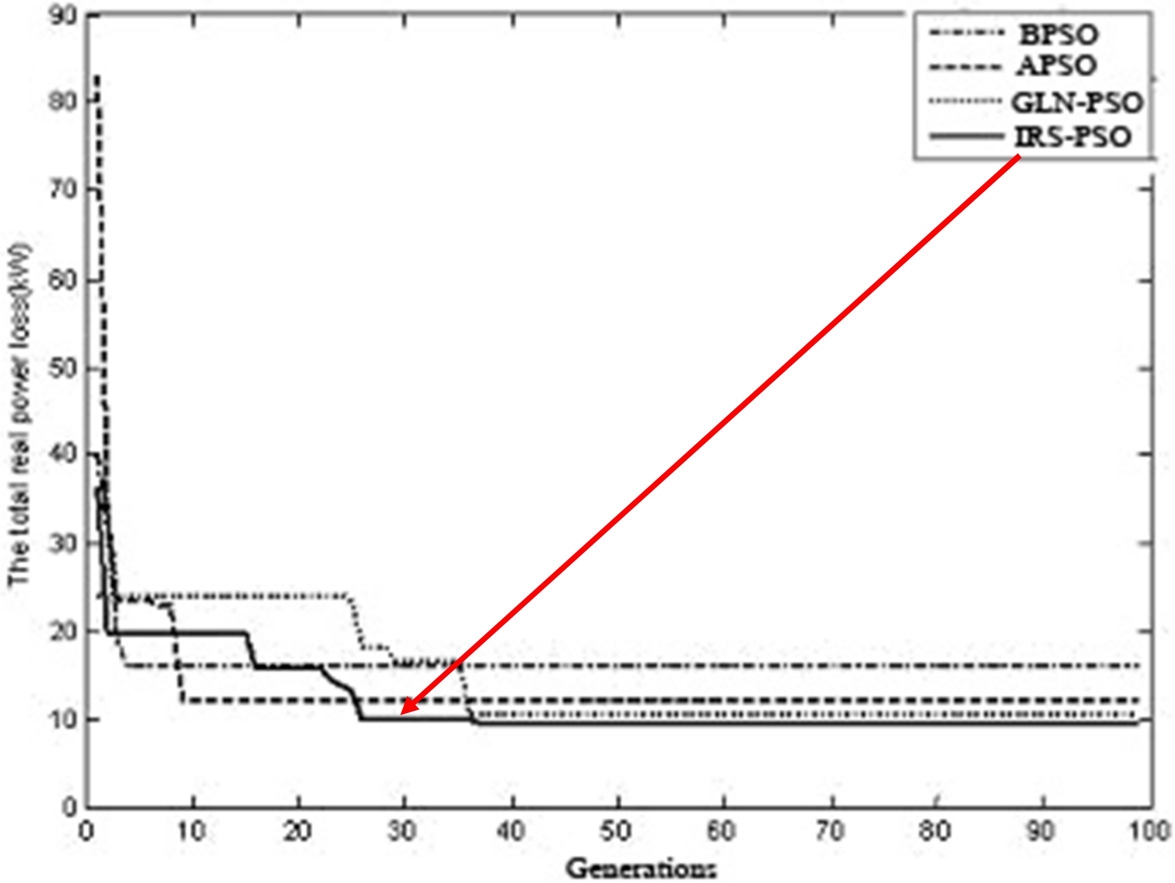


Table VI. The voltage levels in the 69 test system.

MG type	The number of DG (unit)	V_{min} (p.u.)	V_{avg} (p.u.)	V_{max} (p.u.)
The original voltage level in the 69 bus system		0.8885	0.9537	0.98
1	3	0.9587	0.9736	0.98
2	3	0.9103	0.9601	0.98
3	3	0.9502	0.9714	0.98
4	3	0.9740	0.9780	0.98
5	4	0.9730	0.9778	0.98

Table VI depicts voltage levels of each bus on the 69 bus MG system. In non-DG case, there are voltage levels of some buses which are lower than the low limit (0.90 p.u.). The lowest voltage level is 0.8885 per unit. After DGs are installed, the voltage levels are improved (0.9–0.98 p.u.) which are within the operating range of ±10%. Note three DGs of MG type 4 and type 5 have little different voltage levels. Furthermore, MG type 4 gives the best average voltage levels compared with other type.



In Figure 4.1, the convergence characteristics of different methods with four different DG types in a MG are shown. IRS-PSO with particle movement converges faster to a better solution than the other methods on the 69 bus MG system.

Figure 4.1 Convergence characteristics of real power loss minimization when MG has four DG types

Table VII. The statistic variances of BPSO, APSO, GLN-PSO, and IRS-PSO for Optimal three DGs placement.

MG type	Method	The 69 bus MG system			Standard deviation
		$Ploss_{avg}$ (kW)	$Ploss_{max}$ (kW)	$Ploss_{min}$ (kW)	
1	BPSO	73.7267	74.6739	71.2724	1.0239
	APSO	73.1755	76.0267	70.7626	1.4227
	GLN-PSO	71.8472	73.3411	70.8859	1.0045
	IRS-PSO	71.8716	73.3381	70.7626	0.7408
2	BPSO	150.1792	151.3095	148.3845	0.6786
	APSO	149.4936	150.1493	148.3845	0.6421
	GLN-PSO	149.4824	150.7666	148.3845	0.7454
	IRS-PSO	149.1244	150.1148	148.3845	0.4620
3	BPSO	93.6108	94.9339	91.6334	0.7874
	APSO	92.7820	94.8750	91.5170	1.0124
	GLN-PSO	93.1101	94.9098	91.5171	1.0476
	IRS-PSO	92.4182	94.2841	91.5060	1.0007
4	BPSO	14.2072	17.9239	15.3254	2.1239
	APSO	12.5498	16.5498	11.2669	3.3927
	GLN-PSO	11.1973	17.4145	8.0046	2.0272
	IRS-PSO	9.3895	12.3519	6.3153	1.5864
5	BPSO	24.9358	31.9157	25.4921	4.2728
	APSO	16.8993	21.2939	16.7280	2.2988
	GLN-PSO	18.4923	21.4473	16.1829	2.4222
	IRS-PSO	15.9841	20.9372	15.0527	2.2892

Table 7 shows that the average and minimum real power losses of IRS-PSO are less than the other methods for every MG types on the 69 bus system with smaller standard deviations.

5. Conclusion

In this research, IRS-PSO method effectively determines the optimal placement of distributed generation in a microgrid.

The salient features include four vectors of particle movement, resulting in a better search direction than BPSO and APSO. Moreover, IRS-PSO can escape from the local optimum by reinitiaization process.

Test results indicate that IRS-PSO with MG type 5 in microgrid renders the minimum loss in a faster convergence rate than BPSO, APSO, and GLN-PSO on the 69 MG distribution system.