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Assessment of Techno-Socio-Economic Performances of Distribution Network with Optimal Planning of Multiple DGs

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Abstract: The presented paper provides the distribution network analysis with optimum size and site of multiple DGs utilizing real world load models like industrial, residential, commercial and constant loads using optimization techniques like BF-PS, PSO and GA optimization. The problem function is multi-objective function taken into account on the basis of distinct technical performance index of distribution power network for the assessment of the optimum place and size of DG. The technical, social and economic performance analysis of system comprises of various parameters assessment related to these performances. The system performance like power loss (active & reactive), reliability, voltage profile, pollutant and carbon emission are considered. Subsequently, the economic performance like system total cost, loss cost, ENS cost and benefit-cost are reported. The pollutant emission (CO_2, NOx and SO_2 etc.) and the particulate matter (PM) also known as particle pollution are analyzed as social parameter for the system planning. The presented work is carried out with the IEEE 33-bus radial distribution network. Afterward, the analysis of aforesaid performances and parameters (social, technical and economic) for distribution system shows the effective results including DGs with practical loads using different optimization techniques.

Keywords: Distributed Generations (DGs), Carbon Emission, Power loss, Reliability, Load Models, Technical, Economic and Social Performance, Optimization Techniques.

1. Introduction

The analysis of techno-economic feasibility of electrical system is necessary to utilize the system more efficiently. The techno-economic feasibility of renewable sources-based system for presented case study is reported based on technical and economic parameters[1-4)]. The renewable sources are very effective as distributed generations (DGs) due to the social, technical and economic advantages[3-9)]. Therefore, the optimum planning of multiple renewable sources based on distributed generations is taken into account as a power source to reduce the power losses of network (active & reactive-losses) on the basis of DGs capability to consume or supply the powers[7-15)]. The practical load models considering mixed load, commercial, industrial, residential, and constant loads for optimum allocation of different DGs at optimum power-factor are also explored based on multiple objectives appproach[11-18)]. Generally, the constant loads are assumed in distribution system planning, which may mislead system's actual parameters. Hence, the actual load models dependent on the voltage are planned in the system for optimum allocation of distinct type of DG[16-17)]. The DG's optimum site and size on the basis of the minimum value of multi-objective function is presented with BF-PSO (butterfly-particle swarm optimization), PSO (particle swarm optimization) and GA (genetic algorithm) optimization techniques[13, 17-20)]. Various types of DGs are considered in this work by power delivering capability such as Type-1 DGs are capable to delivers only Active Power (P), Type-2 DGs are capable to delivers only Reactive Power (Q), Type-3 DGs are capable to de-livers Active Power (P) but consume Reactive Power (Q), and Type-4 DGs are capable to delivers both Active Power (P), and Reactive Power (Q).

2. Defining Problem and System Parameters

The problem formulation in this section is consist of defining the objective function (F_{obj}) based on multiple system parameters for optimum size and site of DGs which is minimized through GA, PSO and BF-PSO techniques for the proposed test systems as follows:

$$F_{Obj} = \lambda_1 \times f_1 + \lambda_2 \times f_2 + \lambda_3 \times f_3 + \lambda_4 \times f_4 + \lambda_5 \times f_5 \quad (1)$$

Where, sum of weights is unity i.e. $\sum_{i=1}^{5} \lambda_i = 1$, also $\lambda1$=0.38, $\lambda2$=0.25, $\lambda3$=0.15, $\lambda4$=0.12, and $\lambda5$=0.10 are system parameter weight factors[7-9].

Also, $f1 = \text{Loss index for real power} = \frac{PL_{DG}}{PL_{No-DG}}$,

$f2 = \text{Loss index for reactive power} = \frac{QL_{DG}}{QL_{No-DG}}$,

$f3 = \text{Voltage profile index} = max\left(\frac{V_{reff} - V_{DGj}}{V_{reff}}\right)$,

$f4 = \text{Index for power transfer distribution} = \frac{\Delta P}{\Delta t}$,

$f5 = \text{index for reliability} = \frac{ENS_{DG}}{ENS_{NoDG}}$

The different system parameters based on that the system performances are assessed can be explained as:

2.1 Social Parameters

The pollutant emission pollutant emission (CO_2, NOx and SO_2 etc.) and particular matter (PM) are taken in to consideration as social performances. The pollutants emission component like CO_2 (carbon dioxide), CO (carbon monoxide), NOx (nitrogen oxides), SO_2 (sulfur dioxide) and particulate matter (PM) considered for grid utility because majorly power supplied through thermal power plant in a grid. The pollutant emission components adversely affect to the human health and global environment. The PM have two components namely $M_{2.5}$ (pollutant particle ≤ to2.5 μm) and PM_{10} (pollutant particle ≤ 10.0μm). The emission factors for pollutants are assumed as 632.0g/kWh for CO_2, 2.74g/kWh for SO_2 is and 1.34g/kWh for NOx[4]. Also, the Particular Matter (PM) is given on the basis of linear regression equation with correlation r=0.884 of PM and CO_2[6, 20]:

$$PM = (0.47 \times \text{Weight of } CO_2) + 0.127 \quad (2)$$

2.2 Technical Parameters

The technical performances based on system parameters can be evaluated as:

- System's real and reactive power losses[15-16]:

$$P_{loss} = \sum_{k=1}^{Nbr} |I_{bk}|^2 \times R_k; \ \& \ Q_{loss} = \sum_{k=1}^{Nbr} |I_{bk}|^2 \times X_k \quad (3)$$

Where, I_{bk}, R_k & X_k are k^{th} branch current, resistance & reactance.

- Then, *m-n* line PTDF can be given as:

$$PTDF_{inj}^{mn} = \frac{\Delta P_{mn}}{\Delta P_{inject}} \quad (4)$$

Where, ΔP_{inject} & ΔP_{mn} are injected power and change in real power flows in *m-n* line.

- Energy Not Supplied (ENS) with respect to load demand of system is given as:

$$ENS = \alpha \times t \times \sum_{k=1}^{Nbr} \lambda_k |I_{kmx}| \times V_r \quad (5)$$

Where, I_{kmx} is maximum line current, λ_k is k^{th} line failure rate and Vr is rated system voltage. The *t* and *α* are time of repair and load factor correspondingly.

- The system reliability is specified with ENS and load demand (P_{Load}) relation which can be given as[15]:

$$Reliability = 1 - \left(\frac{ENS}{P_{Load}}\right) \quad (6)$$

Where, ENS and P_{Load} are total ENS and load demand of test system.

2.3 Economic Parameters

The annual system cost is comprising of fixed cost, energy loss cost and energy not supply cost, which is calculated as[15-17]:

$$\text{Annual system Cost} = C_{fix} + C_{ESN} + C_{loss} \quad (7)$$

- The fixed cost (C_{fix}), ENS (C_{ESN}) and loss (C_{loss}) costs of system network are given as:

$$C_{fix} = g \sum_{k=1}^{Nbr} C_k;$$

$$C_{ESN} = c_i \times ENS;$$

and $$C_{loss} = 8760 \times c_l \times \beta \times \sum_{k=1}^{Nbr} |I_k|^2 \times R_k$$

Where, $\beta = 0.15\alpha + 0.85\alpha^2$, N_{br} is No. of branches C_k is k^{th} line cost of feeder, *g* is recovery rate (annual), α & β are load factor and loss factor respectively.

- Grid utility/Substation and DG cost for supplied power are determined as follows:

$$C_{grid} = c_{Per\ unit} \times \left(\sqrt{P_{grid}^2 + Q_{grid}^2}\right) \quad (8)$$

$$C_{dg} = c_{dg\ per\ unit} \times \left(\sqrt{P_{dg}^2 + Q_{dg}^2}\right) \quad (9)$$

Where, $C_{perunit}$ is the grid sell power cost in per unit ($/kVA), $C_{dg\ perunit}$ is DG power supply per unit cost ($/kVA).

3. System Load Modeling

The system loads are practical loads which are voltage dependent loads (commercial, industrial and residential) have been implemented with proposed network. The mathematical modelling of practical load models for the network are as follows[12,15, 21-25]:

$$P_{Di} = P_{Doi}\left(a_1\left(\frac{V_i}{V_o}\right)^{\mu o} + b_1\left(\frac{V_i}{V_o}\right)^{\mu i} + c_1\left(\frac{V_i}{V_o}\right)^{\mu r} + d_1\left(\frac{V_i}{V_o}\right)^{\mu c}\right) \quad (10)$$

$$Q_{Di} = Q_{Doi}\left(a_2\left(\frac{V_i}{V_o}\right)^{\gamma o} + b_2\left(\frac{V_i}{V_o}\right)^{\gamma i} + c_2\left(\frac{V_i}{V_o}\right)^{\gamma r} + d_2\left(\frac{V_i}{V_o}\right)^{\gamma c}\right) \quad (11)$$

Where, P_{Di} & Q_{Di} = i^{th} bus real & reactive load, P_{Doi} & Q_{Doi} = i^{th} bus real & reactive demand at point of operation, V_o = operating point voltage, V_i = i^{th} bus voltage, μ & γ = exponents of active and reactive power for, residential(r), industrial (i), commercial(c) and constant (o) load models respectively. The considered practical load model modeling cases are, case-1: Constant load, a_1 = 1.0, a_2 = 1.0, and other value set as 0.; case-2: Industrial load, b_1 = 1.0, b_2 = 1.0, and other value set as 0; case-3: Residential load, c_1 = 1.0, c_2 = 1.0, and other value set as 0; case-4: Commercial load; d_1 = 1.0, d_2 = 1.0 and other values set as 0. The flowchart of proposed methodology for optimal development of distinct kinds of DG using BF-PSO, PSO and GA is given in Fig. 1.

4. Result and Discussion

The multiple renewable DG planning by utilizing multi-objective function with real loads is proposed for this work to analyze social, technical and economic performance of distribution network using distinct optimization techniques (GA, PSO & BF-PSO). The multiple renewable DG (PV solar & wind with capacitor bank) is considered for installation in the proposed network. The renewable DGs are not contribute for pollutant emission and PM therefore the DGs power is consider as fully green power. The distinct DG type and the power factor is determined including with the optimum DG placement in the test network.

The presented method is tested with the IEEE 33-bus radial network, with the base of 100 MVA. The voltage profile for the proposed network with multiple-DG in cooperating practical load cases by means of GA, PSO and BF-PSO are shown in Figure 2. It clearly illustrates that improved voltage profile of proposed network including multiple renewable DG is superior for DG-BFPSO technique as compared to other considering various load cases. The system load cases such as case 1-system with constant load, case 2- system with industrial load, case 3- system with residential load and case 4-system with commercial load are considered. The results for real and reactive power loss of IEEE 33-bus system including load models by GA, PSO and BF-PSO are illustrated in Figure 3 (i). The analysis clearly indicates losses are more efficiently decreased including DGs over No-DG condition of system and the losses vary with the different type of load models with multi-DGs. It's clear from the result analysis that the superior results regarding reducing losses are achieved through BF-PSO.

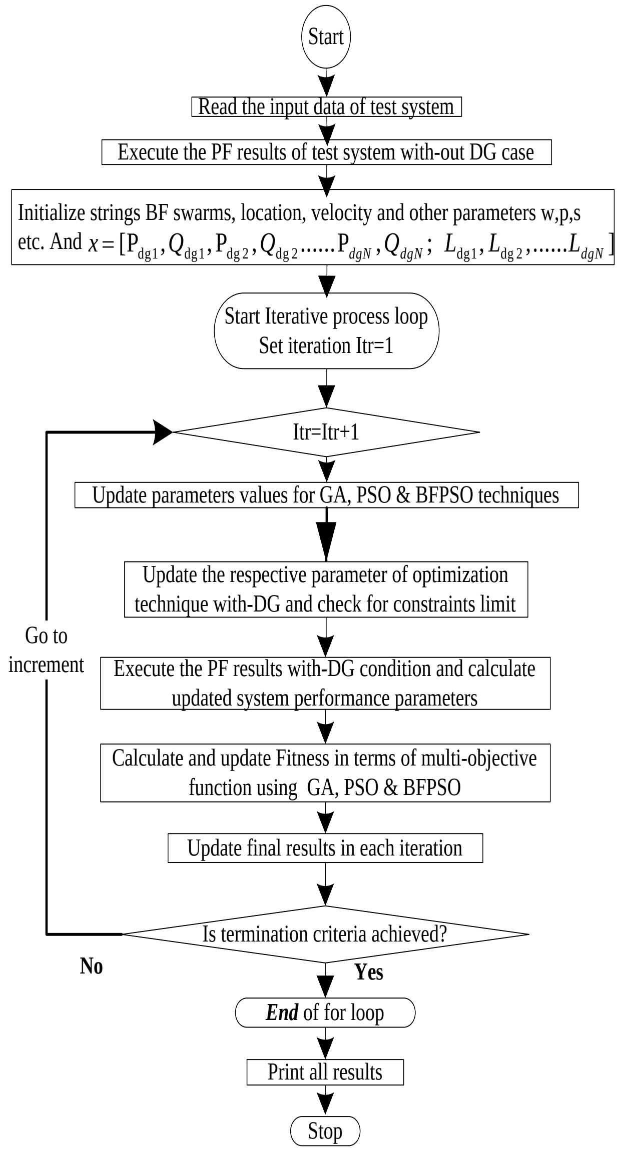
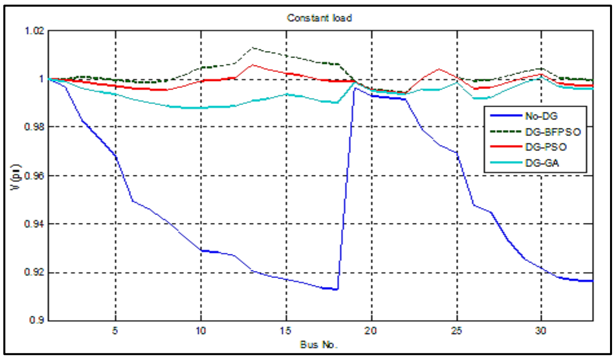
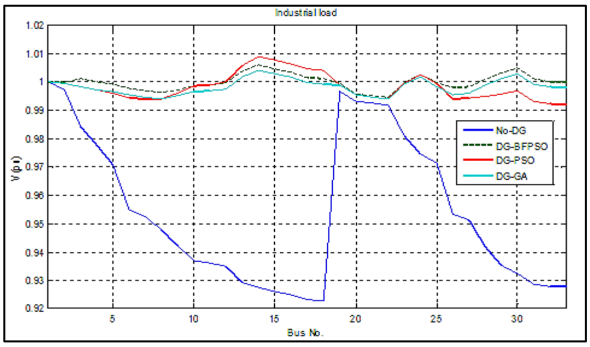


Fig. 1: General flow chart for proposed algorithm using BF PSO, PSO and GA optimization

The reliability and ENS vary in the proposed distribution test network, including multiple DG, including distinct load case by using optimization techniques is given in Fig. 3(ii) & 3(iii). This demonstrates that the ENS is more effectively decreased and reliability is enhanced including DGs by GA, PSO and BF-PSO than No-DG case. The best results for decrement of reliability and ENS enhancement are obtained for optimal allocation of multiple DGs with BF-PSO. The average pollutant emissions CO_2, SO_2, NO_x and particular matter **(**PM) using GA, PSO and BF-PSO for best optimum solution is shown in Fig. 4. The particular matter and other pollutant emissions vary with the different optimization solutions. The efficient results for all social parameter performances are found with BFPSO than GA and PSO. The multi-objective-function minimum value (f_{obj}) and indices optimum value for test network including multiple DG with practical loads through BF-PSO, PSO and GA are tabulated through Table 1. The constant load objective function f_{obj} values for are 0.1540, 0.1639 and 0.1872 respectively applying BF-PSO, PSO and GA. The DGs optimal size and place including practical loads in distribution network through BF-PSO, PSO and GA are specified via Table 2.



(i)



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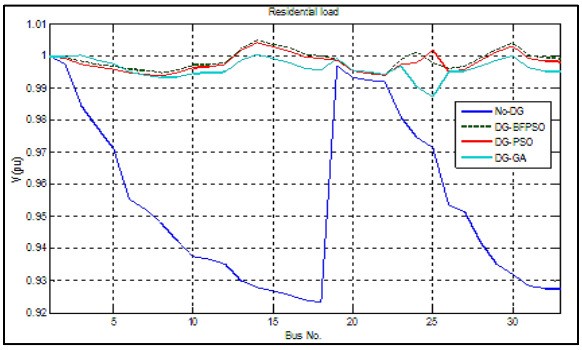

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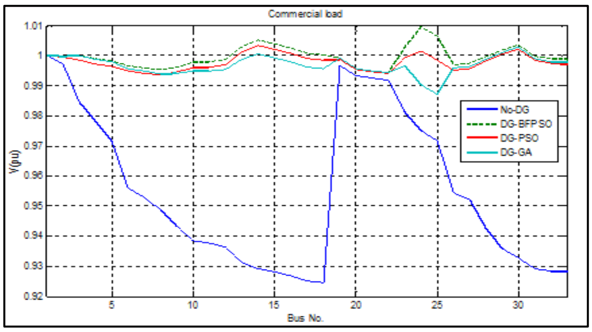
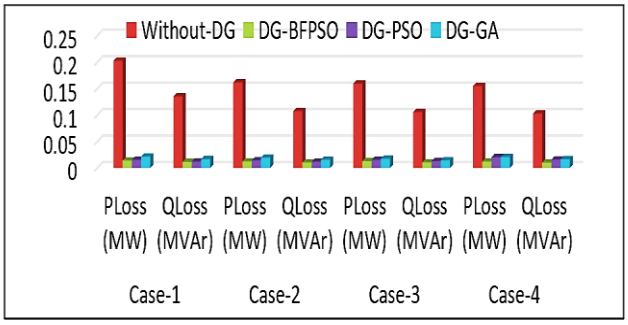


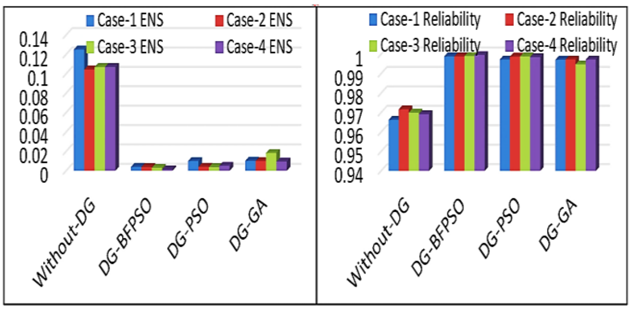
(iv)

Fig. 2: The radial IEEE 33-bus test network voltage profile for different load cases (i) Case-1, (ii) Case-2, (iii) Case-3, (iv)Case-4

The multi-DG optimum places by BF-PSO are on bus buses 13, 24 and 30 with size of 0.8215MW & 0.4756 MVAr, 1.1268MW & 0.8652MVAr and 1.0121MW & 1.0196MVAr respectively; by PSO are on bus buses 30, 15 and 25 with size of 1.0823MW & 1.1503MVAr, 0.6476MW & 0.2458MVAr and 0.6478MW & 0.6004MVAr and also by GA on bus buses 3, 13 and 30 with size of 1.4879MW & 0.9880MVAr, 0.9464MW& 1.0982MVAr, 0.4330MW& 1.0573MVAr respectively which are revealed by Table-2. This exposes that different DG can be connected on different places and with dissimilar size utilizing different technique including distinct load model. The power losses (real & reactive loss) of IEEE 33-bus radial network considering multiple DGs by different optimization technique are presented in Table 3.



(i)



(ii) **(iii)**

Fig. 3: (i) Active and Reactive power loss, (ii) ENS, (iii) Reliability of IEEE 33-bus test network

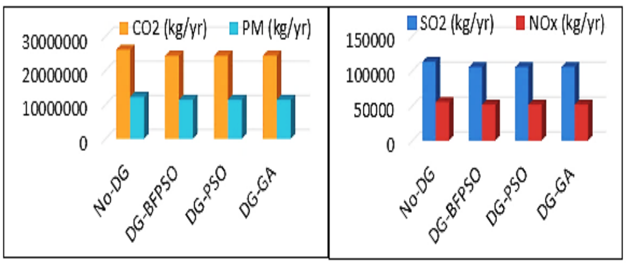


Fig. 4: The average social parameter (Pollutant Emissions and PM) for 33-bus radial network

The reduction of power losses (active/real as well as reactive) with DG condition through GA are 89.39%&87.65%; through PSO are 92.30%&90.98%; and also, through BF-PSO are 93.04%&91.57% for BF-PSO, as compared to without-DG condition for constant load. The reliability and ENS for constant load using GA are 99.72%& 0.0103MW; using PSO are 99.73%& 0.0101MW; using BFPSO are 99.89%&0.0041MW; also, with No-DG are 96.63%&0.1251MW as demonstrated by Table 4 for IEEE 33-bus network including multi-DGs. The economy benefits for system costs of IEEE-33-bus-network including multi-DGs for case-1 (including constant load) are $63320.02 with GA, $65378.57 with PSO and $65929.5 with BFPSO respectively as publicized by Table 5.

Table-1: Objective function and variables for test system including DGs

Load Cases	f_{obj}	f_1	f_2	f_3	f_4	f_5	Technique
Case-1	0.1540	0.0693	0.0844	0.0059	0.0327	1.0174	BF-PSO
	0.1639	0.0768	0.0901	0.0117	0.081	1.0068	PSO
	0.1872	0.1061	0.1234	0.0122	0.0819	1.0439	GA
Case-2	0.1607	0.0762	0.0957	0.0059	0.0375	1.0239	BF-PSO
	0.1727	0.0891	0.1101	0.0079	0.0395	1.0537	PSO
	0.1998	0.121	0.1453	0.0118	0.0963	1.0413	GA
Case-3	0.1625	0.0808	0.0997	0.0063	0.029	1.0246	BF-PSO
	0.1758	0.0974	0.1217	0.0059	0.0352	1.0324	PSO
	0.1990	0.1112	0.1362	0.0127	0.1715	1.0024	GA
Case-4	0.1631	0.0784	0.0984	0.0063	0.0487	1.0187	BF-PSO
	0.1953	0.133	0.1601	0.0062	0.0139	1.0212	PSO
	0.2046	0.132	0.1554	0.0128	0.0888	1.0303	GA

Table-2: Different load case results for DGs locations and size in test system

Load Case	1-DG		2-DG		3-DG		Optimal bus	Type	Optim. Tech.
	P(MW)	Q(MVAr)	P(MW)	Q(MVAr)	P(MW)	Q(MVAr)			
Case-1	0.8215	0.4756	1.1268	0.8652	1.0121	1.0196	13, 24, 30	All DG Type-4	BF-PSO
	1.0823	1.1503	0.6476	0.2458	0.6478	0.6004	30, 15, 25		PSO
	1.4879	0.9880	0.9464	1.0982	0.4330	1.0573	3, 13, 30		GA
Case-2	0.7590	0.4160	1.0999	0.6217	1.0420	1.1043	14, 24, 30		BF-PSO
	1.1860	0.6596	0.9305	0.8473	0.8106	0.5738	24, 30, 14		PSO
	1.6667	1.1265	0.9784	1.1594	0.8124	0.3285	3, 30, 14		GA
Case-2	0.7601	0.4283	1.0982	1.0702	0.8693	0.4981	14, 30, 25		BF-PSO
	1.2459	0.8901	0.6281	0.5974	1.0709	0.5816	30, 14, 24		PSO
	1.7462	0.8063	0.9706	0.9862	0.6940	0.3643	3, 30, 14		GA
Case-4	1.1189	0.6142	1.0039	1.1140	0.7720	0.3820	24, 30, 14		BF-PSO
	0.6710	0.3708	1.1473	0.9133	1.3156	1.3662	14, 30, 24		PSO
	1.1962	1.4069	1.0789	1.0004	0.7399	0.4308	3, 30, 14		GA

In the same way, the IEEE 33-bus system performance parameters including multiple DGs and load models for case-2 industrial, case-3 residential and case-4 commercial loads can be evaluated and the optimal DG planning with impact of varying load model can also be described. The social parameters including pollutant emission (CO_2, NO_x SO_2 and PM) for radial 33-bus network are 26076067.2 kg/yr, 113051.304 kg/yr, 55287.864kg/yr & 12255751.71kg/yr for No-DG and 24289496.74kg/yr, 105305.7295kg/yr, 51499.88232kg/yr & 11416063.59kg/yr with DG using BFPSO as shown in Table 6. Hence, the social technical and economic performances of the radial IEEE 33-bus distribution network including multiple DGs with practical load models are enhanced efficiently by using BFPSO than PSO & GA techniques.

Table-3: The test system power loss (Active-P & Reactive-Q) with different cases

Load Case	System Loss		Without-DG	DG-BFPSO	DG-PSO	DG-GA
Case-1	PLoss (MW)		0.2027	0.0141	0.0156	0.0215
	QLoss (MVAr)		0.1352	0.0114	0.0122	0.0167
	Loss Reduction (%)	Loss	-----	93.04%	92.30%	89.39%
		Loss	------	91.57%	90.98%	87.65%
Case-2	PLoss (MW)		0.1617	0.0123	0.0144	0.0196
	QLoss (MVAr)		0.1075	0.0103	0.0118	0.0156
	Loss Reduction (%)	Loss	-----	92.39%	91.10%	87.88%
		Loss	------	90.42%	89.02%	85.49%
Case-3	PLoss (MW)		0.1594	0.0129	0.0155	0.0177
	QLoss (MVAr)		0.1059	0.0106	0.0129	0.0144
	Loss Reduction (%)	Loss	-----	91.91%	90.28%	88.90%
		Loss	------	89.99%	87.82%	86.40%
Case-4	PLoss (MW)		0.155	0.0121	0.0204	0.0206
	QLoss (MVAr)		0.1029	0.0101	0.016	0.0165
	Loss Reduction (%)	Loss	-----	92.19%	86.84%	86.71%
		Loss	------	90.19%	84.45%	83.96%

Table-4: Technical performances (Reliability (%) and ENS (MW) of test network with DGs

Load Cases	Compon--ents	Without-DG	DG-with-BFPSO	DG-with-PSO	DG-with-GA
Case-1	ENS	0.1251	0.0041	0.0101	0.0103
	Reliability	0.9663 (96.63%)	0.9989 (99.89%)	0.9973 (99.73%)	0.9972 (99.72%)
Case-2	ENS	0.1044	0.0039	0.0041	0.0101
	Reliability	0.9717 (97.17%)	0.9989 (99.89%)	0.9988 (99.88%)	0.9973 (99.73%)
Case-3	ENS	0.1071	0.0031	0.0038	0.0184
	Reliability	0.97 (97.0%)	0.9991 (99.91%)	0.9989 (99.89%)	0.9948 (99.48%)
Case-4	ENS	0.1071	0.0015	0.0052	0.0095
	Reliability	0.9692 (96.92%)	0.9996 (99.96%)	0.9985 (99.85%)	0.9973 (99.73%)

5. Conclusion

The optimum size and placement of multiple renewable DGs including different load models is reported to scrutinize social, technical and economic performance of distribution test network through optimization techniques (BF-PSO, PSO & GA). The result analysis reveals that the proposed method using BFPSO is effective to decrease the technical parameters like the power loss (active & reactive), ENS, and to enhancement of reliability and voltage profile. The overall cost economy benefits including the system as well generated power cost benefits are increased using BFPSO with DGs. Here the reduction of value of active as well as reactive power losses using GA are 89.39%& 87.65%; using PSO are 92.30%& 90.98% and using BF-PSO are 93.04%& 91.57% as related to base case system. ENS and the reliability of 33-bus radial system with DGs are enhanced up to 0.0041MW&99.89% with BFPSO then other method and also as compared to base case. The system cost benefits of radial system with DGs for constant, industrial, residential and commercial load are more considerable and best result is achieved with DG using BFPSO. Similarly, the social parameters including pollutant emission (CO_2, NO_x SO_2 and PM) for radial 33-bus network are improved with DG using BFPSO. Hence, the social technical and economic performances of the radial IEEE 33-bus distribution network including multiple DGs with practical load models are enhanced efficiently by using BFPSO than PSO &GA techniques.

Table-5: Economic performances of test network System with DGs (Fix, loss, ENS, Total and Benefit Cost)

Load Cases	Costs ($)	Without-DG	DG-using-BFPSO	DG-using-PSO	DG-using-GA
Case-1	Fix	41465.38	41465.38	41465.38	41465.38
	Loss	70321.53	4876.23	5402.97	7461.08
	ENS	500.58	16.38	40.57	41.01
	Total	112287.49	46357.99	46908.92	48967.47
	System Cost Benefit	--------	65929.5	65378.57	63320.02
	Benefit %	--------	58.72%	58.23%	56.39%
Case-2	Fix	41465.38	41465.38	41465.38	41465.38
	Loss	56101.12	4274.64	4996.63	6789.36
	ENS	417.53	15.67	16.48	40.23
	Total	97984.03	45755.69	46478.49	48294.97
	System Cost Benefit	--------	52228.34	51505.54	49689.06
	Benefit %	--------	53.30%	52.57%	50.71%
Case-3	Fix	41465.38	41465.38	41465.38	41465.38
	Loss	55280.58	4467.79	5387.07	6148.82
	ENS	428.31	12.44	15.09	73.47
	Total	97174.27	45945.61	46867.54	47687.67
	System Cost Benefit	--------	51228.66	50306.73	49486.6
	Benefit %	--------	52.72%	51.77%	50.93%
Case-4	Fix	41465.38	41465.38	41465.38	41465.38
	Loss	53753.37	4212.09	7093.22	7150.26
	ENS	428.48	5.95	20.86	38.05
	Total	95647.23	45683.42	48579.46	48653.69
	System Cost Benefit	--------	49963.81	47067.77	46993.54
	Benefit %	--------	52.24%	49.21%	49.13%

Table-6: Average social parameters (CO_2, NOx SO_2 and PM) for test system

Parameters	Without-DG	DG-using-BFPSO	DG-using-PSO	DG-using-GA
CO_2 (kg/yr)	26076067.2	24289496.74	24298908.48	24339877.25
SO_2 (kg/yr)	113051.304	105305.7295	105346.5336	105524.1514
NOx(kg/yr)	55287.864	51499.88232	51519.8376	51606.70176
PM (kg/yr)	12255751.71	11416063.59	11420487.11	11439742.43

Nomenclature

DG	Distributed Generation
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
BFPSO	Butterfly-Particle Swarm Optimization
P_{Di}	i^{th} bus real power load
Q_{Di}	i^{th} bus reactive power load
P_{Doi}	i^{th} bus real power demand at operating point
Q_{Doi}	i^{th} bus rective power demand at operating point
V_o	operating point voltage
V_i	i^{th} bus voltage

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