Optimal allocation of distributed generation to mitigate power quality issues

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Abstract : ***The intervention of DG's in the electrical network has increased remarkably which has led to the requirement of optimally allocating them in the system. They should be allocated with an optimal size and appropriate locations such that they increase the system performance, reduce losses as well as to obtain better voltage profile. In this paper the nature inspired algorithm based intelligent technique called Flower pollination algorithm (FPA) is used to obtain the optimal size of the generator and also the location is chosen on the basis of the multi objective function which includes LVDRI, power loss reduction index (PLRI). Also, constant power load model is considered for the case of heavy load where drastic changes in the test system can be observed. Under this condition the optimal placement and type of DGs are the important factors for consideration. The enhancement of power quality is achieved by nullifying the effect of the voltage sag, at the affected busses by using the indices based on the variations in voltage. The entire analysis is carried out on standard IEEE 33bus test system.***

IndexTerms – Distributed generation , flower pollination algorithm, voltage sag.

I. Introduction

In the power system, it is required that the operator maintains the voltage within the limits for each customer bus. There are many standards which have been proposed for satisfactory voltage profiles in distribution systems. It is proposed that the voltage variations in the distribution system must stay in the range of -13% to 7%, which is generally maintained at 6% in the utilities. Introduction of the DGs in the networks enhances the voltage profile by changing the path of power flow.

The FPA has been proposed in recent years by the researcher Xin-She Yang which is applied to only some research problems. This algorithm was compared with Genetic Algorithm (GA) and PSO which showed the results derived with FPA more accurate than the other two [1]. A technique was proposed for the solution methodology to the economic load dispatch problems (ELD) using the FPA technique by considering the objective of minimizing the fuel cost by the effective setting of real power outputs from generators [2].

The study indicates that the FPA is a very flexible, simple and exponentially beneficial to solve optimization problems. FPA reduces the execution time as it has a higher convergence rate and hence improves the results and the system performance is observed to be better as compared to that of the other optimization algorithms.

II. PROBLEM FORMULATION

In this work, DG's are installed to improve the performance of the system in the electrical networks. Power quality and reliability can be improved by optimally allocating the distributed generation sources using the flower pollination algorithm. The inclusion of DG in an appropriate way will give a better profile of the voltage and reduce the system losses, hence improving the system performance.

2.1.Power Quality assessment Indices

The performance of the system will be depending on the quality of the power supplied and in various cases it is specified by using System Average rms Frequency Index (SARFI) [100]., it presents the average number of RMS variations over the assessment period to the customer served, and it calculates the number of busses effected by voltage sag by crossing the lower limit of 0.9.p.u. If the limit is fixed to 90% irrespective of the duration it is represented as SARFI-90.

$$SARFI = \frac{Total\ number\ of\ buses\ experiencing\ voltage\ sag\ (Nsag)}{\text{Total number of customers served}}$$

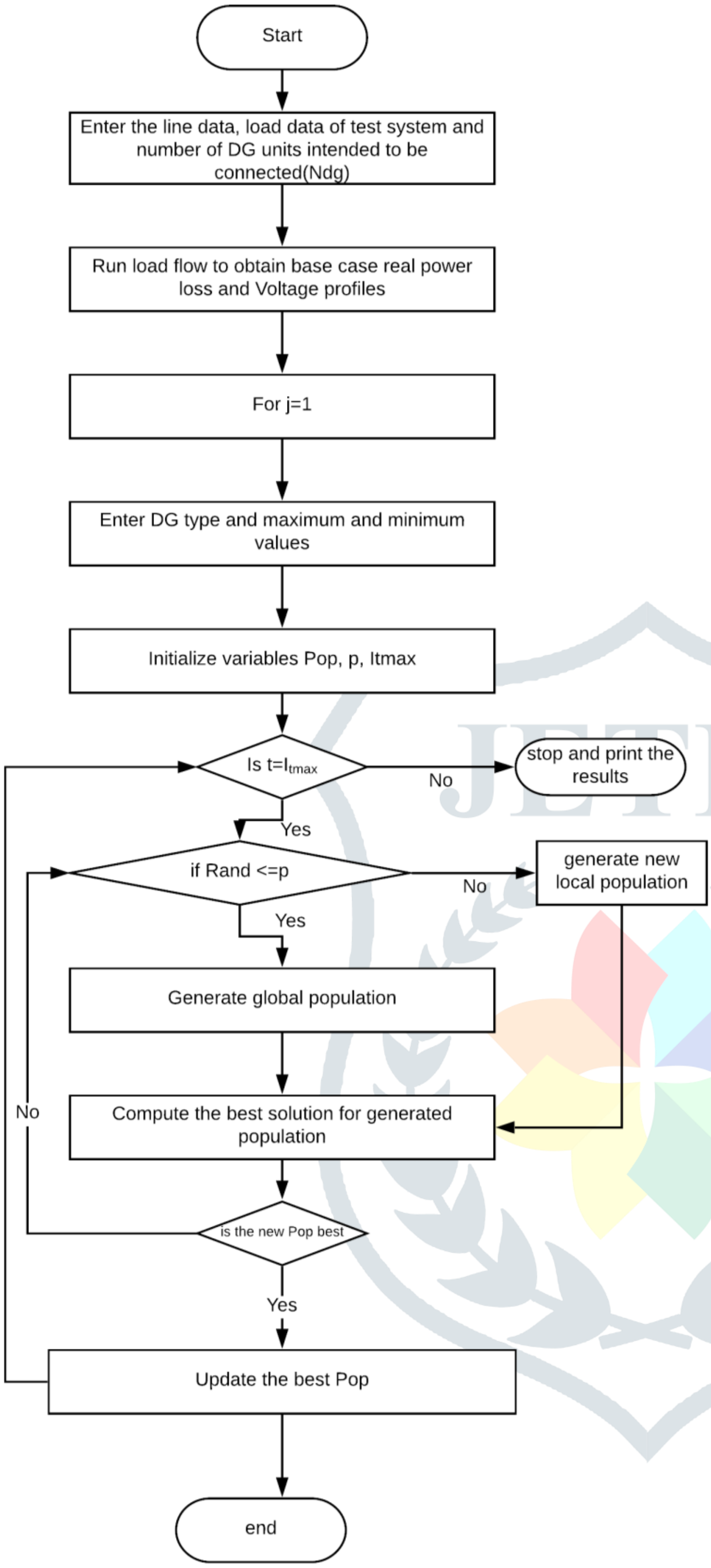

Figure 2.1: Flowchart of flower pollination algorithm

Figure 2.1 shows the flowchart for optimal allocation of distributed generators using a nature inspired flower pollination algorithm**.**

And the improvement index of the SARFI is represented as

$$SARFII = \frac{(SARFI_{before} - SARFI_{after})}{SARFI_{before}}$$

Where,

SARFI = System Average rms Frequency Index

SARFII = System Average rms Frequency Improvement Index

SARFI $_{before}$ = System Average rms Frequency Improvement Index without DG

SARFI $_{after}$ = System Average rms Frequency Improvement Index with DG

Nsag = Total number of buses experiencing voltage sag.

$$N_{sag} = \sum_{i=1}^{N_{bus}} \begin{cases} 1 & if\ 0.1\ pu < V_i < 0.9\ p.u \\ 0 & otherwise \end{cases} \quad \ldots \ldots \ldots \ldots \ldots \ldots (2.1)$$

Where, N_{sag} corresponds to busses which fall below the lower limit under the heavy loaded condition. Nbus corresponds to number of buses.

Hence, the following fitness functions are to be minimized to improve the quality of power.

$$F1 = min\ (Nsag) \ldots \ldots \ldots \ldots \ldots \ldots (2.2)$$

$$F_2 = min(_{SARFI}) \ldots \ldots \ldots \ldots \ldots \ldots (2.3)$$

2.2. Methodology

This section shows the results obtained after the execution of FPA on IEEE 33 bus, For the network considered the following three cases are analyzed and for each case, three scenarios are considered.

Case-1 : Allocation of Type -1 DG units

Case-2 : Allocation of Type -1 DG units

Case-3 : Allocation of Type -1 DG units

Scenario -1: Placement of single DG unit

Scenario -2: Placement of two DG units

Scenario -3: Placement of three DG units

For case 4, case 5 and case 6 the system is heavily loaded by an additional 60% of the load at all busses with constant power, for each case two scenarios are considered. Under this condition, the system losses will increase to 559.66 KW compared with 202.8 KW of 100% load. Number of buses which falls below the lower limit of 90% regardless of sag duration are treated as sag buses. Then SARFI is calculated from total number of sag buses and also SARFII is calculated to show the power quality improvement after DG placement.

Case -4: Allocation of Type-1 DG unit for heavy load

Case -5: Allocation of Type-2 DG unit for heavy load

Case -6: Allocation of Type-3 DG unit for heavy load

Scenario -1: Integration of single DG unit

Scenario -2: Integration of Two DG units

The allocation of DG is based on the population of FPA with its levy flight carriers will decide the size and location of DG. With respect to the power requirement and the deviation in voltage, the bus with maximum voltage deviation is chosen as the best location with the corresponding size depending on power losses.

III. RESULTS AND DISCUSSION

This method is applied to the standard IEEE 33 bus system operated at 12.66kV level of voltage and consists of 33 busses, 32 branches, with 3715kW and 2300kVar of power respectively as shown in Figure.3.1. The base case load flow is obtained where the power losses without the connection of the DG's are 202.68kW and 143.22kVAr respectively. The maximum DG unit size is limited to 2MW active and 2 MVAR reactive powers for the purpose of analysis.

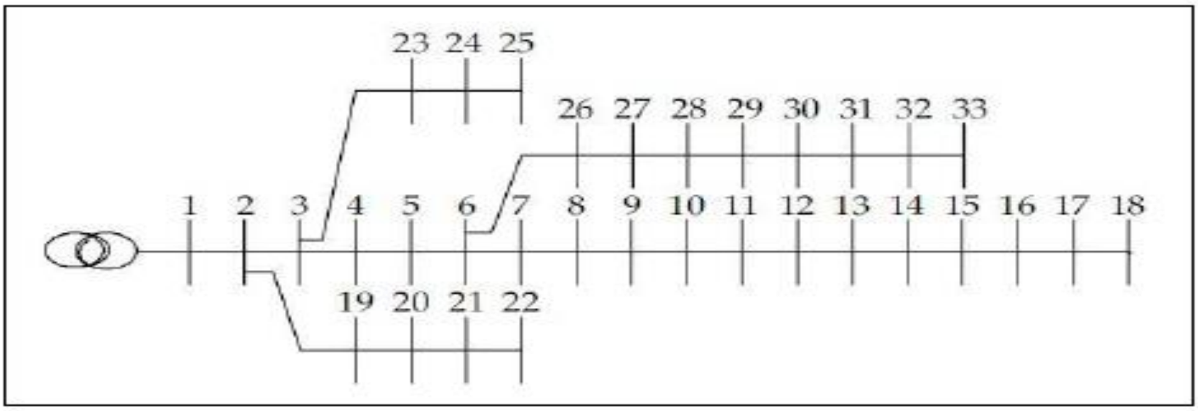

Fig.3.1: Single diagram of IEEE 33 bus test system

Table 3.1 . Case 1,2,3 for scenario-1

Particulars	FPA Type 1 DG	FPA Type 2 DG	FPA TYPE 3 DG
1: Optimal location	Bus 7	Bus 31	Bus 31
2: Optimal DG size	1.101	1.220	1.3559MW, 0.6136MVAR
3: Base case power losses in kW	202.68	202.68	202.68
4: Power losses with DG in kW	108.08	143.23	61.23
5: Power loss reduction in kW	94.6	59.45	141.45
6: power loss reduction in %	46.67	29.32	69.7
7: Minimum voltage without DG in p.u.	Bus 18	Bus 18	Bus 18
	0.91309	0.91309	0.91309
8: Minimum voltage with DG in p.u.	Bus 18	Bus 18	Bus 18
	0.94526	0.92515	0.9398

Table 3.2 . Case 1,2,3 for scenario 2

Particulars	FPA Type (1,1)	FPA{Type(2,2)}	FPA{Type(3,3)}
1: Optimal location	Bus 32, 0.9455	Bus 2, 1.667.7	Bus 6, 1.648.7 MW, 0.636 MVAR
2 : Optimal size in MW	Bus15, 1	Bus30, 1.118	Bus33, 0.636MW, 1.066 MVAR
3: Base case power losses in kW	202.68	202.68	202.68
4: Power losses with DG in kW	83.10	128.15	44.877
5: Power loss reduction in kW	119.58	74.53	157.803
6: power loss reduction in %	58.92	36.88%	77.85
7: Minimum voltage without DG in p.u.	Bus 18	Bus 18	Bus 18
	0.91309	0.91309	0.91309
8: Minimum voltage with DG in p.u.	Bus 30	Bus 18	Bus 18
	0.96872	0.9249	0.96308

Table 3.3 . Case 1,2,3 for scenario 3

Particulars	FPA{Type(1,1,1)}	FPAType(2,2,2)	FPA(Type 3,3,3)
1: Optimal location	Bus 17, 0.354.55	Bus 29, 1.336	Bus 33, 1.112MW, 292.58 MVAR
2 : Optimal size in MW	Bus 07, 0.876.81	Bus 07, -0.7421	Bus 06, 0.292MW, 1.557 MVAR
	Bus31, 0.934.16	Bus31, 0.6721	Bus31, 1.557MW, -0.408 MVAR
3: Base case power losses in kW	202.68	202.68	202.68
4: Power losses with DG in kW	79.625	121.055	40.12
5: Power loss reduction in kW	123.055	80.78	162.56
6: power loss reduction in %	60.82	39.99%	80.31
7: Minimum voltage without DG in p.u.	Bus 18	Bus 18	Bus 18
	0.91309	0.91309	0.91309
8: Minimum voltage with DG in p.u.	Bus 14	Bus 18	Bus 18
	0.96517	0.93978	0.95705

Table 3.4 Case 4,5,6 for scenario 1

Heavy load	Type 1	Type 2	Type 3
1: Optimal location	Bus 29	Bus 30	Bus 31
2 : Optimal size in	2.000MW	2.000MVAR	1.608MW, 1.856 MVAR
3: Base case power losses in kW	559.66	559.66	559.66
4: Power losses with DG in kW	322.16	381.28	206.69
5: Power loss reduction in kW	237.5	178.38	352.97
6: power loss reduction in %	42.43	31.87%	63.06%
7: Minimum voltage without DG in p.u.	Bus 18	Bus 18	Bus 18
	0.85493	0.85493	0.85493
8: Minimum voltage without DG in p.u	Bus 18	Bus 18	Bus 18
	0.8853	0.87733	0.90211
LVDRI	0.01509	0.01492	0.021604
PLRI	0.42436	0.31872	063068
Sag exposed area % before DG placement	53.33	53.33	53.53
Nsag, Before DG placement	16	16	16
Sag exposed area % after DG placement	15.15	18.18	3.03
Nsag, After DG placement	5	6	1
SARFI,Before DG placement	0.0051233	0.0051233	0.0051233
SARFI,after DG placement	0.001601	0.001701	0.0011
SARFII	0.68750	0.80286	0.78529

Table 3.5 Case 4,5,6 for scenario 2

Heavy load	TYPE 1,TYPE 1	TYPE 2,TYPE 2	TYPE 3,TYPE 3
1: Optimal location 2 : Optimal size in	Bus 29, 1.999 MW	Bus 30, 1.313 MVAR	Bus 31, 2.000 MW, 1.345MVAR
	Bus12, 1.755 MW	Bus 5, 1.966 MVAR	Bus 10, 1.345MW, 0.224 MVAR
3: Base case power losses in kW	559.66	559.66	559.66
4: Power losses with DG in kW	232.05	369.84	108.58
5: Power loss reduction in kW	327.61	189.82	451.08
6: power loss reduction in %	58.53%	33.92%	80.59%
7: Minimum voltage without DG in p.u	Bus 18	Bus 18	Bus 18
	0.85493 pu	0.85439 pu	0.85493 p u
8: Minimum voltage without DG in p.u	Bus 33	Bus 18	Bus 18
	0.9526 pu	0.8801 pu	0.95661 p u
LVDRI	0.01313	0.012531	0.01131
PLRI	0.5853	0.3392	0.8059
Sag exposed area % before DG placement	53.33	53.53	53.53
Nsag, Before DG placement	16	16	16
Sag exposed area % after DG placement	6.06	9.09	00
Nsag, After DG placement	2	3	0
SARFI,Before DG placement	0.0051233	0.0051233	0.0051233
SARFI,after DG placement	0.00121	0.001301	0.00
SARFII	0.76382	0.74606	1

Table 3.1 to 3.5 shows the results obtained by integrating DG at optimal buses with optimal size using FPA. Table.3.6 shows the comparison of different methods with their obtained results for IEEE 33 bus RDS system with proposed FPA method. The results of the different methods are taken from the literature [5,11,12]. Proposed FPA results are compared with other methods for the case of multiple DG (three) allocation. Total losses obtained are 79.625kW i.e., 60.82% reduction of losses which provides much better operation of the systems when compared to other techniques.

Table 3.6: Comparison table for allocation of DG using different techniques

Method	Ploss with DG	Loss reduction	Minimum voltage	(bus) DG	Optimal DG	Optimal size (MVA)
GA[11]	107.1	49.71	0.9810 (25)	11	1.5	2.9942
				29	0.4228	
				30	1.0714	
PSO [11]	105.35	50.06	0.9806(30)	13	0.9816	2.9881
				32	0.8297	
				8	1.1768	
GA/PSO [11]	103.4	50.99	0.9808(25)	32	1.2	2.988
				16	0.863	
				11	0.925	
SA [12]	82.03	59.12	0.9676(14)	6	1.1124	2.4677
				18	0.4874	
				30	0.8679	
BFOA [12]	89.9	57.38	0.9705(29)	14	0.6521	1.9176
				18	0.1984	
				32	1.0672	
IWO[5]	85.86	57.47	0.9716(29)	14	0.6247	1.7856
				18	0.1049	
				32	1.056	
FPA	79.625	60.82	0.96517(14)	17	0.354.55	2.16552
				7	0.876.81	
				31	0.934.16	

Table.3.7 shows the comparison of PSO with proposed FPA for IEEE 33 bus RDS system. The results of the PSO method are taken from the literature [73]. Proposed FPA results are compared with other methods for the case of three different type of DGs allocation say Type1,Type2 and Type3. Total losses obtained to be less in FPA compared to PSO in all cases, which can be observed in the table.

Table 3.7: Comparison table for allocation of Type 1,Type 2 and Type3 DG using PSO and FPA techniques

Test System	Optimal Location	DG type	Optimal Size of different types of DG			Active power Losses			Minimum Voltage in p.u	
			kW	kVAR	kVA	Without DG(kw)	With DG(kw)	%PLR	Without DG(p.u)	With DG(p.u)
PSO	6	I	3150	-	-	211	115.29	45.36	0.91309	0.92952
	30	II	-	1230	-		151.41	28.24		0.92136
	6	III			3020		67.95	67.79		0.93472
FPA	7	I	1.101	-	-	202.68	108.08	46.67	0.91309	0.94526
	31	II	-	1220	-		143.23	29.32		0.92515
	31	III	1355	613.6			61.23	69.7		0.9398

IV. CONCLUSION

In this paper, the allocation of DG with optimal size and location is done using a nature-inspired algorithm called flower pollination technique. This is a newly developed intelligent technique which gives better results when compared with many other intelligent techniques as discussed in the results and table of comparison. Here, optimal placement of DG is done based on levy flight mechanism. The analysis is carried out on the IEEE 33bus test system for different scenarios. Also, the comparison is done for the different type of DG's and their allocation with the PSO method shown in the comparison table. It is evident that the percentage losses in the system are reduced up to 75% and minimum voltage at the bus is increased to 0.9669 under normal condition. During heavy load, the DG will compensate the entire additional load to give an efficiency of 98% by nullifying voltage sag at the affected nodes. .

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