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Optimal Placement of DG and FCL Sizing By using Fuzzy-Jaya Algorithm

Vasavi.C, T.Gowri Manohar

Abstract: ***Smart grid is the most significant topic in power system due to numerous benefits. Smart grid is the integration of distributed generation. DG plays an important role in different configurations either in grid connected mode or islanded mode. Multiple configurations will result in fault currents this may lead to damage to the existing protective devices. In this paper Fuzzy is used to optimally locate DG and Jaya a new optimization technique is adapted to size the Fault current limiter. Controlled Impedance Fault Current Limiter (CI-FCL) is used to reduce the magnitude of fault current and also avoid false tripping of protective devices. A program is developed in MATLAB 2017Ra to test the IEEE 33 and 69 bus distribution systems the results are compared with the analytical PSO method. The results shows the effectiveness of Jaya Algorithm and also reduces the computational time and no. of iterations.***

Keywords: Controlled Impedance FCL (CI-FCL), Distributed Generation, JAYA Algorithm, Fuzzy Approach.

I. INTRODUCTION

In Modern technology the demand for electricity is increasing day by day due to the environmental concerns and shortage of fossil fuel based energy. Renewable energy resources (RES) is having more attention towards DG. The advantages of renewable energy resources introduces Distributed Generation (DG) in to a distribution system. The integration of DG in to a distribution network improves voltage profile, power quality and reduces the transmission and distribution system losses [17]. Besides all these advantages, there are some disadvantages introduced by DG, increase in the fault current levels may exceed the existing protective devices such as circuit breakers, relays which lead to the need for installing new protective devices which in turn increases the installation cost. Integration of DG introduces protection coordination problems results in mal functioning of the existing protective devices. To address this issue genetic algorithm was adapted for optimal placement and sizing of DG [18].The effect of DG on protection coordination will depend on many factors such as size of DG, type and nature of DG and placement of DG. The author explores the effect of DG on protective coordination such as fuse-fuse coordination, fuse-recloser and relay-relay coordination [12].The integration of DG to the existing distribution network have significant impact on the protection system they are location, number and capacity of DG. With the interconnection of DG the fault current level gradually increases and causes miss-coordination between the protective devices [6].With the integration of DG causes loss of coordination of relays. For example in a distribution network with DG, for a downstream fault operation of relay may be interface and for upstream fault disoperation of relay for fault current is possible, there by placing various capacities of DG located at various buses have been discussed [7].In order to overcome the protection issues with the integration of DG, the assembled distribution system protection is analyzed by carrying out at different locations 1) DG at the source bus 2) DG at the middle point. Super conducting Fault Current Limiter (SFCL) was utilized in this paper and observed that with use of SFCL and observed that with the use of SFCL coordination between the protective devices is improved substantially [13].The impacts of distributed generation on short-circuit current, power quality issues and coordination problems have been discussed in this paper [14].The integration of DG causes several problems and uses different types of FCL to study over-current relay coordination issues. Multi objective PSO is adopted to step-up the coordination between the main relay and backup relay [1]. A new thyristor controlled Impedance type of FCL was proposed which reduces the fault current magnitudes with the integration of DG and also provides several economic benefits [8]. The TCI-FCL was utilized to reduce the fault current level under multiple configurations by using PSO [9].The main impact of DG to the existing protection system is when DGs are installed in a distribution system, it loses its radial nature. There is a bidirectional power flow this causes risk to the existing protection system. For this problem, genetic algorithm was adapted for optimal placement and sizing of DG [2]. Several possible solutions have been proposed to overcome the above problems, such as upgrading circuit breakers, decreasing the generation capacity of DGs or even cut off the DGs from the main grid during fault condition. These methods are complex and expensive, and in many cases put constraint in using DG capacity and limiting the benefits from DG units. One approach to limit this problem is to install fault current limiter (FCL) at optimal places [8, 10, 11, 15, and 16].

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* Correspondence Author
Vasavi.C*, Research Scholar, Dept. of Electrical and Electronics Engineering, Sri Venkateswara University, Tirupati (A.P), India. Email: cvasavi11788@gmail.com
Dr.T.Gowri Manohar, Professor, Dept. of. Electrical and Electronics Engineering, Sri Venkateswara University, Tirupati (A.P), India.

In this paper a new device controlled impedance fault current limiter has been adopted to minimize the adverse impacts of DGS on distribution system protection

II. PROBLEM FORMULATION

From the above literature, it is clear that the incorporation of DG has impact on the short circuit currents .The traditional devices such as circuit breakers, relays, fuses cannot with stand the current capability limits. Conventionally, the short circuit currents are limited by inductor connected to the system. Now the modern technology is to install fault current limiters in the power system. This approach is a cost –effective way of accommodating higher fault levels without compromising on system performance .the effectiveness of this approach is due to the extension of the useful life of the existing devices.

FCLs are arranged so that it do not cause any voltage drops during normal operation, but when fault occurs the impedance must rise to limit the fault current level.

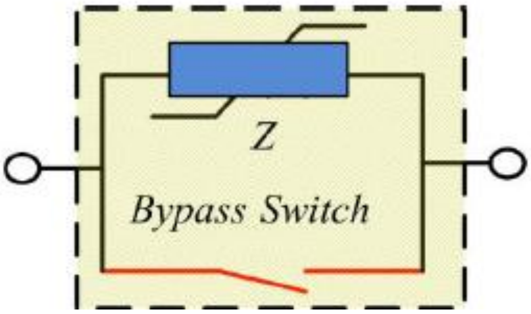

Fig.1.Active Type of FCL.

Hence, the problem is formulated to optimally place DG and FCL sizing. Fuzzy approach is utilized to locate DG and a new optimization technique jaya algorithm is adapted to size the FCL.

The objective function is formulated as,

Minimize F(x,y) =

$$[\sum_{i=1}^{m} PiLoss + \sum_{i,j=1}^{m} [ZAbsolutei,j - ZModifiedi,j]] \quad (1)$$

Power loss equation is given by

$$Pi=\sum_{i=1}^{m} I2R \quad (2)$$

Subject to voltage constraints

$$|Vimin| \leq |Vi| \leq |Vimax| \quad (3)$$

And current constraints

$$|Ii| \leq |Iimax| \quad (4)$$

A. Optimal DG Location

Fuzzy logic is used to optimally DG in distribution system to reduce the losses, fuzzy logic is a mathematical representation of information in a way that resembles human communication. Prof.L.Zadh [4] proposed the theory of fuzzy logic (FL).the main advantages of fuzzy are

- Easy to implement
- Can deal with any unstable load conditions.
- It is simple and fast adaptive.

With these advantages Fuzzy logic is used for optimal DG allocation process, the following objectives are considered. While designing a fuzzy system for identifying the optimal DG location.

- To minimize the real power loss.
- To improve the voltage profile.

Fuzzy inference system (FIS) containing a set of rules is then used to determine the suitability of each node for DG placement in the distribution system.in this work two input and one output variables are selected for the FIS.

B. Membership Function of Input and Output Variables

Power loss reduction(PLR) index varies from 0 to 1.Five membership functions are selected for these variables they are L,LM,M,HM and H which represents Low, Low-Medium, Medium, High-Medium and High the membership functions are triangular.

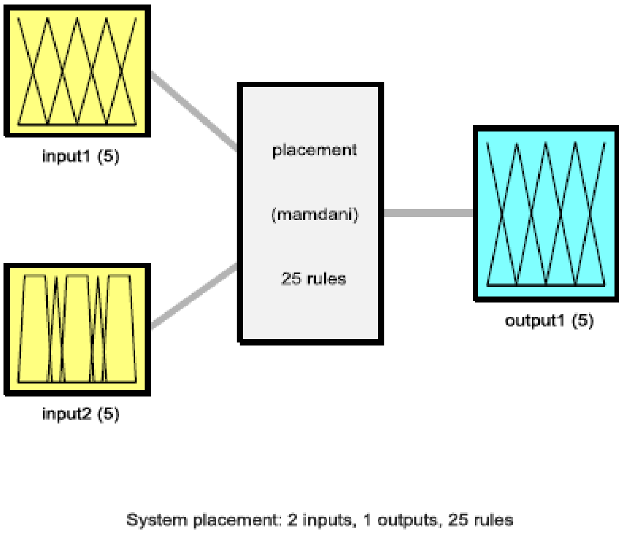

Fig.2.Input and output variables

Nodal voltages varies from 0.9 to 1.Five membership functions are selected for voltage they are L, LM, M, HM, H. The membership functions are trapezoidal and triangular. The output variables DGPSI (DG suitability index) varies from 0 to 1.Five membership functions are selected for DGPSI. They are L, LM, M, HM and H. These five membership functions are also triangular.

Rules are framed to determine the suitability of DG placement at each node. Rules are expressed as

"IF premise (antecedent), THEN conclusion (Consequent)"

A set of rules are framed to find the optimal value at each particular node. In any distribution system, the bus with High PLI and low nodal voltages is ideal placement of DG. The decision matrix is shown in table. I

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Table-I: Decision matrix

AND		VOLTAGE				
		L	LM	M	HM	H
PLR	L	L	L	L	LM	LM
	LM	L	L	LM	LM	M
	M	L	L	LM	M	HM
	HM	L	LM	M	HM	HM
	H	LM	LM	M	HM	H

Table - II: Input and output variables of fuzzy method for 33 bus system

BUS. No	PLI	VOLTAGES	DGPSI
2	0	0.9972	0.08
3	0.0197	0.9838	0.1011
4	0.1034	0.9769	0.1628
5	0.1976	0.9701	0.2036
6	0.1305	0.9529	0.0850
7	0.1970	0.9494	0.0899
8	0.6640	0.9446	0.0874
9	0.7372	0.9384	0.0985
10	0.2578	0.9326	0.0948
11	0.2838	0.9317	0.0922
12	0.2174	0.9302	0.0917
13	0.2956	0.9241	0.0905
14	0.3227	0.9218	0.0884
15	0.6418	0.9204	0.0858
16	0.3379	0.9191	0.0872
17	0.3438	0.9170	0.0868
18	0.3509	0.9164	0.0863
19	0.5177	0.9966	0.2526
20	0.0203	0.9931	0.1016
21	0.0365	0.9924	0.1165
22	0.0392	0.9917	0.1188
23	0.0407	0.9802	0.1201
24	0.1240	0.9736	0.1736
25	0.6743	0.9702	0.2527
26	0.7199	0.9513	0.0919
27	0.2044	0.9491	0.0906
28	0.2142	0.9393	0.0963
29	0.2490	0.9323	0.0945
30	0.5358	0.9295	0.0863
31	0.9038	0.9267	0.0830
32	0.7286	0.9263	0.0926
33	1.000	0.9260	0.0805

Table-III: Input and output variables of fuzzy method for 69 bus system

BUS.NO	PLI	VOLTAGES	DGPSI
2	0	1	0.08
3	0	0.9999	0.08
4	0	0.9998	0.08
5	0	0.9990	0.08
6	0	0.9901	0.08
7	0.0003	0.9809	0.0804
8	0.0098	0.9781	0.0910
9	0.0203	0.9768	0.1016
10	0.0086	0.9719	0.0933
11	0.0100	0.9709	0.0973
12	0.0520	0.9678	0.1501
13	0.0576	0.9649	0.1791
14	0.0037	0.9620	0.1058
15	0.0040	0.9591	0.0927
16	0	0.9586	0.0915
17	0.0244	0.9577	0.0896
18	0.0326	0.9577	0.0896
19	0.0326	0.9573	0.0887
20	0	0.9570	0.0881
21	0.0006	0.9565	0.0872
22	0.0610	0.9565	0.0872
23	0.0031	0.9564	0.0872
24	0	0.9562	0.0868
25	0.0161	0.9561	0.0865
26	0	0.9560	0.0864
27	0.0082	0.9560	0.0863
28	0.0082	0.9999	0.0893
29	0	0.9999	0.08
30	0	0.9997	0.08
31	0	0.9997	0.08
32	0	0.9996	0.08
33	0	0.9993	0.08

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34	0.0001	0.9990	0.0801
35	0.0002	0.9989	0.0800
36	0.0001	0.9999	0.0800
37	0	0.9997	0.08
38	0	0.9996	0.08
39	0	0.9995	0.08
40	0.0001	0.9995	0.0801
41	0.0001	0.9988	0.0801
42	0	0.9986	0.08
43	0	0.9985	0.08
44	0.0001	0.9985	0.0801
45	0	0.9984	0.08
46	0.0004	0.9984	0.0805
47	0.0004	0.9984	0.0805
48	0	0.9985	0.08
49	0.0006	0.9947	0.0808
50	0.0090	0.9942	0.0901
51	0.0096	0.9781	0.0907
52	0.0110	0.9781	0.0923
53	0.001	0.9740	0.0817
54	0.0014	0.9708	0.0875
55	0.0097	0.9663	0.1137
56	0.0105	0.9619	0.1159
57	0	0.9394	0.0960
58	0	0.9284	0.0839
59	0	0.9241	0.08
60	0.1057	0.9191	0.0835
61	0	0.9116	0.08
62	1	0.9114	0.08
63	0.04909	0.9110	0.0807
64	0	0.9091	0.08
65	0.2756	0.9085	0.0923
66	0.0768	0.9708	0.1524
67	0.0067	0.9708	0.0938
68	0.0067	0.9676	0.1037
69	0.0117	0.9676	0.1102

C. Jaya Algorithm for FCL Sizing

All the swarm-intelligent based and evolutionary algorithms are probabilistic algorithms and require some parameters like population size, no. of. Generation's etc. These require, tuning of the parameters which affects the performance of the algorithms. Considering this Rao (2011) [5] introduced teaching-learning based optimization (TLBO) algorithm which does not require any specific parameters. Keeping in view of this TLBO algorithm the author [3] proposed Jaya algorithm.

Keeping in view of the objective function optimal DG location is obtained by Fuzzy approach and for FCL sizing is obtained by JAYA algorithm. For this, two configurations of matrices is considered .*Zabsolute* and Z*modified*. *Zabsolute* is the matrix without DG connected to the grid. Z*modified* is the matrix with DG connected.

$$\sum_{i,j=1}^{m}[ZAbsolutei,j - ZModifiedi,j]] \quad (5)$$

Z modified: F ((Ci_r ,L_r , P_r, Ci_s) $\forall r = 1{:}m$ (6)

Z modified is the configuration with m is the no of DGs in the system, r represents DG between m DG'S.

Ci_r - Controlled Impedance in series with the DG

Number r

L_r - Location of DG number

P_r - Power generated by DG number r

Ci_s - Source Impedance at the utility.

FCL source impedance at the utility FCL source is connected to bus 1.FCL is always placed in series with DG to reduce the fault current magnitude. Both real and imaginary parts are considered. It is given as follows

$$Zci_r = R_r + jX_r \quad \forall r=1{:}\ m \quad (7)$$

$$Zci_s = R_s + jX_s \quad (8)$$

Where R_r and R_s is resistive part and X_r and X_s are for reactance.

The i[th] diagonal element (Z_{ii}) of the matrix represent thevenin's impedance the fault current of this bus is calculated as follows. Consider a circuit connected to no. of series and parallel resistors and a load resistance and convert it into thevenin's equivalent circuit

Then find the short circuit current at the fault bus at bus i

$$I_f \text{ bus } i = 1/\ Zii \quad (9)$$

Zij is the fault current between bus i and bus j, as mentioned earlier the objective function is expressed as

$$\sum_{i,j=1}^{m}[ZAbsolutei,j - ZModifiedi,j]] \quad (10)$$

Therefore fault current levels can be maintained by minimizing the difference in two matrices as low.

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By running the optimization the location of DG and FCL size are obtained

No of variables for 'm' DG'S is given as

No of variables = $m_{FCL} + m_{DG} = m_{FCL(R+jX)} + m_{DG}$ (11)

FCL consists of both resistive and reactive components and the limitations of controlled impedance (FCL) is given as follows

$0 \leq R_r \leq Rmax_r$ (12)

$Xmin_r \leq X_r \leq Xmax_r$ (13)

$0 \leq R_s \leq Rmax_s$ (14)

$Xmin_s \leq X_s \leq Xmax_s$ (15)

Eqs (12) & (13) are boundaries of CI FCL, Eqs (14) & (15) Source FCL connected at PCC.

III. PROPOSED ALGORITHM

Let F(x), be the objective function
Assume, i= no. of. iterations
h=1,2…….s
s-is the no. of. deisgn variables
k=1,2…..n
n- no.of.candiadate solutions.
f(x)best-best candidate in the entire population
f(x)worst-worst candidate in the entire population.
If $X_{h,k,i}$ is the value of h th variable for k th candidate during the ith iteration.

$$X'_{h,k,i} = X_{h,k,i} + r1,h,i\,(X_{h,best,i} - |X_{h,k,i}| - r2,h,i(X_{h,worst,i} - |X_{h,k,i}|)) \quad (16)$$

$X_{h,best,i}$= it is the value of the variable 'j' for the best candidate.
$X_{h,worst,i}$ = it is the value of the variable 'j' for the worst candidate.
$X_{h',k,i}$ = updated value of $X_{h,k,i}$
$r_{1,h,i}$ and $r_{2,h,i}$ = random numbers for the hth variable during i th iteration in the range of [0,1]
The term "$r_{1,h,i}$ ($X_{h,best,i}$ -|$X_{h,k,i}$|)" indicates the tendency of the solution to move closer to the best solution .
The term "-$r_{2,h,i}$ ($X_{h,worst,i}$-|$X_{h,k,i}$|)" indicates the tendency of the solution to avoid the worst solution.
$X'_{h,k,i}$ is updated only if it gives better function value.
The proposed algorithm always tries to get closer to the best value and avoids the worst value. Hence it is named as "Jaya" algorithm.

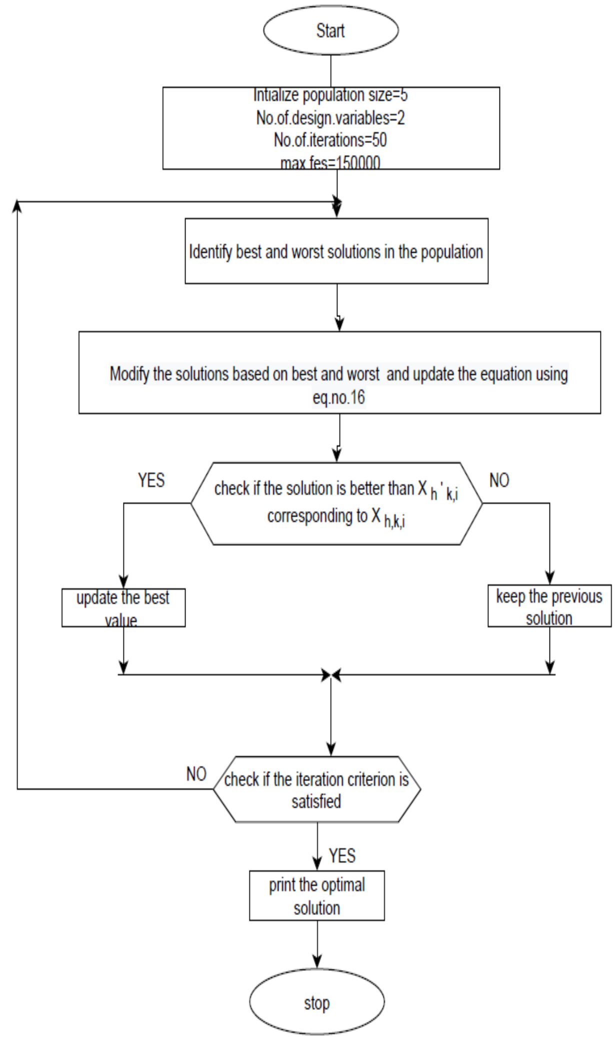

Fig.3.Flowchart of Jaya Algorithm

IV. RESULTS AND ANALYSIS

The proposed method was tested on IEEE 33 and IEEE 69 bus distribution system. The single line diagram for both test systems are shown in Figure 4 and Figure 5 respectively. The results are obtained from the proposed algorithm.

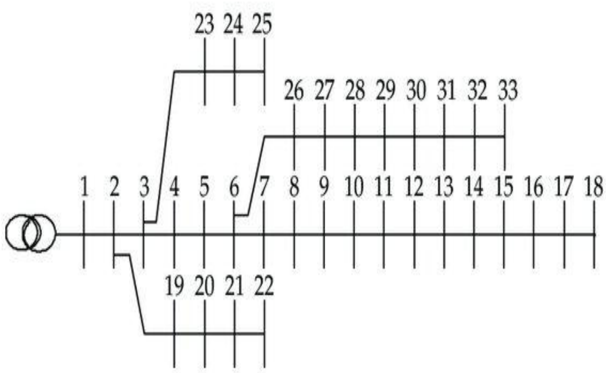

Fig.4.Single-line diagram of 33 bus system

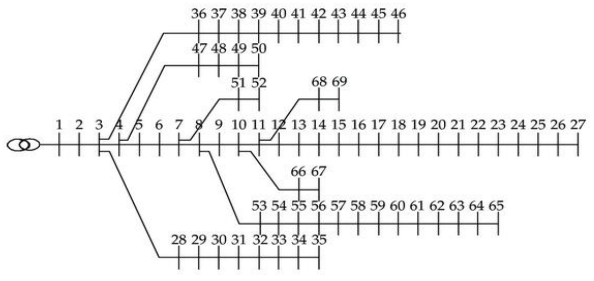

Fig.5.Single line diagram of 69 bus system

The optimal location of DG was determined by using Fuzzy logic. The optimal location was selected based on the power loss reduction index and voltage magnitude values. The output of DGPSI decides the optimal location of DG. The highest value of DGPSI is the best value to place DG in the distribution network. The type of DG used is Type-I DG, the total demand is considered as 4.5 MW (4.4 for 33 bus and 4.6 for 69 bus systems) the optimal location is obtained for both 2 DG location and 3 DG location.

Table-IV: Location and DGPSI values for 33 bus distribution system

Location	DGPSI
25	0.2527
19	0.2526
5	0.2036

Table-V: Location and DGPSI values for 69 bus distribution system

Location	DGPSI
13	0.1791
66	0.1524
12	0.1501

The simulation is carried out in Matlab 2017Ra and the optimal locations of DG is obtained as 25, 19 and 5 for 33 bus system and 13,66 and 12 for 69 bus system. After obtaining the optimal location the most fault contributing three-phase fault is considered ,the buses which are near to the substation are mostly affected and the buses far away from the substation are least affected. FCL sizing is obtained by using JAYA algorithm. the graphs shows the fault contribution is more when DG is connected the FCL is connected in order to reduce the fault currents levels and protect the traditional devices to avoid false tripping of feeders.

Table-VI: Optimization variables of FCL for JAYA algorithm for 33 and 69 bus system

33 bus system		
variable	Minimum	maximum
Xr & Xs	-10	10
Rr & Rs	0	10
m	2	33
69 bus sytem		
Xr & Xs	-10	10
Rr & Rs	0	10
M	2	69

Table-VII: Simulation data

33 bus and 69 bus source and DG system data	
Utility data	MVA_{sc}=100MVA,X/R=6
DG transformer reactance	$X^+=X^-=5\%$ Y-grounded
DG reactance	$X^+=X^-=9.67\%$
Base KV	12.47
Base MVA	100

A. IEEE 33 Bus System

The single line diagram of 33 bus system is shown in figure .4 The total real and reactive power loads is P = 3715 Kw, Q =2300 KVAr .The load at the main lateral (1-18) is P =1,505KW,Q =740 KVAr, the load at the sublaeral1 which is connected to bus 2(19-22)is P=360KW,Q=160KVAr,the load at the sub lateral2 which is connected to bus 3 (23-25) is P = 930 Kw, Q = 450KVAr,the load at the sub lateral3 which is connected to bus 6 (26-33) is P = 920KW,Q= 450 KVAr. The optimal values for DG location is obtained from fuzzy approach and the values for 33 bus system is 25, 19 and 5. Fig. 6 shows comparison of fault currents with and without DG fig.7.the comparison of fault currents with DG and FCL connected. Without FCL the fault currents are very high in DG connected mode when CI-FCL is connected the fault currents are reduced to normal values so that there is no mis-coordination between the protective devices.

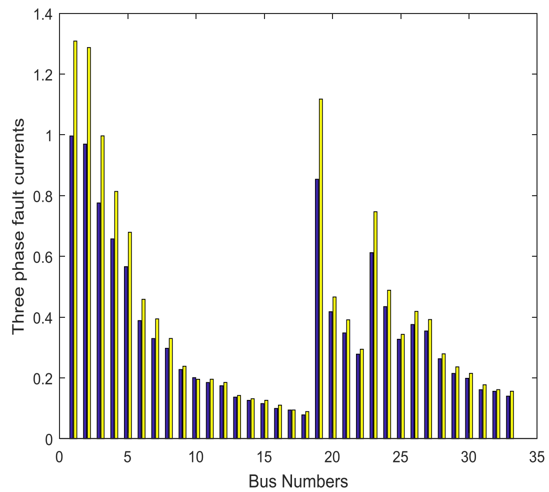

Fig.6.Comparision of Fault current in Normal mode and DG connected mode.

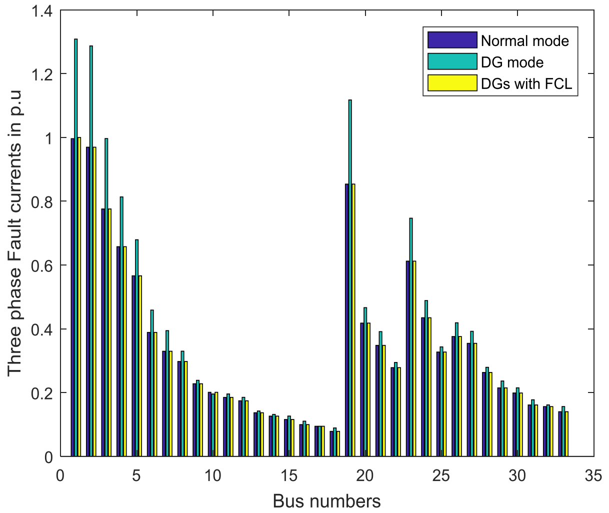

Fig.7.Comparision of Fault current with DG connected and FCL.

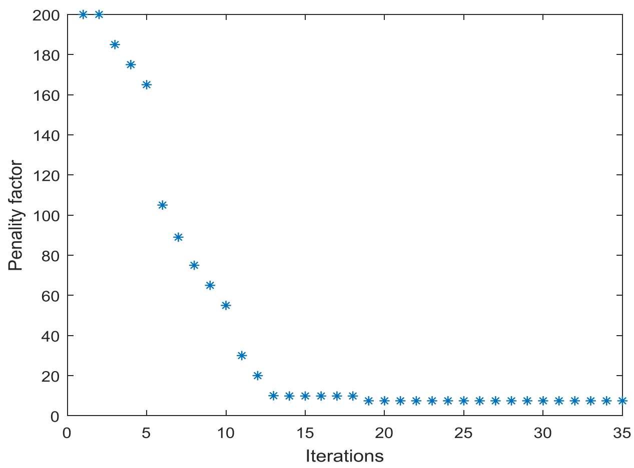

Fig.8.Convergence Diagram of 33 bus system.

B. IEEE 69 Bus System

The single –line diagram of 69 bus system is shown in Figure.5. The total real and reactive power of this radial distribution system is P=3,801.9kW,Q=2694.1kVAr .It is divided in to one main lateral and 7 sub laterals. The load at the main lateral (1-27)is P =849.8KW,Q =589.9 KVAr, the load at the sublaeral1 which is connected to bus 3(28-35)is P=91.5KW,Q=65.15KVAr,the load at the sub lateral2 which is connected to bus 3 (36-46) is P = 159.64 Kw, Q = 110.45KVAr,the load at the sub lateral3 which is connected to bus 4 (47-50) is P = 888.2KW,Q= 633.7 KVAr,the load at the sub lateral4 which is connected to bus 7 (51,52)P = 7.95KW,Q=6.2 KVAr,the load at sublateral5 which is connected to bus 8 P=1730.4KW,Q= 1236.2KVAr,the load at sublateral6 which is connected to bus 10(66,67)P = 46KW,Q= 33KVAr,the laod at sublateral7 which is connected to bus 11 (68,69) P= 28KW,Q=20 KVAr.The optimal values for DG location is obtained by using fuzzy approach. The DG locations for 69 bus system is 13,66 and 12.The Figure 9 shows comparison of fault currents with and without DG fig.10.the comparison of fault currents with DG and FCL connected.

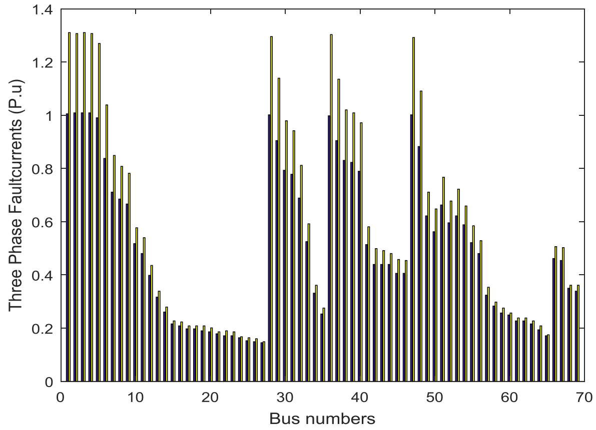

Fig.9.Comparision of Fault currents with normal and DG connected.

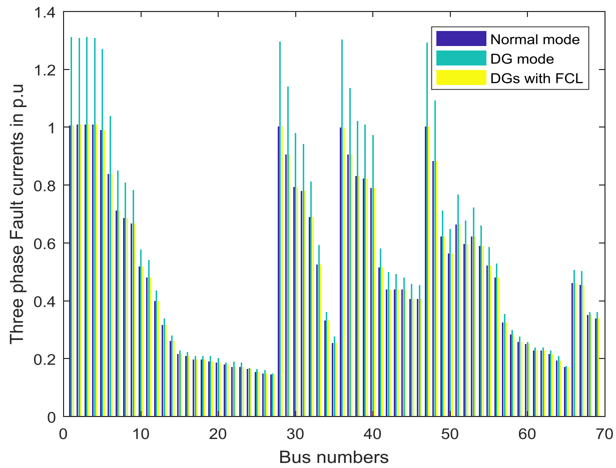

Fig.10.Comparision of fault currents with DG and FCL.

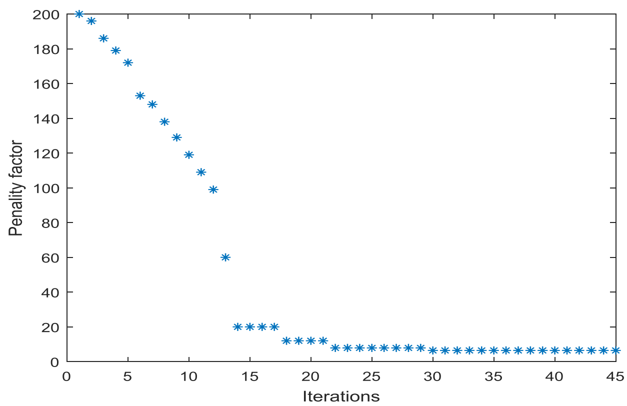

Fig.11.Convergence Diagram of 69 bus system.

From the above figures 7 and 10 it is clear that after placing controlled impedance fault current limiter (CI-FCL) the three phase fault currents are reduced to acceptable limits.by considering the penalty factor FCL sizing is obtained by using Jaya algorithm. The obtained results are compared with analytical PSO method. Table. IX and X Shows the values of optimal DG location and FCL sizing for 33 and 69 bus systems.

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Table –VIII: Jaya algorithm Implementation data to 33 and 69 bus systems.

Population size	5
Max.no.iterations	50
No.of.design variables	2
Max fes	150000
Mini,maxi	[1 -5],[5 5]

Table-IX: Comparison of optimal values of PSO and Jaya algorithm for IEEE 33 bus system.

PSO results for 3 DG					Jaya algorithm results for 3 DG				
DG Number	Location	FCL size	FCL source	Best Fitness	DG Number	Location	FCL size	FCL source	Best Fitness
DG1 (1.5MW)	2	1.8464+1.994j	0.11566 +0.36305i	9.9140	DG1 (1.5MW)	25	1.4623+1.3582i	0.1000+0.2630i	7.4526
DG2 (1.5MW)	3	6.3021+4.2043j			DG2 (1.5MW)	19	4.8304+3.6823i		
DG3 (1.5MW)	19	3.89+2.35j			DG3 (1.5MW)	5	0.0900+1.9860i		
PSO results for 2 DG operation					**Jaya algorithm results for 2 DG operation**				
DG Number	Location	FCL size	FCL source	Best Fitness	DG Number	Location	FCL size	FCL source	Best Fitness
DG1 (2MW)	3	9.9882+4.2141j	0.012514 +0.21371i	9.7	DG1 (2MW)	25	1.5752+3.6783i	0.0100+0.1792i	4.49824
DG2 (2MW)	19	6.0836+6.3737j			DG2 (2MW)	19	1.34100+4.0140i		

Table-X: Comparison of optimal values of PSO and Jaya algorithm for IEEE 69 bus system

PSO results for 3 DG					Jaya algorithm results for 3 DG				
DG Number	Location	FCL size	FCL source	Best Fitness	DG Number	Location	FCL size	FCL source	Best Fitness
DG1 (1.5MW)	4	4.0267+0.29311j	0.01046 +0.30675i	1.0615	DG1 (1.5MW)	13	3.179+0.1120i	0.0100+0.2340i	6.4382
DG2 (1.5MW)	28	2.2563+2.0257j			DG2 (1.5MW)	66	2.0680+1.5630i		
DG3 (1.5MW)	36	3.3053+6.2336j			DG3 (1.5MW)	12	2.8970+4.7820i		
PSO results for 2 DG operation					**Jaya algorithm results for 2 DG operation**				
DG Number	Location	FCL size	FCL source	Best Fitness	DG Number	Location	FCL size	FCL source	Best Fitness
DG1 (2MW)	2	1.8318+4.5763j	0.029363 +0.19119i	5.4484	DG1 (2MW)	13	1.3236+1.7320i	0.0163+0.2984i	1.09120
DG2 (2MW)	5	2.7356+5.1776j			DG2 (2MW)	66	2.0763+4.8230i		

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V. CONCLUSION

Integration of DG in to a distribution system results in increase in the fault current level, loses its radial nature. The buses which are connected near to the substation will contribute more current when compared to the buses away from the substation .In this paper, the problem is formulated for optimal placement of DG and sizing of CI-FCL. Fuzzy-Jaya algorithm is proposed for optimal placement and sizing. All the evolutionary algorithms require proper tuning of specific parameters in addition to tuning of common controlling parameters, whereas Jaya algorithm does not require any specific parameters for tuning.it tunes only common controlling parameters .the results obtained shows that Jaya algorithm can be applied for both constrained and unconstrained optimization .it gives optimum results with less no of function evaluations when compared with the PSO method. Results obtained shows satisfactory performance of Jaya algorithm to optimal locate DG and FCL sizing.

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AUTHORS PROFILE

Vasavi.C, received her Btech in Electrical and Electronics Engineering from JNT University Ananta -puram in 2010, Mtech from S.V. Univeristy in 2012 and currently pursuing Ph.D in the Department of Electrical and Electronics Engineering at S.V. University, Tirupati. Her research interests are in the area optimization techniques, Power quality problems, Distributed Generation, Micro grids, Protection systems, FACTS Technologies

Dr. T. Gowri Manohar, received his B.Tech, M.Tech and Ph.D. Degrees from S.V. University, Tirupati, India, in 1996, 1998 and 2007 respectively. Currently, he is working as a professor in the department of EEE, SV University, Tirupati. His current research areas include power quality issues, FACTS technology, distributed energy resources and the application of artificial intelligent techniques on a power system.