Differential Evolution Technique for Determining Shortest Distance to Voltage Collapse

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Abstract: *This paper describes an algorithm for computing shortest distance to voltage collapse for determination of closest saddle node bifurcation point (CSNBP) using Differential Evolution (DE) technique. A direction along CSNBP gives conservative results from voltage security view point. This information is useful to the operator to steer the system away from this point by taking corrective actions. The distance to a closest bifurcation is a minimum of the loadability given a slack bus or participation factors (PCM) for increasing generation as the load increases. CSNBP determination has been formulated as an optimization problem to be used in DE technique. DE is a new floating point coded evolutionary algorithm (EA). It differs significantly from other evolutionary algorithms (EA) in the sense that distance and direction information from the current population is used to guide the search process. It can handle optimization problems with any complexity since mechanization is simple with a very little effort put to tune the parameters. The performance of the proposed algorithm is tested on two standard IEEE test systems. The potential and effectiveness of the proposed approach are demonstrated.*

Keywords:-*Voltage collapse, CSNBP, DE, EA, PCM.*

I. Introduction

This paper describes an algorithm for computing shortest distance to voltage collapse for determination of CSNBP using Differential Evolution (DE) technique. A direction along CSNBP gives conservative results from voltage security view point. This information is useful to the operator to steer the system away from this point by taking corrective actions. The distance to a closest bifurcation is a minimum of the loadability given at the slack bus or participation factors for increasing generation as the load increases. CSNBP determination has been formulated as an optimization problem to be used in DE technique. Voltage instability problem will be more dominant in electric power system in the years to come due to continuous growth demand. It has been faced in many parts of the world indicating the need to improve voltage profile by optimized use of reactive power available [1]. Modern power networks are operating under stressed condition owing to environmental and economic constraints. Usually in such situation static voltage stability assessment focuses primarily on the proximity of the operating point to a collapse point. This type of assessment provides needed time to the operator for voltage stability enhancement. This instability seems from the attempt of load dynamics to restore power consumption beyond the amount that can be provided by the composite (transmission and generation) system. Basically voltage collapse involves load dynamics hence voltage stability is known as load stability [2, 3, 4, 5].PV-curve is one of the important tool for voltage stability analysis and identifying saddle node bifurcation point. PV-curve at a node is obtained using continuation power flow. One important aspect in static voltage stability studies is that of transfer limit surface. The transfer limit is the upper limit imposed by the system characteristics on the power flowing from generator buses to load buses. The transfer limit surface is this upper limit, and is defined as a hyper surface in load parameter space. Load parameter space is multidimensional space spanned by loads of the buses. A static condition corresponds to a point in this load parameter space. The transfer limit is the upper limit imposed by the system characteristics on the power flow from Generator buses to load buses [6]. The transfer limit surface is the upper limit and it is defined as a hyper surface in load parameter surface. The hyper surface provides information about change in maximum loading with respect to change in load scenario. One important aspect in static voltage stability studies is that of determination of closest saddle node bifurcation point (CSNBP) [7]. A saddle limit induced bifurcation may result due to reactive limits of the generators. It is well established that reactive power limits greatly affects voltage stability [6]. Hiskens et al. [8] developed techniques for computing saddle limit induced bifurcation points efficiently. Dobson et al. [7] proposed two approaches for obtaining CSNBP with respect to a given operating point. The number of iteration of the iterative method depends on the curvature of hyper surface and distance of present operating point to CSNBP. Artificial intelligence techniques are attractive and interesting to solve such estimations problem [9, 10].

II. Differential Evolution Algorithm

Differential evolution (DE) algorithm is a new evolutionary computation technique introduced recently [11,12]. It is inspired by biological and sociological motivations and can take care of optimality on rough, discontinuous and multi-modal surfaces. It results in near optimal solution which is independent of initial parameters.It is found that, DE algorithm is the best performing algorithm as it find the lowest fitness value for most of the problems considered in that study. Also, DE algorithm is robust, it is able to reproduce the same results consistently over many trials, whereas the performance of PSO is far more dependent on the randomized initialization of the individuals [13]. Therefore, the DE algorithm seems to be a promising approach for engineering optimization problem. It has successfully been applied and studied to many artificial and real optimization problems [14,15].

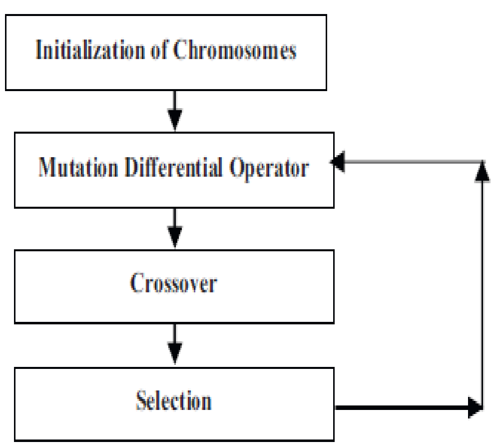

Fig. 1 Different stages of Differential Evolution Algorithm

DE algorithm is population based algorithm using three operators; crossover, mutation and selection as shown in Fig 1. Several optimization parameters must also be tuned. These parameters have joined together under the common name control parameters. In fact, there are only three read control parameters in the algorithm, which are differentiation (or mutation) constant σ, crossover constant CR, and size of population NP. The read of the parameters are dimension of problem D that scales the difficulty of the optimization task, maximum number of generations (or iterations) GEN, which may serve as a stopping condition, and low and high boundary constraints of variables that limit the feasible area. These stages can be explained as follows [16].

Step-(I) **Initialization**

Initial population of size 'NP' is generated as follows:

$$p^o = [X_1^0, X_2^0, X_3^0, \dots \dots . X_{NP}^0] \qquad (1)$$

$$X_i^0 = [x_{i1}^0, x_{i2}^0, x_{i3}^0, \dots \dots . x_{iD}^0] \qquad (2)$$

x_{ij}^0 i.e. jth parameter of vector is obtained from uniform distribution as follows:

$$x_{ij}^0 = \underline{x_i^0} + (\overline{x_j^0} - \underline{x_j^0})\, rand_j^{(0,1)} \qquad (3)$$

Where $\underline{x_j^0}$ and $\overline{x_j^0}$ are the lower and upper bounds on variable.

$rand_j^{(0,1)}$ is a random digit in the range [0,1].

Step-(II) **Mutation**

DE mutates and recombines the population to produce a population of 'NP' trial vectors. Differential mutation adds a scaled, randomly sampled, vector difference to a third vector as follows.

$$\underline{V_i^{(k)}} = X_{base}^{(k)} + \sigma(X_p^{(k)} - X_q^{(k)}) \qquad (4)$$

σ is known as the scale factor which usually lies in range [0,1],

$X_p^{(k)}$ and $X_q^{(k)}$ are two randomly selected vectors,

$X_{base}^{(k)}$ is known as a base vector,

$\underline{V_i^{(k)}}$ is a mutant vector.

The base vector index 'b' may be determined in a variety of ways. This may be a randomly chosen vector.

Step (III) **Crossover**

To increase the diversity of the population, crossover operator is carried out in which the donor vector exchanges its components with those of the current member

Crossover generates trial vectors as follows:

$$t_{ij}^{(k)} = \begin{cases} v_{ij}^{(k)}, if\,(rand_j^{(0,1)} \leq CR\ or.\ j = j\,rand) \\ x_{ij}^{(k)}, otherwise \end{cases} \quad (5)$$

Crossover probability lies in the range [0, 1]. CR is user defined value which controls the number of parameter values which are copied from the mutant. If the random number randj is less than or equal to CR the trial parameter is adopted from the mutant $v_{ij}^{(k)}$.

Further, the trial parameter with randomly chosen index, j_{rand} is taken from the mutant to ensure that trial vector does not duplicate target vector $x_{ij}^{(k)}$. Otherwise the parameter is adopted from the target vector $x_{ij}^{(k)}$.

Step-(IV)**Selection**

To keep the population size constant over subsequent generations, the selection process is carried out to determine which one of the child and the parent will survive in the next generation, i.e..at time $t = t + 1$. DE actually involves the Survival of the fittest principle in its selection process. In selection process objectivefunction is evaluated for target vector and trial vector. Trial vector is selected if it provides better value of the function than the target vector as follows:

$$X_i^{(k+1)} = \begin{cases} t_i^{(k)}, if\,\left[f\left(t_i^{(k)}\right) \leq f(X_i^{(k)})\right] \\ X_{ij}^{(k)}, otherwise \end{cases} \quad (6)$$

The process of mutation, crossover and selection is executed for all target vector index 'i' and a new population is created till the optimal solution is obtained. Some of the variables may cross the lower or upper bounds in a mutant vector $v_i^{(k)}$ in executing differential as governed by relation (4). Bounce back mechanism is adopted to bring such decision variables within limit. The bounce-back method replaces element which has violated limits by the new element whose value lies between the base parameter value and the bound being violated. The following relations are used for violated mutant vector elements [17].

$$v_{ij}^{(k)} = \begin{cases} x_{basej}^{k} + rand.\left(\underline{x_j^k} - x_{basej}^{k}\right), if\,(v_{ij}^{(k)} \leq \underline{x_j^k}) \\ x_{basej}^{k} + rand.\left(\overline{x_j^k} - x_{basej}^{k}\right), if\,(v_{ij}^{(k)} > \overline{x_j^k}) \end{cases} \quad (7)$$

S

(i) $t_i^{(k)}$ satisfies all constraints and has a lower or equal value of objective function than $X_i^{(k)}$.

(ii) $t_i^{(k)}$ is feasible and $X_i^{(k)}$ is not feasible.

(iii) $t_i^{(k)}$ and $X_i^{(k)}$ are both infeasible,but does not violate any constraint more than $X_i^{(k)}$.Otherwise $X_i^{(k)}$ is retained in the new population.

III. Methodology

In order to Implement of Differential Evolution Algorithm to solve CSNBP problem, following steps have been adopted.

1:Base case load flow solution is obtained. Continuous power flow algorithm is used to determine the distance to voltage collapse.

2:Generate 'NP' problem independent individuals which are unit vectors in the directions of load increase i.e.

These are generated by generating random digits between [-1, 1] and then converting the resulting vector as unit vectors.

Xi(0) = di(0) = [ΔPi(0), ΔQi(0)]T
i = 1, 2, ……NP

3: collapse for each direction di(k) using continuation power flow as follows. Evaluate objective function i.e. distance to voltage

di = i = 1, 2, …..NP (8)

ΔPi,n(k) and ΔQi,n(k) are the changes in real and reactive power load for ith vector at nth load bus. In continuation power flow reactive power limits and allowable changes are incorporated.

4: Select target vector i.

5: Select base vector X_base^ which is feasible and gives the best value of objective function using relation (4).

6: Select two vectors 〖,X〗 _p^ and X_q^ such that base ≠ i ≠ p ≠ q.

7: Obtain a mutated vector using Eq. (4).

8: Generate trial vector t_ij^((k)) using Eq. (5).

9: If any component of the trial vector crosses the boundary then apply bounce back technique using relation (7). Thus it is assumed that all components of trial vectors are within limit.

10: The trial vector t_i^((k)) is selected in the new population according to condition of Eq. (6).

11: Obtain decision variables (Xi(k+1) di(k+1))

12: Convert all positions / directions to unit vectors and go for the next iteration if stopping criterion is not met.

IV-Results and Discussion

The DE based technique developed and has been implemented on a 6–bus, and 25-bus standard test systems for determining the closest saddle node bifurcation point. It determines the optimum direction/scenario which leads to this shortest distance to voltage collapse. System data are given in [19].

6 –Bus system

The 6-bus test system has two generator buses and four load buses. Table - 1 shows base case load flow solution. Total base case real and reactive power load on the system is 0.675 pu and 0.16 pu respectively. The susceptance of lines are assumed zero. Table 1 shows base case load flow solution. Ten initial solutions (search directions) were assumed and are given in Table-2. Table-2 also shows distance to voltage collapse for each of the initial solution i.e. $d_i^{(0)}$ in the last column. These are the load scenarios. DE control parameters σ and CR are selected as 0.9 and 0.5 respectively. Maximum numbers of iterations were set equal to 150. Table-3 shows the load scenario which gives minimum distance to voltage collapse.

25 –Bus system

Load flow solution for 25-bus system at base case real load of 7.3pu and reactive load of 2.28 pu is given in Table-4. DE control parameter σ, CR are selected as 0.9 & 0.5 were selected. Maximum iterations were set equal to 150. Fifteen initial solutions are given in Table 5 . Last row of Table-5 gives the distance to voltage collapse for each of the initial solution. Fig. 2 shows the plot of shortest distance to voltage collapse versus number of iteration for 25 bus system. Solution converges in 108 iterations. Shortest distance to voltage collapse is estimated as 1.028 pu MVA. Table 6 shows the load scenario which gives the minimum distance to voltage collapse.

Table 7 reveals a comparison for determining the shortest distance to voltage collapse using DE and PSO techniques for 6 bus and 25 bus system which are in close agreement and DE performance was found slightly better than PSO.

Table-1: Current operating point for 6- bus test system

Total real load (Pd) = 0.675pu

Total reactive load (Qd) =0.16pu

Bus No.	P_G Pu	Q_G Pu	P_D Pu	Q_D Pu	|V| Pu	Phase angle (degree)
1	0.23	0.273	0.00	0.00	1.000	00.00
2	0.50	0.031	0.00	0.00	1.000	11.34
3	0.00	0.000	0.27	0.06	0.912	-3.07
4	0.00	0.000	0.00	0.00	0.932	-2.13
5	0.00	0.000	0.15	0.09	0.900	-0.03
6	0.000	0.0000	0.250	0.005	0.9279	-2.61

Table-2: Initial solutions for 6- bus test system

S N	ΔP_3 pu	ΔP_4 pu	ΔP_5 pu	ΔP_6 pu	ΔQ_3 pu	ΔQ_4 pu	ΔQ_5 pu	ΔQ_6 pu	di
1	0.59	0.071	-0.09	0.377	0.112	0.000	-0.015	-0.229	0.64
2	0.121	0.201	-0.09	0.191	0.018	0.195	-0.15	0.078	0.268
3	-0.295	-0.315	-0.09	-0.05	0.213	0.195	-0.15	0.085	0.359
4	-0.295	-0.315	-0.09	0.441	0.362	0.335	0.107	-0.096	0.914
5	-0.094	-0.114	0.030	0.363	0.458	0.195	-0.15	0.769	0.934
6	0.358	0.338	-0.038	0.328	0.411	0.195	0.458	0.090	0.719
7	0.220	0.200	0.073	0.427	0.331	0.195	0.185	0.074	0.309
8	-0.295	-0.315	0.348	-0.05	0.136	0.195	0.668	0.195	0.785
9	-0.295	-0.315	0.455	-0.05	0.257	0.5053	-0.15	0.465	0.628
10	-0.042	-0.062	0.367	-0.27	0.675	0.195	0.366	0.321	0.712

Table-3: Direction or load scenario which gives shortest distance to voltage collapse for 6-bus system

ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔQ_3	ΔQ_4	ΔQ_5	ΔQ_6
0.2231	0.000	0.0176	0.0715	0.5127	0.2459	0.0411	- 0.012

Table-4: Base case load flow solution for 25-bus system

Bus No.	P_G pu	Q_G Pu	P_D Pu	Q_D Pu	V Pu	Phase angle (Degree)
1	2.6697	0.7680	0.0000	0.0000	1.0000	0.000
2	0.9937	- 0.0325	0.0000	0.0000	1.0000	8.551
3	1.4719	0.1862	0.0000	0.0000	1.0000	6.312
4	0.3910	0.3474	0.0000	0.0000	1.0000	- 3.286
5	1.9300	- 0.3071	0.0000	0.0000	1.0000	7.695
6	0.0000	0.0000	0.1500	0.0500	0.9783	5.099
7	0.0000	0.0000	0.1500	0.0500	0.9910	3.635
8	0.0000	0.0000	0.2500	0.0000	0.9923	3.011
9	0.0000	0.0000	0.1500	0.0500	0.9851	2.276
10	0.0000	0.0000	0.1500	0.0500	0.9949	3.452
11	0.0000	0.0000	0.0500	0.0000	0.9958	2.308
12	0.0000	0.0000	0.1000	0.0000	0.9926	2.292
13	0.0000	0.0000	0.2500	0.0800	0.9772	4.860
14	0.0000	0.0000	0.2000	0.0700	0.9438	- 2.248
15	0.0000	0.0000	0.3000	0.1000	0.9432	- 3.290
16	0.0000	0.0000	0.3000	0.1000	0.9566	- 3.052
17	0.0000	0.0000	0.6000	0.2000	0.9943	1.939
18	0.0000	0.0000	0.1500	0.0500	0.9844	- 0.591
19	0.0000	0.0000	0.1500	0.0500	0.9942	- 1.446
20	0.0000	0.0000	0.2500	0.0800	0.9843	- 5.413
21	0.0000	0.0000	0.2000	0.0700	0.9801	- 6.582
22	0.0000	0.0000	0.2000	0.0700	0.9736	- 7.416
23	0.0000	0.0000	0.1500	0.0500	0.9831	- 4.065
24	0.0000	0.0000	0.1500	0.0500	0.9754	- 8.392
25	0.0000	0.0000	0.2500	0.0800	0.9792	- 7.517

Table-5: Initial solutions for 25- bus test system

ΔP/ΔQ	Initial Search directions														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
ΔP_6	0.297	0.8609	-0.0664	-0.072	-0.13	0.683	-0.0464	0.429	0.3111	0.5081	0.2886	0.8595	-0.2	-0.28	-0.14
ΔP_7	-0.0884	0.4804	-0.36	0.6668	-0.13	0.4487	0.3838	-0.23	0.1945	0.1482	0.3886	0.01	-0.2	-0.28	-0.14
ΔP_8	0.5746	0.8802	0.094	0.8148	0.9121	-0.03	-0.1355	-0.33	-0.084	-0.242	0.6975	-0.09	-0.3	0.1209	-0.129
ΔP_9	0.0536	0.2399	0.4798	0.5562	-0.0539	0.07	-0.33	0.0691	0.016	-0.0907	0.08	0.01	0.5443	-0.28	-0.14
ΔP_{10}	-0.0895	0.8189	-0.3084	0.019	-0.13	0.3146	-0.33	-0.23	0.5736	-0.1073	0.08	0.01	0.8552	0.0375	-0.14
ΔP_{11}	0.0294	0.08	-0.71	0.028	-0.03	0.6023	-0.0805	-0.13	0.1601	-0.58	0.3202	0.9278	0.4937	-0.0674	-0.04
ΔP_{12}	0.0208	0.03	-0.31	0.0276	1.0543	0.3197	0.2516	0.7289	0.6906	0.143	0.3136	0.928	0.2056	-0.23	0.7962
ΔP_{13}	-0.135	0.73	0.2065	-0.0722	0.6868	-0.03	-0.43	-0.33	-0.084	0.0196	0.1864	-0.09	0.2796	-0.38	-0.24
ΔP_{14}	-0.33	0.6317	0.4833	-0.122	1.0881	1.07	-0.38	-0.1992	0.5895	0.2357	0.0887	0.5883	0.4919	0.5357	-0.19
ΔP_{15}	0.0352	-0.17	-0.51	0.5381	-0.28	0.5579	0.0818	-0.3193	0.7688	-0.1674	0.8675	0.8922	0.5212	-0.2917	-0.29
ΔP_{16}	-0.0254	0.7528	-0.51	-0.0889	1.0021	0.272	-0.2925	1.0555	-0.134	0.3049	0.6741	-0.14	-0.35	0.6054	0.0174
ΔP_{17}	0.3568	0.0062	0.3305	0.2791	-0.58	0.7562	-0.3562	-0.68	0.4025	0.4499	-0.37	-0.44	0.3386	-0.73	-0.0965
ΔP_{18}	-0.28	-0.02	-0.0725	0.5173	0.4658	0.7724	-0.2651	-0.23	0.016	0.5341	0.08	0.01	0.4147	0.662	1.1495
ΔP_{19}	0.2806	-0.02	0.0602	0.22	0.7082	0.07	-0.33	-0.23	0.2145	-0.23	0.08	0.5897	0.8176	-0.28	0.8439
ΔP_{20}	0.024	-0.12	0.5602	-0.172	1.0473	-0.03	-0.43	-0.33	0.6921	0.2227	-0.02	-0.09	-0.3	0.1784	-0.1949
ΔP_{21}	-0.0492	0.4146	-0.41	0.0941	-0.0532	0.8829	-0.38	-0.28	0.7027	-0.1912	0.1129	1.0163	-0.25	-0.2927	0.3403
ΔP_{22}	0.4158	0.6313	-0.41	0.4399	-0.18	0.02	0.0736	-0.28	0.2302	-0.28	0.3185	1.212	-0.25	0.2548	-0.0528
ΔP_{23}	0.6945	0.087	0.3937	-0.0183	0.564	0.07	0.083	0.4918	0.016	0.2719	0.08	0.1716	1.0965	-0.28	0.5054
ΔP_{24}	-0.28	0.0964	-0.36	-0.072	-0.13	0.6927	0.3287	-0.23	0.5013	0.5584	0.6758	0.01	-0.0225	-0.0162	0.5686
ΔP_{25}	-0.38	0.2629	-0.46	-0.172	0.6193	0.6509	-0.43	0.3373	0.4404	0.4559	0.1273	0.1763	-0.3	0.2501	-0.24
ΔP/ΔQ	**Initial Search directions**														

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ΔQ_6	0.247	0.08	0.3644	0.028	-0.03	0.9649	0.326	-0.13	0.5756	0.0129	0.6162	1.1176	0.9079	-0.18	-0.04
ΔQ_7	0.5504	0.6355	-0.26	0.028	-0.03	1.0411	-0.23	0.9068	0.116	-0.13	0.18	0.3048	-0.1	-0.18	0.0925
ΔQ_8	-0.13	0.13	-0.21	0.2221	0.02	0.3905	-0.18	-0.08	0.5107	-0.08	0.4114	1.0427	-0.05	0.4012	0.01
ΔQ_9	-0.18	0.8968	-0.26	0.6742	-0.03	0.3242	-0.23	-0.13	0.851	-0.13	0.18	0.9489	-0.1	-0.18	0.539
ΔQ_{10}	-0.18	0.5546	-0.26	0.6525	-0.0082	1.0662	0.3645	-0.13	0.3081	-0.0411	0.9561	0.4804	0.7154	-0.18	-0.04
ΔQ_{11}	0.0121	0.4885	0.1451	0.7629	0.0444	0.22	-0.18	-0.08	0.166	-0.08	0.67	0.16	-0.05	0.4224	0.01
ΔQ_{12}	0.1649	0.13	-0.1345	0.078	0.02	0.22	0.3954	0.0597	0.3167	0.231	0.23	0.16	0.6724	-0.0597	0.7341
ΔQ_{13}	-0.21	0.6121	-0.29	-0.722	1.0764	0.7946	-0.26	1.1158	0.8803	-0.16	0.872	1.0718	0.8993	-0.067	0.5335
ΔQ_{14}	-0.2	0.7962	0.5369	0.6206	-0.05	0.2129	-0.88	-0.15	0.096	0.1781	0.16	0.5501	-0.12	-0.2	-0.06
ΔQ_{15}	0.1858	0.03	-0.062	-0.022	-0.08	0.8537	-0.28	-0.18	0.1763	0.3571	0.13	0.7364	-0.15	-0.23	1.1473
ΔQ_{16}	-0.0441	0.03	0.4497	-0.022	-0.08	0.5238	0.4021	-0.18	0.0909	-0.18	0.13	0.213	0.4464	0.2536	0.7977
ΔQ_{17}	-0.33	-0.07	-0.378	-0.122	0.9465	0.9916	-0.1649	0.4969	0.6859	0.0535	0.3917	0.36	0.4661	-0.33	-0.19
ΔQ_{18}	-0.0575	0.7741	-0.26	0.028	-0.03	0.17	-0.0103	0.9639	0.7672	-0.13	0.18	0.1899	-0.1	0.015	-0.04
ΔQ_{19}	-0.18	0.6804	-0.1919	0.028	-0.03	0.17	0.2599	-0.13	0.855	0.5458	0.5586	0.11	0.2464	-0.18	-0.04
ΔQ_{20}	-0.21	0.2444	-0.29	-0.002	0.6194	0.14	0.4419	0.7902	0.086	-0.16	-0.57	0.9727	-0.13	-0.21	0.165
ΔQ_{21}	0.4957	0.06	-0.91	0.008	0.4106	0.15	-0.2118	1.077	0.6099	0.3187	0.5289	0.2405	1.2114	-0.0377	0.2718
ΔQ_{22}	0.6657	0.3565	0.4394	0.008	0.6921	0.2943	-0.25	-0.15	0.3857	0.4312	0.16	0.1587	-0.12	0.56	-0.06
ΔQ_{23}	-0.18	0.4462	-0.1056	0.028	0.5077	0.4326	-0.23	0.0064	0.5819	-0.13	0.18	0.11	-0.1	0.2826	0.1967
ΔQ_{24}	-0.18	0.6543	-0.26	0.1581	-0.03	0.2072	0.2155	-0.13	0.4511	-0.13	0.8708	0.11	-0.1	0.2409	-0.04
ΔQ_{25}	-0.0553	-0.67	-0.29	-0.002	-0.06	0.3636	0.2244	0.5891	0.086	-0.16	0.3518	0.2309	-0.13	-0.21	-0.07
di	1.809	3.134	2.375	2.207	3.318	3.514	2.003	3.024	2.977	1.789	2.796	3.699	3.057	1.970	2.649

Table-6: Load scenario which gives shortest distance toVoltage collapse for 25-bus system

ΔP_6	-0.0105	**ΔQ_6**	0.0133
ΔP_7	0.3414	**ΔQ_7**	0.1419
ΔP_8	-0.0071	**ΔQ_8**	0.0116
ΔP_9	-0.152	**ΔQ_9**	0.0674
ΔP_{10}	-0.1258	**ΔQ_{10}**	0.115
ΔP_{11}	0.0277	**ΔQ_{11}**	-0.0002
ΔP_{12}	0.0642	**ΔQ_{12}**	0.1228
ΔP_{13}	-0.252	**ΔQ_{13}**	-0.0601
ΔP_{14}	-0.0286	**ΔQ_{14}**	-0.0702
ΔP_{15}	0.0092	**ΔQ_{15}**	-0.014
ΔP_{16}	0.1963	**ΔQ_{16}**	0.1532
ΔP_{17}	-0.0506	**ΔQ_{17}**	0.0857
ΔP_{18}	-0.0099	**ΔQ_{18}**	0.284
ΔP_{19}	-0.152	**ΔQ_{19}**	0.1378
ΔP_{20}	0.1229	**ΔQ_{20}**	0.0152
ΔP_{21}	0.1826	**ΔQ_{21}**	-0.0702
ΔP_{22}	0.0246	**ΔQ_{22}**	0.0442
ΔP_{23}	-0.152	**ΔQ_{23}**	0.1946
ΔP_{24}	0.4506	**ΔQ_{24}**	0.4513
ΔP_{25}	0.1726	**ΔQ_{25}**	0.1622

Table-7: Shortest distance to voltage collapse using DE & PSO techniques for 6-bus and 25-bus

IEEE test system	**DE approach**	**PSO approach [18]**
	Shortest distance to Voltage collapse (pu MVA)	**Shortest distance to Voltage collapse (pu MVA)**
6-bus	0.5490	0.5575
25-bus	1.0210	1.0321

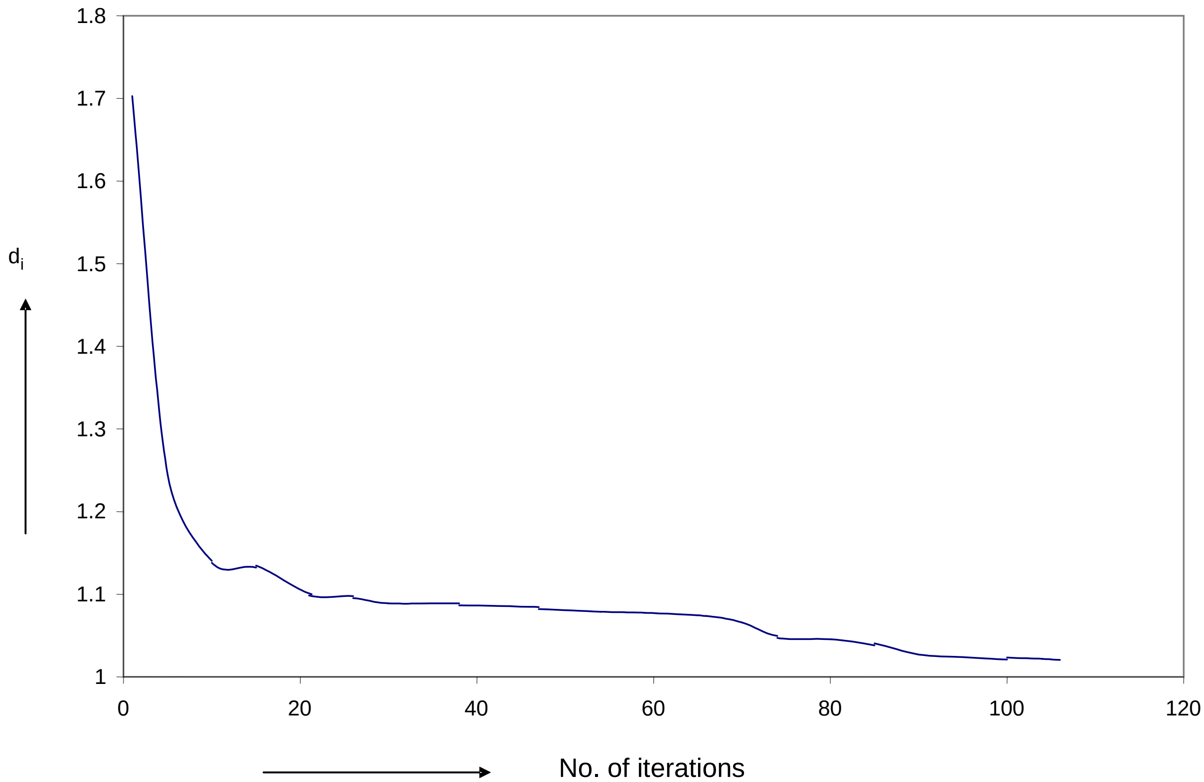

Fig. 2 -Estimated minimum distance to voltage collapse v/s no. of iteration for 25-bus system with size of population 5.

V. Conclusion

A methodology has been developed and implemented on three test systems to obtain shortest MVA distance to voltage collapse using one of the best evolutionary algorithm i.e. differential evolution technique. Effect on convergence of number of groups and number of vectors in a group has been studied. The significance of shortest distance to voltage collapse lies in the fact that it is a realistic proximity indicator. This type of index may be used for voltage stability assessment and enhancement. The results obtained using DE has been compared with PSO. The methodology has been developed and implemented on three test systems to obtain shortest MVA distance to voltage collapse using one of the best evolutionary algorithm i.e. differential evolutionary technique. Effect on convergence of number of groups and number of vectors in a group has been studied. The significance of shortest distance to voltage collapse lies in the fact that it is a realistic proximity indicator. This type of index may be used for voltage stability assessment and enhancement. The results obtained using DE has been compared with PSO.

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