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Optimization of Shortest Distance to Voltage Collapse by Corrective Rescheduling of Reactive Power Control Variables Employing Sine Cosine and Rao-1 Metaphor-less Algorithm

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Abstract — *This paper presents a new viewpoint for voltage stability enhancement by rescheduling reactive power control variables by maximizing the shortest distance to voltage collapse. The shortest distance to voltage collapse represents a proximity indicator based on the worst-case loading scenario. Such a loading scenario may be of importance when the system is operating near to collapse point. The objective is to maximize the loadability from the current operating point based on the worst-case load scenario. The aim is to get an optimum set of reactive power control variables that maximize the shortest distance to voltage collapse. Thus it is max. (min.) problem. The max. (min.) problem incorporates the operating constraints. An algorithm has been presented to solve the formulated problem using the Rao-1 algorithm, and results have been validated using Sine Cosine algorithms. Results have been presented for IEEE 6-bus and 25-bus standard test systems.*

Keywords — *Voltage collapse, Voltage stability, Optimization, Sine Cosine algorithm, Rao-1 algorithm.*

I. INTRODUCTION

Modern interconnected power systems are forced to operate near voltage collapse points due to economic and operational constraints. In such a situation, a sufficient voltage stability margin (VSM) is required. This VSM is also defined as the distance to voltage collapse point (expressed in MVA) from the current operating point. A sufficient stability margin is usually obtained by rescheduling reactive power control variables, i.e., PV bus settings, shunt compensation, and OLTC settings.

VSM depends on the settings of the control variables and load increase scenario. For specific control variables, the distance to voltage collapse will be different for a various ray of load scenarios. But there will be one load scenario that will give the least MVA distance to the voltage collapse point. This is termed as worst-case loadability and is a pessimistic proximity indicator. This becomes important when uncertainty in the loading pattern occurs near the collapse point and maybe a realistic indicator. Many researchers have developed algorithms for obtaining a loading scenario, which gives the worst loadability [1-8]. These methodologies are iterative and based on eigenvector, tangent vectors, and optimization techniques, e.g., PSO. All such above-referred articles give the closest saddle-node bifurcation point for particular reactive power control variables.

A further large article has been published [9-25] for rescheduling reactive power control variables. All such articles optimize voltage stability margin using proximity indicators. Proximity indicators indirectly reflect the distance to voltage collapse. Formulation of such problems is usually in two ways. (i) Optimizing the reactive power reserves and maintaining a threshold value of proximity indicators. (ii) Optimizing the value of proximity indicator or distance to voltage collapse subject to the satisfaction of constraints on control variables.

Further, in all such cite & research articles, the load increase scenario conforms to base case loading conditions. But in realistic operation, the load increase scenario is not conformal due to uncertainty in load increase and the load dependency on voltage magnitudes. This will be of significance, particularly when the power system is operating under a stressed condition. Hence, the closest distance to voltage collapse becomes important to know the realistic voltage stability margin. Hence in this paper, corrective rescheduling of reactive power control variables is used to maximize the shortest distance to voltage collapse. Ultimately we have to obtain a suitable set of control variables for which a load increase scenario gives the shortest distance to voltage collapse.

II. Min-Max problem formulation for optimizing closest saddle-node bifurcation point

The chosen objective function is stated as given below

$$J = \max_{\underline{U}} \left[\min_{\underline{d}} L \right] \quad (1)$$

Where J indicate objective function

L denotes the shortest distance to voltage collapse

U is the set of reactive power control variable

$\underline{d}$ is load increase direction.

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J is maximized with respect to control variables and gives the shortest voltage stability margin, which is a function of the ray of load increase in load space. Hence two set of independent decision variable has to obtain.
i.e., $\underline{U}$ and $\underline{d}$

For an optimal '$\underline{U}$' is required to get $\underline{d}$, which gives CSNBP. This $\underline{U}$ amounts that one select U and gets the worst load scenario. The one U is selected, which gives the maximum worst-case loading. The objective function (1) optimized by considering the following constraints

(a) Inequality constraints on reactive power control variables

$$\underline{U}_p \le U_p \le \overline{U}_p, \quad p = 1, \ldots NC \qquad (2)$$

$\underline{U}_p$ and $\overline{U}_p$ are lower and upper bound on p[th] control variables.

$$\underline{U} = [\underline{V}_{pv}, \underline{t}, \underline{Q}_{sh}]$$

(b) Load flow equations

$$F(\underline{X}, \underline{U}, \underline{P}_d, \underline{Q}_d) = 0 \qquad (3)$$

Repeated load flow runs are required to get the distance to voltage collapse for a selected $\underline{U}$ and direction of load increase $\underline{P}_d$, $\underline{Q}_d$

(c) Load bus voltage constraints optimization is carried out at current loading conditions. Hence following inequality constraints must be satisfied on load bus voltage magnitudes.

$$\underline{V}_{n,min} \le V_n \le \overline{V}_{n,max} \quad n \in SLB \qquad (4)$$

V_n is a bus voltage of the n[th] bus

$\underline{V}_n$, $\overline{V}_n$ are respectively the lower and upper bounds on load bus voltage

SLB denotes a set of load buses.

In summary, the aim is to obtain CSNBP maximized by an optimal set of reactive power control variables in currents loading conditions by satisfying inequality constraints on control variables and load bus voltages.

III. APPLICATION OF SINE COSINE ALGORITHM(SCA) FOR OBTAINING THE OPTIMUM DISTANCE TO CSNBP

The SCA for solving optimization problems was developed by Mirjalili [26]. No free lunch theorem [27] was a motivation for the developments of SCA. The algorithm is effective for complex problems with unknown explicit feasible space. SCA adopts sine and cosine functions by which the search is an efficient infeasible space. The starting point is a set of the randomly selected population. Each solution of the population is updated as follows

$$Y_i^{(k)} = \begin{cases} Y_i^{(k-1)} + r_1 . Sin(2\Pi U_1)\left|2U_2 G_{best}^{(k-1)} - Y_i^{(k-1)}\right|, if\ U_3 \le 0.5 \\ Y_i^{(k-1)} + r_1 . Cos(2\Pi U_2)\left|2U_2 G_{best}^{(k-1)} - Y_i^{(k-1)}\right|, if\ U_3 > 0.5 \end{cases} \qquad (5)$$

In above

$Y_i^{()}$ is member of random population

U_1, U_2, U_3 are random variables from uniform distribution between [0,1]. r_1 is control parameter which varies iteration wise as follows

$$r_1 = b - b. k^*/k_{max}$$

where

b > 1, k* is currents iteration. K_{max} is maximum number of iterations specified. $G_{best}^{(k)}$ represents the best solution so far. Details of the algorithms may be found in Ref [26]. The formulated problem is solved by using the sine cosine algorithm in the following steps.

Step-1 Run load flow program for base caseload

Step-2 Generate an initial random population of size 'M' for the reactive power control variable

$$[Y_1^{(0)}, Y_2^{(0)}, Y_3^{(0)}, \ldots Y_M^{(0)}]$$

Each Y_i is represented as

$$Y_i^{(0)} = \{\underline{V}_{pvi}^{(0)}, \underline{t}_i^{(0)}, \underline{Q}_{shi}^{(0)}\}$$

These are generated using the following relations

$$V_{p,i}^{(0)} = V_{p,min} + r.(V_{p.max} - V_{min})$$

$$t_{p,i}^{(0)} = t_{p,min} + r(t_{p.max} - t_{p,min})$$

$$Q_{SH,p,i}^{(0)} = Q_{SH,p,min} + r(Q_{SH,p.max} - Q_{SH,p,min})$$

$V_{p\ min}$, $V_{p,\ max}$ are the minimum and maximum values of PV-bus voltage settings.

$t_{p,\ min}$, $t_{p,\ max}$ is the minimum and maximum value of p[th] tap settings.

$Q_{Sh,p,\ min}$, $Q_{Sh,p,\ max}$ are minimum and maximum shunt-compensation values available at the p[th] bus.

Step-3 First set the iteration count k=1

Step-4 Implement SCA as explained in Ref [18] and find the shortest distance to voltage collapse for each $Y_i^{(k-1)}$.

Step-5 Obtain $G_{best}^{(k-1)}$ as one solution which gives the maximum value of the shortest distance to voltage collapse. Along with its direction of load increase as $\underline{d}_{best}$. Also, store objective function $J^{(k-1)}$ as given by eqn. (1)

Step-6 Update the population using relations (5)

Step-7 In step-6 if any control variable violates the bounds, then it is set to its limiting value, i.e.

$$\text{if } Y_{ij}^{(k)} < \underline{U}_j, \text{ then } Y_{ij}^{(k)} = \underline{U}_j$$

$$\text{if } Y_{ij}^{(k)} > \overline{U}_j, \text{ then } Y_{ij}^{(k)} = \overline{U}_j$$

Step-8 Selection: One has to selects $Y_i^{(k-1)}$ or $Y_i^{(k)}$ for the new population. Therefore the shortest distance of voltage collapse is obtained for $Y_i^{(k)}$

$$\text{if } L_i^{(k)}(Y_i^k) > L_i^{(k-1)}(Y_i^{k-1})$$

than

$Y_i^{(k)}$ is retained in a new population, otherwise Y_i^{k-1} goes in the new population. Thus modified or updated population is created.

Step- 9 Now increase the iteration count, k=k +1

if k > k_{max}, then stop the procedure,

Otherwise, repeat the procedure from step (4)

The iteration process is repeated for the maximum number of the specified generation. The iterative process may even be stopped if improvements are not observed in a specified number of generations in objective function J.

IV. RAO-1 METAPHOR-LESS ALGORITHM FOR THE SOLUTION OF THE PROPOSED PROBLEM

Rao-1 is one of the simplest metaphor-less algorithm developed recently by Rao [28]. It is a parameterless algorithm. Hence it is free from the problem of the set of the control parameter. The starting point is, again, an initial population. Updating of the member of the population is achieved using the following relation

$$Y_i^{(k)} = Y_i^{(k-1)} + \underline{r}\,(G_{best}^{(k-1)} - G_{worst}^{(k-1)}) \qquad (6)$$

$G_{best}^{(k-1)}$ denote the best solution concerning objective function in the current population

$G_{worst}^{(k-1)}$ denote worst solution in the current population concerning the objective function

$\underline{r}$ is a vector of random digits between [0,1]

If the modified solution $Y_i^{(k)}$ is better than $Y_i^{(k-1)}$ then accept the modified solution in the new population, otherwise the previous solution $Y_i^{(k-1)}$ is retained in a new population,

$$\begin{aligned} Y_i^{(k)} &= Y_i^{(k)} , \quad \text{if } J\,(Y_i^{(k)}) > J\,(Y_i^{(k-1)}) \\ &= Y_i^{(k-1)}, \text{ if } J\,(Y_i^{(k)}) \le J\,(Y_i^{(k-1)}) \end{aligned} \qquad (7)$$

Details of the implementation to solve the problem formulated are given in the following steps.

Step-1 Obtain initial solutions or population of size 'M' as explained in the previous section, i.e. $[Y_1^{(0)}, Y_2^{(0)}, \ldots Y_M^{(0)}]$

Step-2 First set the iteration count k=1

Step-3 For every member of the population $Y_i^{(k-1)}$ find out the shortest distance to voltage collapse, as explained in Ref [18]. Obtain $G_{best}^{(k-1)}$ and $G_{worst}^{(k-1)}$

Step-4 Modify every member of the population by using relation (6)

Step-5 If any decision variable in the modified solution, $Y_i^{(k)}$, crosses the bounds, it is set as its limiting value.

Step-6 For each modified solution $Y_i^{(k)}$ obtain shortest distance to voltage collapse $L_i^{(k)} = 1, \ldots M$

Step-7 Obtain modified population by selection criterion as follows

$$\begin{aligned} Y_i^{(k)} &= Y_i^{(k)} \quad \text{if } L_i^{(k)} > L_i^{(k-1)} \\ &= Y_i^{(k-1)} \text{ if } L_i^{(k)} \le L_i^{(k-1)} \end{aligned}$$

Step-8 Now increase the iteration count k = k+1,

if k > k_{max}, stop the procedure, otherwise repeat the procedure from step-4.

V. RESULTS AND DISCUSSIONS

The algorithms developed in this paper to maximize the shortest distance to voltage collapse concerning the rescheduling of reactive power control variables using (i) SCA and (ii) Rao-1 metaphor-less algorithm have been implemented in two standard test systems, i.e., 6-bus and 25-bus test system.

A. 6- Bus System

The 6-bus system consists of 2 generator buses and 4 load buses. Generator bus voltages limits are 0.95 pu to 1.15 pu. In the baseload conditions, the limits on the load bus voltage are 0.95 to 1.05 pu. The total real and reactive power load is (0.675 + j 0.16) pu in case of baseload condition [29, 30]. Total reactive power control variables are six, i.e. (i) Bus #1 and Bus #2 generator voltages (ii) Shunt compensation at bus #4 and #6. The lower and upper limits of these shunt compensation are 0.0 to 0.055pu. (iii) OLTCs are on lines number 4 and 7. These settings vary between 0.9 to1.1. Table-1 gives the initial settings of control variables. The total population size selected was 10, and the maximum number of iterations specified 100 (kmax). The constant 'a' was selected as 2. Table-1 also gives an optimized set of reactive power control variables. The solution converged in 50 iterations.

The formulated problem was also solved using the Rao-1 algorithm, which is metaphor-less and does not require any control parameter. Again a population size of 10 members was selected, and kmax = 100. Solution converged in 60 iterations, and after that, no significant improvement was found in the objective function. Table-1 also provides the optimized set reactive power control variable as obtaining using the Rao-1 algorithm. Table-2 shows the initial and maximized value of the shortest distance to voltage collapse obtained by the two algorithms. The un-optimized shortest distance to collapse point concerns the initial settings of the control variables. Table-2 also gives CPU time required by both the methods. It is observed that the CPU time required using the Rao-1 algorithm is around 90% that required by SCA. Since the mechanization of the Rao-1 algorithm is simple and computationally efficient. Table-3 gives optimum load increase directions for the 6-bus test system as obtained by SCA and Rao-1 algorithm.

TABLE I
INITIAL AND OPTIMIZED REACTIVE POWER CONTROL VARIABLES FOR THE IEEE STANDARD 6-BUS TEST SYSTEM AS OBTAINED USING SCA AND RAO-1 ALGORITHM

Sr. No.	Variable	Initial base case settings	Optimized Solution	
			SCA	Rao-1 algorithm
1	V_1 (pu)	1.00	1.14	1.14
2	V_2 (pu)	1.00	1.14	1.14
3	OLTC(t_4)	1.00	0.90	0.90
4	OLTC(t_7)	1.00	0.95	0.95
5	Q_{SH-4} pu	0.00	0.045	0.045
6	Q_{SH-6} pu	0.00	0.045	0.045

TABLE II
OPTIMIZED SHORTEST DISTANCE TO VOLTAGE COLLAPSE AND CPU TIME FOR 6-BUS TEST SYSTEM

	Optimized		Un-optimized	
Algorithm	**SCA**	**Rao-1**	**SCA**	**Rao-1**
CPU time (sec)	2.15	1.96	1.37	1.40
distance to voltage collapse pu MVA	0.9675	0.9685	0.521	0.541

TABLE III
WORST LOAD INCREASE DIRECTIONS FOR MAXIMIZATION OF THE SHORTEST DISTANCE TO VOLTAGE COLLAPSE FOR IEEE STANDARD 6-BUS TEST SYSTEM

Sr. No.	$\Delta P_i + j\,\Delta Q_i$	Magnitude as obtained by	
		SCA	Rao-1 algorithm
1	$\Delta P_3 + j\,\Delta Q_3$	0.601+ j 0.11	0.63 + j 0.12
2	$\Delta P_4 + j\,\Delta Q_4$	0.068 + j 0.005	0.066 + j 0.009
3	$\Delta P_5 + j\,\Delta Q_5$	-0.15 – j 0.98	-0.148 – j 0.096
4	$\Delta P_6 + j\,\Delta Q_6$	0.380 + j 0.480	0.378 + j 0.465

B. 25- Bus System

25 bus system data have been taken from Ref.[29,30]. The specific test system contains 25 buses and 35 lines. Base case total complex load is (7.3+j 2.28) pu. The system contains five generator buses numbered from 1 to 5. These five are the control variable. The bounds on the PV-buses are again given as 0.95 to 1.15 pu. The problem of obtaining the maximum shortest distance to collapse has been solved using SCA and Rao-1 algorithm. Table-4 gives initial and optimized settings of the reactive power control variable as obtained using both the methods. In both, the technique's maximum number of generators specified was 500. Solution converged in 140 iterations in the Sine Cosine algorithm as no further improvements were found in the objective function. The total number of iteration required for convergence using the Rao-1 algorithm was 170, as no improvement in the maximum shortest distance to collapse was observed further. Due to computational efficiency, the CPU time required by the Rao-1 algorithm is around 90% of SCA. Table-5 gives optimized shortest distance to voltage collapse as obtained by both the methods and CPU time required. In both the technique, a population of size 10 was selected. Table-6 presents optimized load increase directions for each load bus for 25 bus test systems obtained by the SCA and Rao-1 algorithms.

TABLE IV
INITIAL AND OPTIMIZED SET OF CONTROL VARIABLES FOR 25 BUS TEST SYSTEM AS OBTAINED USING SCA AND RAO-1 ALGORITHM

		Initial setting	Optimized setting	
			SCA	Rao-1 algorithm
Sr. No.	Control Variable	Mag. (pu)	Mag. (pu)	Mag. (pu)
1	V_1	1.00	1.15	1.14
2	V_2	1.02	1.03	1.031
3	V_3	1.03	1.12	1.14
4	V_4	1.01	1.05	1.05
5	V_5	1.01	1.06	1.07

TABLE V
OPTIMIZED PU MVA DISTANCE TO VOLTAGE COLLAPSE FOR 25 BUS TEST SYSTEM ALONG WITH CPU TIME FOR SCA AND RAO-1 ALGORITHM

	Optimized		Un-optimized	
Algorithm	SCA	Rao-1	SCA	Rao-1
CPU time Sec.	6.95	5.85	3.1	2.8
Distance to voltage collapse pu MVA	1.33	1.37	1.028	1.029

TABLE VI
WORST LOAD INCREASE DIRECTIONS FOR 25-BUS TEST SYSTEM FOR OPTIMIZED DISTANCE TO VOLTAGE COLLAPSE

Sr. No.	ΔPi + j ΔQi	Magnitude as obtained by	
		SCA	Rao-1 algorithm
1	ΔP6 + j ΔQ6	-0.14+ j 0.1579	-0.141 + j 0.1610
2	ΔP7 + j ΔQ7	-0.149 - j 0.047	-0.1465 - j 0.045
3	ΔP8+ j ΔQ8	-0.248 + j 0.0001	-0.245 + j 0.0000
4	ΔP9 + j ΔQ9	0.600 - j 0.465	0.595 - j 0.472
5	ΔP10 + j ΔQ10	0.9100 + j 0.765	0.908 + j 0.756
6	ΔP11 + j ΔQ11	0.5400 + j 0.0001	0.537 + j 0.0000
7	ΔP12 + j ΔQ12	0.2600 + j 0.6265	0.2700 + j 0.6105
8	ΔP13 + j ΔQ13	0.3300 + j 8485	0.331 + j 0.7999
9	ΔP14 + j ΔQ14	0.5398 – j 0.065	0.5399 – j 0.0700
10	ΔP15 + j ΔQ15	0.5569 – j 0.100	0.5600 – j 0.0998
11	ΔP16 + j ΔQ16	-0.2900 + j 0.4764	-0.2889 + j 0.4888
12	ΔP17 + j ΔQ17	0.3900 + j0.5060	0.3850 + j0.5108
13	ΔP18 + j ΔQ18	0.4788 – j 0.05200	0.4780 – j 0.0530
14	ΔP19 + j ΔQ19	0.9988 + j 0.2758	0.7887 + j 0.2699
15	ΔP20+ j ΔQ20	-0.2478 – j 0.0801	-0.2397 – j 0.0799
16	ΔP21 + j ΔQ21	-0.1995 + j 0.2614	-0.2015 + j 0.2588
17	ΔP22 + j ΔQ22	-0.1895 – j 0.0685	-0.1877 – j 0.0676
18	ΔP23 + j ΔQ23	0.1465 – j 0.0475	0.1476 – j 0.0468
19	ΔP24 + j ΔQ24	0.0285 – j 0.465	0.0286 – j 0.477
20	ΔP25 + j ΔQ25	-0.238 – j 0.0756	-0.235 – j 0.0787

VI. CONCLUSIONS

A new viewpoint for voltage stability improvement using reactive power control variables has been introducing by maximizing the minimum MVA distance to voltage collapse. The shortest distance to voltage collapse is a realistic proximity indicator, particularly when the system is heavily loaded. The direction of the load increase is uncertain due to the voltage dependency of the load. This paper's contribution is (i) Selection of new performance index (ii) Solving the formulated problem using SCA, which is capable of solving such a complex problem by exploring large implicit feasible space. The objective was to employ the Rao-1 algorithm to solve such a recently developed problem and simplest in implementation and mechanization. Results have been obtained by both the technique for two test systems and the results obtained are in close agreement. The further computational time required in the Rao-1 algorithm is less than that required in SCA. This justifies the utility of the Rao-1 algorithm for solving such complex optimization problems.

REFERENCES

[1] Dobson, and L.LU, "*New methods for computing the closest saddle-node bifurcation and worst-case load power margin for voltage collapse*" IEEE Trans. on the power system, vol.8, No.3, August 1993, pp 905-913

[2] Jin Lu, C.W. Liu, and J.S. Thorp, "*New methods for computing a saddle-node bifurcation point for voltage stability analysis*" IEEE Trans. on PS, Vol.10, No.2, May 1995, pp.978-989.

[3] LD. Arya and VS Pande, "*Determination of closest saddle-node bifurcation point using tangent vector"* IEE sponsored National conference on power engineering practices and energy management,2005, Patiala, India, pp.23-26

[4] Z. Yan, Y.Liu, F.Wu and Y.Ni, "*Method for direct calculation of quadratic turning points"* Proc. IEEE, GTD, Vol.151, No.1, January 2004,pp.83-89.

[5] LD.Arya, SC Choube, M.Shrivastava, DP Kothari, "*Particle swarm optimization for determining the shortest distance to voltage collapse*" Int.J. of Electrical power and Energy Systems, vol.29, No.10, 2007, pp.796-802

[6] SD. Rao, D.J. Tylavsky, Y.Feng, "*Estimating the saddle-node bifurcation point of static power systems using the holomorphic embedding method"* Int. J. of Elect. Power and Energy Systems, vol. 84, No.1, 2017, pp. 1-12

[7] A.R. Phadke, M.Fozdar, K.R. Niazi, "*A new technique for computation of closest saddle-node bifurcation point of power system using real coded genetic algorithm*" Int. J. of Electric Power and Energy Systems, vol.33, No.5, 2011,pp. 1203-1210

[8] R.A. Jabr, B.C. Pal, "*Computing closest saddle-node bifurcations in a radial system via conic programming*" Int. J. of Electric Power and Energy Systems, vol.31, No.6, 2009, pp. 243-248

[9] A. Tiranuchit and R.J. Thomas, "*A posturing strategy against voltage instabilities in electric power systems*," IEEE Trans. on PS, Vol.3, No.1, 1988, pp. 87-93.

[10] TJ overdye and CL De Marco, *"Voltage security enhancement using energy-based sensitivities,"* IEEE Trans. on PS, Vol.6, No.3,1991, pp.1196-1202.

[11] MM Begovic and A.G. Phadke, "*Control of voltage stability using sensitivity analysis*," IEEE Trans.PS, Vol.7, No.1, 1992, pp. 114-123.

[12] A.M. Chebbo, M.R. Irving, and MJH sterling, "*Reactive power dispatch incorporating voltage stability*," IEE Proc, GTD, Part-c, Vol.139, No.3, 1992, pp. 253-260.

[13] R.R. Zalpa and B.J. Cory, "*Reactive Reserve management*," IEE Proc. GTD, Part-c, Vol.142, No.1, 1995, pp. 17-23.

[14] Bansilal, D.Thukaram, and K. Parthsarthy, "*Optimal reactive power dispatch algorithm for voltage stability improvement*," Int. J. of Electrical Power and Energy Systems, Vol.18, No.7, 1996, pp.461-468.

[15] RS Tare, and P.R. Bijwe, *"Look-ahead approach to power system loadability enhancement,"* IEE Proc., GTD, Part-c, Vol.144, No.4, 1999, pp. 357-362.

[16] D. Thukaram and A. Lomi, "*Selection of static VAR compensation location and size for system voltage stability improvement*," Electric Power system Research, Vol.54, No.2, 2000, pp.139-150.

[17] LD. Arya, S.C. Choube, and D.P. Kothari, "*Reactive power optimization using static voltage stability index,"* Electric Power Components and systems, Vol.29, No.7, 2001, pp. 615-628.

[18] Ashish Kumar Upadhyay, Dr. S.C. Choube, "*Determination of closest saddle-node bifurcation point for power system using Sine Cosine and Rao-1 metaphor-less algorithm* ", International Journal of Electrical Engineering & Technology (IJEET), Vol.11, No.2, March-April 2020, pp. 62-68.

[19] LD. Arya, D.K. Sakravdia, and D.P. Kothari, "*Corrective rescheduling for static voltage stability control*," Int. J. of Electrical Power and energy systems, Vol.27, No.1, 2005, pp.3-12.

[20] Y. Malachi, and S.Senger,"*A genetic algorithm for corrective control of voltage and Reactive Power*," IEEE Trans. on PS, Vol.21, No.1, 2006, pp.295-300.

[21] M. Varadarajan, and KS. Swarup, "*Differential evolution algorithm for optimal reactive power dispatch*," Int. J. of Electrical Power and energy systems, Vol.30, No.8,2008, pp.435-441.

[22] LD. Arya, S.C. Choube, M.Shrivastava, and D.P. Kothari, *"Loadability margin enhancement using co-ordinated aggregation based particle swarm optimization(CAPSO)*", Int. J. of Electrical Power and Energy Systems', Vol.32, No.9,2010, pp. 975-984.

[23] OA Mousavi, M. Bozorg, and R. Cherkaoui, "Preventive, reactive power management for improving voltage stability margin," Electrical Power System Research, Vol.96, 2013, pp.36-46.

[24] L.S. Titare, P. Singh, L.D. Arya, S.C. Choube, *"Optimal reactive power rescheduling based on EPSDE algorithm to enhance static voltage stability,"* Int. J. of Electrical and Energy Systems, Vol.63, Dec.2014, pp. 588-599.

[25] ESE El-Araby, N. Yorino, *"Reactive Power reserve management tool for voltage stability enhancement*," IET, GTD, Vol.12, No.8, 2018, pp.1879-1888.

[26] S. Mirjalili, "*SCA: A sine cosine algorithm for solving optimization problems*," Knowledge-based systems, Vol.96, No.8, 2018, pp.120-133.

[27] D.H. Wolpert, W.G. Macready, "*No free lunch theorem for optimization*," IEEE Trans. Evol. Comp., Vol.1, 1997, pp.67-82.

[28] R.V. Rao, *"Rao algorithms: Three metaphor-less simple algorithms for solving optimization problems*" International Journal of Industrial Engineering Computations' vol.11, 2020, pp.107-130

[29] Y. Wallach, "*Calculations and programs for power systems network"* Prentice Hall, Inc. 1986(Book)

[30] P.R. Bijwe, D.P. Kothari, and LD. Arya "*Alleviation of line overloads and voltage violations by corrective rescheduling*" IEE Proc. Part-C, Vol.140, No.4, July 1993, pp. 249-255.