Self-Adaptive Multi-Population Jaya Algorithm based Reactive Power Reserve Optimization Considering Voltage Stability Margin Constraints

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Abstract— In this paper an innovative technique is proposed to achieve the optimum value of reactive power reserve accounting voltage stability margin constrains. Reactive power reserve and voltage stability are important issues for proper operation on the power system. This is achieved by suitable settings of reactive power control variables. The fitness function has been minimizes using Self-adaptive multi-population based Jaya Algorithm (SAMP - Jaya). The developed algorithm has been implemented on two IEEE test systems.

Keywords- *Self-adaptive multi-population based Jaya Algorithm, voltage stability margin, reactive power reserve, reactive power control variables*

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NOTATIONS

QG_p	Reactive power output of p[th] generator buses
QG_p^{max}, QG_p^{min}	Upper and lower limit on reactive power output of p[th] bus
QG_p^{max}	Average reactive power output
VSM	Voltage stability margin
VSM^{th}	Threshold value of Voltage stability margin
V_i^{max}, V_i^{min}	Upper and lower limits on load bus voltages
U_K	K[th] control variable
U_K^{min}, U_K^{max}	Lower and upper limits on control variable
NC	Number of total control variables
P_d^0	Current total load

I. INTRODUCTION

Modern power system is highly complex in nature. In this complex power system obtaining the desired voltage profile along with voltage stability margin in very important and is a matter of top priority. Since long proximity indicators have been used for voltage security enhancement. Tiranuchit et al. [1] applied minimum singular value of jacobian to maintain desired voltage stability margin (VSM) and voltage profile. Sensitivity analysis has been used by Begovic et al. [2] for improving voltage security. An algorithm for optimum reactive power dispatch employing LP and an optimal impedance solution on voltage stability index was developed by Chebbo et al. [3]. Ajjarapu et al. [4] developed an optimal planning strategy for reactive power against voltage instability employing repeated load flow runs up to voltage collapse point. Bansilal et al. [5] proposed optimal reactive power dispatch algorithm for voltage stability improvement. Kessel et al. [6] estimated the voltage stability of the power system. Pande et al. [7] used functional link network for reactive power management and voltage stability enhancement. Titare et al [8] developed an approach to mitigate probability of voltage collapse accounting parameter uncertainties using improved PSO algorithm. Fuzzy technique to develop a reactive power optimization algorithm for hybrid system was developed by Taghavi et al. [9]. Khazali et al. [10] applied harmony search algorithm for obtaining optimal performance of the system based on reactive power considerations. Genetic algorithm has been employed for voltage stability margin enhancement and reactive power dispatch by Devaraj et al. [11]. Mousavi et al. [12] developed a preventive strategy for reactive power management along with VSM improvement. Singh et al. [13] developed a multi objective VAR management algorithm using modified differential evolution algorithm. Titare et al. [14] used voltage dependent reactive power reserves modeling for voltage stability enhancement employing ensemble of mutation and crossover strategies and parameters in differential evolution (EPSDE). Fang et al. [15] developed a robust optimal reactive power reserves dispatch under stochastic environment of load injected at buses employing chance constraints relaxation – based method. Bhattacharya and Raj [16] used modal analysis and L-index for optimization of reactive power reserves based on differential evolution technique. Sun et al [17] presented a bi- objective reactive power reserves optimization algorithm to coordinate long and short term voltage stability considerations. Fang et al [18] developed an interval optimal reactive power reserve dispatch considering uncertainties in the load and load direction. Rojar et al. [19] presented an excellent review of various metaheuristic techniques used for optimal reactive reserves dispatch.

In this paper an innovative methodology based on Self-adaptive multi-population based Jaya Algorithm (SAMP - Jaya) for reactive power reserve optimization is proposed. The specific objectives are to limit reactive power generation on both side i.e. over excitation as well as under excitation, such that sufficient reactive power reserve is available on either side. It has been proposed to directly evaluate the VSM and it should have at least some threshold. The proposed methodology has been implemented on IEEE 14-bus and 30-bus standard test systems.

II. PROBLEM FORMULATION

The quadratic performance index is selected as fitness function as proposed by Purey et al. [20]

$$F=\sum_{p=1}^{NG}\left[\frac{QG_p-QG_p^{avg}}{QG_p^{\max}-QG_p^{\min}}\right]^2 \quad (1)$$

Now QG_p^{avg} is given as follows [20]:

$$QP_p^{avg}=0.5[QG_p^{\max}+QG_p^{\min}] \quad (2)$$

The objective function is minimized subject to following constrains [20]:

(i) $VSM \geq VSM^{th}$

(ii) $V_i^{\min} \leq V_i \leq V_i^{\max}$

(iii) $U_K^{\min} \leq U_K \leq U_K^{\max}$ K=1,2,3,4,….NC

(iv) All load bus voltages within limits at p_d^0 and also $(1+VSM_{Th}^{d})P_d^0$

III. SELF-ADAPTIVE MULTI-POPULATION BASED JAYA ALGORITHM (SAMP - JAYA): AN OVERVIEW:

The self-adaptive multi-population based Jaya algorithm for solving the constrained and unconstrained numerical and engineering optimization problem was proposed by Rao et al. [21]. It is based on the concept that the solution obtained for a given problem should move towards the best solution and avoid the worst solution. First, the initial population is generated having population size (NP) and number of design variables (D) is decided. Now divide the total population into m sub populations depending on quality of solution. Identify the best and worst solution in each and every sub population. Obtain the new value as follows:

$$Y_i'=Y_i+rand_1(Y_{best,i}-|Y_i|)-rand_2(Y_{worst,i}-|Y_i|) \quad (3)$$

Where

Y_i is previous value

$Y_{best,i}$ is best solution

$Y_{worst,i}$ is worst solution

$rand_1, rand_2$ are random numbers having range of [0,1]

Accept the better solution in each sub population. Merge the entire sub population together. Now check if previous best solution of entire population is better than the current best solution in the entire population. If yes, then m is decreased by 1, else m is increased by 1. The procedure is terminated if a maximum number of generations have been executed.

IV. RESULTS AND DISCUSSIONS:

In this paper, Self-adaptive multi-population based Jaya Algorithm (SAMP - Jaya) has been applied to obtain optimum reactive power reserve using reactive power control variables such as PV- bus voltages, OLTC and shunt compensations on IEEE 14-bus and 30-bus standard test systems.

4.1 Case-A: IEEE 14-Bus System [14]

Table-1 shows reactive power control variables (PV-bus voltages, shunt compensations and OLTCs) and all load bus voltages under base case condition. Table-2 shows the comparison of each algorithm to find the best optimal control variable settings with and without optimization using the proposed SAMP – Jaya optimization algorithm and the results has been compared with Jaya [20], TLBO [20], DE [20] and CAPSO [20] techniques. Table-3 shows the comparison of reactive reserves at different generator bus (bus nos. 1st, 2nd & 3rd) using SAMP - Jaya optimization algorithm. Table-4 shows the comparison of SAMP - Jaya with other techniques reported in literature based on arithmetic mean value, standard deviation, best value, worst value, frequency of convergence, standard error, length of confidence interval and confidence interval of fitness function. Fig. 1 shows a plot for the convergence of fitness function with respect to number of iteration for SAMP - Jaya technique. It is observed that SAMP - Jaya gives much better global optimal results than other optimization techniques reported in literature [20].

4.2 Case-B: IEEE 30-Bus System [22]

Table-5 shows reactive power control variables and all load bus voltages under base case condition. Table-6 shows the best optimal control variable settings with and without optimization. Table-7 shows the comparison of reactive reserves at different generator bus (bus nos. 1st, 2nd, 5th, 8th, 11th & 13th) using SAMP - Jaya technique. Table-8 shows the comparison of proposed SAMP – Jaya optimization algorithm with Jaya [20], TLBO [20], DE [20] and CAPSO [20] techniques based on arithmetic mean value, standard deviation, best value, worst value, frequency of convergence, standard error, length of confidence interval and confidence interval of objective function. Fig. 2 shows a plot for convergence of fitness function with respect to number of iteration for SAMP – Jaya. It is observed that SAMP - Jaya gives much better global optimal results than in comparison with Jaya [20], TLBO [20], DE [20] and CAPSO [20] techniques.

V. CONCLUSION

An innovative methodology has been presented for reactive power reserves. The objective is to maintain voltage profile and voltage stability margin by using SAMP – Jaya optimization algorithm. The developed algorithm performance is been analysed based on different criteria such as mean value, median value, mean deviation, variance, standard deviation, best value, worst value, frequency of convergence, standard error, length of confidence interval, confidence interval, class interval & proportionate frequencies of fitness function. The results obtained by the proposed SAMP – Jaya optimization algorithm has given better results than in comparison with the different methods shown in the literature.

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Table-1. Load flow solution for 14-bus test system under stressed condition. [20]
Total load (S_d)=3.6758pu, Static voltage stability limit=4.6858pu

S. No.	Control variables	Control variables magnitude (pu)	Load bus voltages	Load bus voltage magnitude (pu)
1	V_1	1.0812	V_4	0.8248
2	V_2	1.0485	V_5	0.8618
3	V_3	1.0739	V_6	0.9522
4	BSH4	0.0015	V_7	0.8618
5	BSH12	0.0057	V_8	0.9696
6	TAP_4	1.0657	V_9	0.8291
7	TAP_{10}	1.0673	V10	0.8126
			V11	0.8114
			V12	0.7970
			V13	0.7917
			V14	0.7897

Table-2 Reactive power control variables using SAMP - Jaya algorithms for IEEE 14-bus system (S_{dt})=3.6758pu.

S. No.	Reactive control variable	Base case [20]	SAMP – JAYA	JAYA [20]	TLBO [20]	DE [20]	CAPSO [20]
1	Tap_4	1.0657	0.9315	0.9317	0.9320	0.9326	0.9284
2	Tap_{10}	1.0673	0.9268	0.9266	0.9254	0.9258	0.9217
3	Qc_4	0.0015	0.0512	0.0508	0.0370	0.0447	0.0409
4	Qc12	0.0057	0.0478	0.0473	0.0483	0.0357	0.0318
5	V_1	1.0812	1.0790	1.0788	1.0798	1.0797	1.0776
6	V_2	1.0485	1.0428	1.0428	1.0445	1.0457	1.0447
7	V_3	1.0739	1.0695	1.0693	1.0704	1.0716	1.0693

Table-3 Reactive power reserve at generator buses and fitness function using SAMP – Jaya technique for IEEE 14-bus system (S_{dt})=3.6758pu.

S. No.	Methodology	Reactive power Reserve (pu)			Total reactive power reserve (pu)	Fitness function
		Qgk(res)1	Qgk(res)1	Qgk(res)1		
1	SAMP – Jaya	2.6988	0.8185	0.014	3.5318	0.2082
2	JAYA [20]	2.6991	0.8181	0.014	3.5312	0.2088
3	TLBO [20]	2.7114	0.7916	0.0152	3.5183	0.221
4	DE [20]	2.737	0.7646	0.012	3.5136	0.2326
5	CAPSO [20]	2.7628	0.707	0.0319	3.5016	0.2489
6	Base Case [20]	2.5295	0.6628	0.0398	3.2321	0.3381

Table -4 statistical inferences based on proposed SAMP – Jaya techniques for IEEE 14-bus system.

Optimization methods	SAMP – Jaya	JAYA [20]	TLBO [20]	DE [20]	CAPSO [20]
Arithmetic mean value of OF	0.2102	0.2132	0.2275	0.2430	0.2669
Median value of OF	0.2078	0.2115	0.2255	0.2421	0.2653
Mean deviation of OF	2.00E-05	2.00E-05	4.00E-05	1.50E-05	1.50E-05
Variance of OF	2.38E-05	2.47E-05	5.05E-05	8.03E-05	1.77E-04
Standard deviation of OF	0.0045	0.0049	0.0071	0.0089	0.0133
Best value of OF	0.2056	0.2088	0.2210	0.2326	0.2489
Worst value of OF	0.2245	0.2273	0.2480	0.2662	0.2951
Frequency of convergence	14	13	11	10	10
Confidence level	0.95	0.95	0.95	0.95	0.95
Determined value for the Engg. Application	2.0452	2.0452	2.0452	2.0452	2.0452
Standard error of the mean OF	0.0020	0.0023	0.0032	0.0041	0.0061
Confidence interval of the OF	$0.2101 \le \mu \le$	$0.2109 \le \mu \le$	$0.2243 \le \mu \le$	$0.2389 \le \mu$	$0.2608 \le \mu \le 0.2730$
Length of confidence interval of the OF	0.0085	0.0094	0.0131	0.0167	0.0249

OF-objective function

Table-5. Load flow solution for 30-bus test system under stressed condition. [20]

Total load (S_d)=4.6759pu, Static voltage stability limit=6.2231pu

S. No.	Control variables	Control variables magnitude (pu)	Load bus voltages	Load bus voltage magnitude (pu)
1	V_1	1.0842	V_3	1.0231
2	V_2	1.0476	V_4	1.0105
3	V_5	1.0112	V_6	1.0052
4	V_8	1.0262	V_7	0.9902
5	V11	1.0845	V_9	0.9400
6	V13	1.0928	V10	0.8948
7	BSH10	0.0106	V12	0.9516
8	BSH24	0.0040	V14	0.9135
9	TAP_{11}	1.0686	V15	0.8996
10	TAP_{12}	1.0693	V16	0.9110
11	TAP_{15}	1.0563	V17	0.8873
12	TAP_{36}	0.9215	V18	0.8686
			V19	0.8578
			V20	0.8651
			V21	0.8674
			V22	0.8693
			V23	0.8703
			V24	0.8511
			V25	0.8593
			V26	0.8379
			V27	0.8749
			V28	0.9981
			V29	0.8311
			V30	0.8084

Table-6 Reactive power control variables using SAMP - Jaya algorithms for IEEE 30-bus system (S_{dt})=4.6759pu.

S. No.	Control variable	Base case [20]	SAMP – JAYA	JAYA [20]	TLBO [20]	DE [20]	CAPSO [20]
1	Tap_{11}	1.0686	0.9246	0.9247	0.9232	0.9232	0.9253
2	Tap_{12}	1.0693	1.0260	1.0263	1.0238	1.0238	1.0275
3	Tap_{15}	1.0563	0.9305	0.9314	0.9327	0.9349	0.9266
4	Tap_{36}	0.9215	1.0743	1.0759	1.0839	1.0692	1.0791
5	Qc10	0.0106	0.1753	0.1750	0.1756	0.1543	0.1556
6	Qc24	0.0040	0.0378	0.0380	0.0372	0.0356	0.0375
7	V1	1.0842	1.0821	1.0820	1.0768	1.0833	1.0710
8	V2	1.0476	1.0315	1.0317	1.0266	1.0352	1.0194
9	V5	1.0112	1.0098	1.0097	1.0011	1.0111	0.9980
10	V8	1.0262	1.0141	1.0141	1.0140	1.0261	1.0234
11	V11	1.0845	1.0839	1.0838	1.0833	1.0846	1.0768
12	V13	1.0928	1.0912	1.0912	1.0807	1.0921	1.0875

Table-7 Reactive power reserve at generator buses and fitness function using SAMP – Jaya technique for IEEE 30-bus system (S_{dt})=4.6759pu.

Methodology	Reactive power Reserve (pu)						Total reactive power reserve (pu)	Fitness function
	Qgk(res)1	Qgk(res)2	Qgk (res) 5	Qgk (res) 8	Qgk (res) 11	Qgk (res) 13		
SAMP – Jaya	0.9753	0.2228	0.0325	0.3028	0.0545	0.0301	1.6278	1.4638
JAYA [20]	0.9759	0.2228	0.0337	0.3076	0.0547	0.0313	1.6260	1.4692
TLBO [20]	0.9908	0.2099	0.0804	0.2292	0.0441	0.0589	1.6133	1.5119
DE [20]	1.0301	0.2027	0.0791	0.1897	0.0684	0.038	1.608	1.5409
CAPSO [20]	0.9931	0.3677	0.0855	0.0303	0.0716	0.0397	1.5879	1.5897
Base Case [20]	1.2278	0.2272	0.0729	0.0965	-0.0749	-0.2348	1.3147	2.2925

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Table -8 statistical inferences based on proposed SAMP – Jaya techniques for IEEE 30-bus system.

Optimization methods	SAMP – Jaya	JAYA [20]	TLBO [20]	DE [20]	CAPSO [20]
Arithmetic mean value of OF	1.4805	1.4814	1.5348	1.5781	1.6461
Median value of OF	1.4768	1.4787	1.5298	1.5751	1.6476
Mean deviation of OF	2.00E-05	2.00E-05	4.50E-05	5.00E-05	-5.00E-05
Variance of OF	1.40E-04	1.40E-04	4.02E-04	7.64E-04	1.38E-03
Standard deviation of OF	0.0115	0.0118	0.0200	0.0276	0.0371
Best value of OF	1.4678	1.4692	1.5119	1.5409	1.5897
Worst value of OF	1.5105	1.5142	1.5849	1.6479	1.7177
Frequency of convergence	13	12	11	10	9
Confidence level	0.95	0.95	0.95	0.95	0.95
Determined value for the Engg. Application	2.0452	2.0452	2.0452	2.0452	2.0452
Standard error of the mean OF	0.0041	0.0054	0.0091	0.0126	0.0169
Confidence interval of the OF	1.4758 ≤	1.4760 ≤	1.5257 ≤	1.5655 ≤	1.6292 ≤
Length of confidence interval of the OF	0.0210	0.0221	0.0372	0.0515	0.0691

OF-objective function

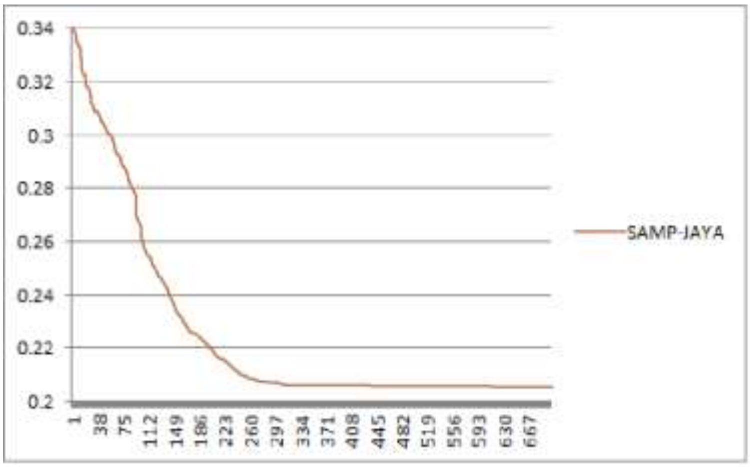

Fig. 1. Plot of convergence of fitness function with respect to number of iteration using SAMP – Jaya techniques for IEEE 14-bus system.

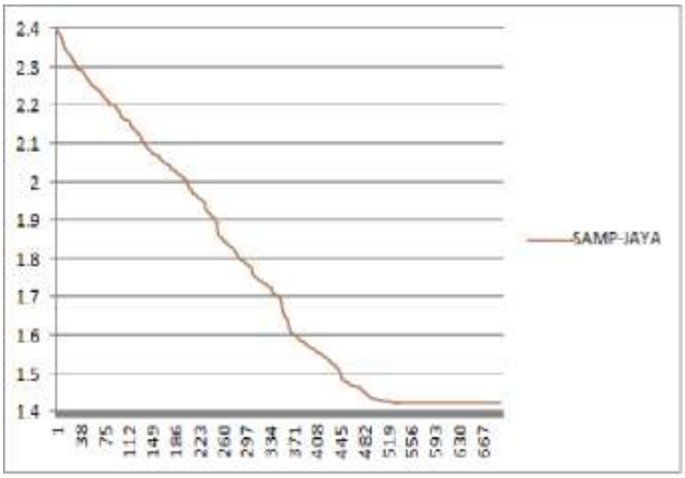

Fig. 2. Plot of convergence of fitness function with respect to number of iteration using SAMP – Jaya techniques for IEEE 30-bus system.