JAYA: A SIMPLE AND NEW ALGORITHM FOR OPTIMIZATION OF CONTROL VARIABLES OF VOLTAGE STABILTY ENHANCEMENT BASED ON PROXIMITY AND MECHANISM ANALYSIS

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ABSTRACT

The Gershgorin's circular disk theorem is proposed in this paper for the analysis of voltage stability. According to this theorem, the diagonal entries of square matrix & sum of the absolute values of the off-diagonal entries of corresponding rows are considered as center of circular disks & a radius of circular disks respectively. It has been proved that the circular disks contain at least one eigenvalue. This theorem is implemented on IEEE-14, 30 & 57 bus test system. The outcomes have proved the better effectiveness of proposed algorithm compared to previous voltage stability assessment technique. The control variables based on voltage stability enhancements are optimized with a recently developed "JAYA" algorithm. The idea of the algorithm is that the resolution obtained for a given problem should move towards the best solution and that avoids the worst solution. It requires only one phase per iteration as TLBO requires two phases per iteration. The proposed algorithm is implemented on IEEE-14 bus test system and the performance is compared with It requires only other familiar TLBO algorithm. In adding together to solving for 14-bus test system, the algorithm is also premeditated on IEEE- 30 bus test system and the performance of "JAYA" algorithm is found better and very simpler.

Keyword: *JAYA, TLBO, Gershgorin's circle theorem, Voltage stability, Eigenvalue*

1. INTRODUCTION

The voltage stability refers to the ability that all the bus voltages are sustained in an acceptable range by power system when it runs in normal or disturbance circumstances. Voltage instability stems from the unbalance between power requirements of load and supply of the system.[1]. Voltage instability is a slow process, means the simulation would frequently last a few minutes, sometimes even tens of minutes.

With increase in pollution levels because of use of fossil fired power plants, power system optimization becomes the need of the hour. It is necessary to control various power system parameters like voltage, power factor, frequency, reactive and active power and harmonic distortion. Various parameters in the power system like voltage, frequency, active and reactive power, harmonic distortion. [2] With the advent of generator deferment, it has become possible to analysis of multiple power system parameters.

Direct applications of conventional methods for power system eigen value problems is computationally not feasible or [3] . The selective model analysis approach uses a reduced order model to compute the desired critical eigen values relevant to the selected modes [4].

PSO algorithm introduced by Kennedy and Eberhart (1995) was applied to determine shortest distance to voltage collapse. (L.D.Arya and S.C.choube, 2007). The developed technique was compared with one of the existing method based on modal analysis whose basis is that left eigen vector corresponding to minimum eigen value is normal to hyper surface in load space for shortest distance to voltage collapse. [6]

Recently, a new population-based algorithm known as Teaching-Learning-Based Optimization (TLBO) was proposed by Rao et al.(2011) for mechanical design problem. This is an algorithm-specific parameter-fewer algorithm, as reported by Rao and Patel

(2013) in the sense that it does not require to supply the parameters which are algorithm-specific such as weight, cognitive and social parameters used in PSO.The implementation of TLBO algorithm compared to PSO algorithm is straightforward, high accuracy but requires more time of computation. It is new and latest optimization procedure for solving controlled and unimpeded problems. The results obtained in the previous iterations were updated by grouping them together and also by sharing their individual knowledge towards the optimal solution of defined problems. The individuals (Control Variables) are also rationalized by means of Mean and Best value of entity group. [7]

L.D. Arya & at. All presents an competent method for voltage stability evaluation using a newly developed line voltage stability index that becomes half at a collapse point[8] . L.D. Arya & at. All also developed new algorithm to compute shortest distance to voltage collapse and optimized by Particle Swarm Optimization method. The results shows that the proposed PSO technique gives better and optimal rather than obtained from eigen vector approach. [9]

K. Morision & at. All discusses the key factors that make load modelling for voltage stability study and its challenge. The study also gives the solution in close proximity into key issues when performing practical aspects [10].

Y.Kataoka & at..all proposed voltage stability index VMPI(Voltage Margin Proximity Index)taking into consideration as lower voltage limits. The proposed method was implemented on the IEEJ West 30 machine 115 bus systems. Voltage stability indices based on effective control have been studied. Determination of voltage stability margins to a critical point is the conventional voltage stability indices [11].

A. S.Yome said that voltage unbalance is taken as one of the most problems to power system networks. Voltage instability is influenced by generation, load pattern. Voltage stability enhancement can be achieved by FACTS devices and shunt & series compensation technique and also tap settings of transformer. Realistic load direction based on a practical load variation in static voltage stability was studied [12]

P. Uronen & at all (2007) has developed the assessment technique of stability for complicated linear system by Gerschgorin circular disk theorem . It is basically based on eigenvalues of the system matrix and concluded that this method is informative about the state variables with different dimensions.[13]

S.I.Ahson & at all (March 2007) presented the design of an integrated control scheme of Hydro-electric governing system of turbo-generator. The design of controllers was developed based on liniarized mathematical Gershgorin theorem. The performance of turbo-generator and whole power system with respect to transient stability, recovery of voltage before fault, damping of control system was found to be considerable improvements.[14]

Masashi TSUJI & at all described the method of controlling the regulation of power level in the different cores of the nuclear reactor. The approximated decoupling controller was developed by the graphical study and digital simulations based on Gerschgorin band analysis. The design of precompensator were easy and simple structure. The developed controller is generalized and applicable to wide range of frequency. [15]

Solution of optimal reactive power flow dispatch problem was achieved by optimizing the control variables like tap setting of tap changing transformer, bus voltages at generator, setting of shunt VAR reactors. Jirawadee Polprasert & at all proposed pseudo-gradient search-particle swarm optimization (IPG-PSO) algorithm to minimize the voltage stability index, active power loss and deviations in voltage. The proposed algorithm was implemented on IEEE-30 bus and IEEE-118 bus test system and proved that the solution was obtained in very short time and viable for online implementation.[22]

Oluwaseyi & at all studied the important role of ventilation, air conditioning and heating in electricity consumption and its load profile with respect to multi zone building. The main objective of the studied was to reduce the electricity consumption without sacrificing the advantages of multi-zone building. The design of cooling coil & physical thermal model was developed to reduce the thermal losses and electricity consumptions. The electricity supply to the multi-zone building & the speed of the air conditioning unit , ventilating fan etc was developed based on the fundamental thermal law. The minimization of objective function was implemented by JAYA algorithm.[16]

R. Venkata Rao & at all in Mar 2017 was developed the article of range of most favorable parameters of welding process to accomplish the high quality of welding and its productivity. The objective of the studied was to improve the performance of different types of welding process like friction stir welding, electron beam welding, submerged arc welding etc. The control variable are optimized by new Quasi-oppositional based -JAYA algorithm and the results were compared with the teaching learning based optimization (TLBO) and genetic algorithm (GA).[17]

Sahand Ghavidel & at all developed a hybrid-JAYA algorithm to minimize the reliability allocation problems of non-linear mixed integer. Standard real parameter test was carried out on the multi-model functions with dimensions 30-100 & then tested on various types of non-linear mixed integers. The results were obtained with hybrid JAYA algorithm proved its reliability , better optimization with respect to basic JAYA.[18]

Ravipudi Venkata Rao & at all have developed the JAYA algorithm for the design optimization of plate-fin heat exchangers. It is very simple algorithm and does not requires any other algorithm based specific parameters. The previous design of plate fin heat exchangers was very tedious , time consuming and did not give accurate results. The design was upgraded by optimizing its control variables like heat exchange area, total annual cost, pressure drop of the system to minimal and maximized the performance of the system.[19]

Classic unit commitments have the vital role for the allocation of generating units to obtain the minimum generation cost. Power system generation planning is more complex with the addition of distributed energy sources to the modern power system. The improved TLBO algorithm was implemented on IEEE-standard 10 unit system by Manisha Govardhan & at all to minimize the total cost of the combined distributed generationg system. Wind energy generator, emergency demand response and pug in electric vehicles were selected as combined distributed generation system. [23]

In Radial distribution network the optimal allocation of distributed generators has been played a key role in the radial distribution networks. Teaching Learing Based Optimaization algorithm was developed by Neerak Kanwar & at all for the optimal allocation of DGs in radial distribution systems. Optimal allocation of DGs was achieved by minimizing the annul energy loss, maintain the voltage profiles. The proposed method was implemented on the IEEE- 39 bus , IEEE-69 bus distribution systems. The results obtained by proposed algorithm were proved its effectiveness and assured about quality solution. [21]

The Gershgorin's theorem is available to mark out the approximate eigen values as voltage stability indices. The results of the Gershgorin's theorem have proved the better effectiveness and easy method to determine voltage stability indices compared to the older method like VCPI. It is useful in solving matrix equations of the form $Ax = b$ where, $A = J_R = [J_4 - J_3 J_1^{-1} J_2]$ (Reduced Jacobean Matrix) , $x = \Delta v$ (Change in voltage correction) and $b = \Delta Q$ (Change in Reactive power) . In adding together to solving for 6-bus test system, the algorithm is also studied on IEEE- 30 & IEEE-57 bus test system and the performance of this algorithm is found better compared to the older method.

With the success of TLBO method, one another new algorithm of optimization "JAYA" is proposed to optimize the control parameters of voltage stability enhancement. It is free from algorithm-specific parameter. It has only one phase per iteration as TLBO requires two phase per iteration (Teacher & Learner Phase). The proposed algorithm is very simple to apply. The outcomes of JAYA have proved the better effectiveness and easy way of finding the solution of optimization of proposed problem compared to TLBO. In the following sections, the proposed algorithms are explained.

2. Proposed Gershgorin's Circular Theorem :

2.1 Statement: Let P be an n × n matrix. The elements of matrix P is a_{ij} for $i \in \{1,\ldots n\}$. Let

$$K_i = \sum_{j \neq i} |a_{ij}| \quad (1)$$

is the sum of the absolute values of the non-diagonal elements in the *i* –th row. Let $C(a_{ii}, K_i)$ be the closed circular disk centered at a_{ii} with radius K_i. Such a disk is called Gershgorin disc.

2.2 Theorem: All the eigenvalue of matrix A lies inside at least one of the Gershgorin discs $C(a_{ii}, K_i)$.

Let λ be an eigenvalue of matrix P . x be an eigenvector corresponding to the eigenvalue λ such that one component of x_i equal to one. The relation between eigenvalue and eigenvector is as follows.

$$P_x = \lambda x, (P - \lambda I)X = 0$$
$$\sum_j a_{ij} x_j = \lambda x_i = \lambda \quad (2)$$

Considering $x_i = 1$, and rearranging the terms,

$$\sum_{j \neq i} a_{i,j} x_j + a_{i,i} = \lambda$$

Now applying the triangle inequality, the following relation is obtained.

$$|\lambda - a_{ii}| = \left|\sum_{j \neq i} a_{i,j} x_j\right| \leq \sum_{j \neq i} |a_{i,j}||x_j| \leq \sum_{j \neq i} |a_{ii}| = K_i \quad (3)$$

From Eq.(3) , it is to be proved that the eigenvalues of matrix P must lie within the Circular disks K_i corresponding to the columns of matrix P. The explanation of this proposed theorem is, if the off-diagonal elements of the square matrix over the complex numbers have small norms, then the diagonal elements are to be considered as good as nearest to the eigenvalues of the matrix.

To demonstrate the Gershgorin circle theorem, let us assume the matrix P as follows.

$$P = \begin{bmatrix} 4 & 2 & 0 \\ 0 & -1 & 1 \\ 1 & 2 & 5 \end{bmatrix}$$

According to this theorem, the diagonal elements of matrix are considered as center of circular disks. The sum of off-diagonal elements of corresponding rows or diagonal elements is considered as radius of circular disks.
So, the matrix P has three circular disks : $C_1(4,2)$, C_2 (-1,1) & $C_3(5,3)$.
The eigenvalues of matrix P are : 5.5106, 3.7482, -1.2588

Fig.1 shows the plot of Gershgorin's circular disks with reference to the above explained example.The first (C_1) and third (C_3) circular disks overlap each other and the second circular disk C_2 is disjoint from the other two circular disks C_1 and C_3. The eigenvalues 5.5106 and 3.7482 are lies within the spectrum of circular disks C_1 and C_3. The eigenvalue -1.2588 is within the circular disk C_2. The union of circular disks C_1 and C_3 contains two eigen values and the disjoint circular disk C_2 contains only one eigenvalue. [11]

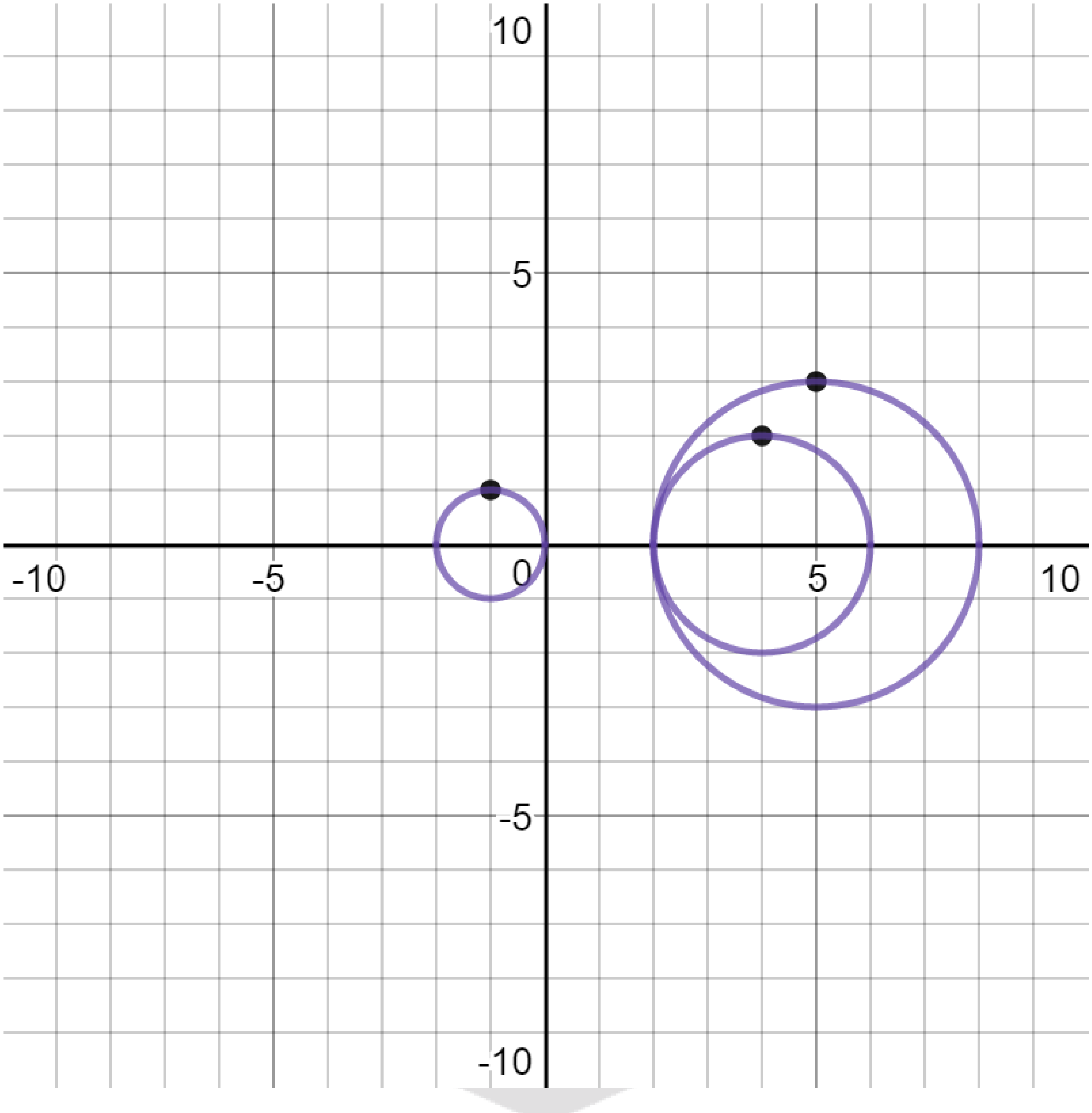

Fig.1 Gerschgorin Circular Disks

2.3 Proposed JAYA Algorithm:

Let the objective function $f(x)=\sum_{j=1}^{k} x_j^{\ 2}$ (3) to be maximized or minimized. At any iteration i , consider number of control variables (j=1,2…k) and size of population is equal to two and five. Best solution among the all the candidates is considered as $f(x)_{best}$ and worst solution among all the candidates is considered as $f(x)_{worst}$. If X_j is the value of j[th] variable for the k[th] candidate then the solution for updated values of control variables according to JAYA algorithm is obtained by following formula.

$$x_i^{(k+1)} = x_i^{\ k} + rand_{1i}[x_i(best)^{(i)} - \left|x_i^{\ k}\right| - rand_{2i}[x_{worst}^{\ (i)} - \left|x_i^{\ k}\right|] \quad (4)$$

If the solution of the objective function correspond to updated control variables (with respect to equation no 4) is better than previous one , accept it otherwise keep the previous solution as final. Where $x_i^{\ (k+1)}$ the updated value of control variable is, $x_i^{(k)}$ is the previous value of control variable. The term $rand1_i[x_i(best)^{(i)} - \left|x_i^{(k)}\right|$ indicates the tendency of the objective function towards the best solution and in equation (4) and the term $rand2_i[x_{worst}^{\ (i)} - \left|x_i^{(k)}\right|$ indicates the tendency of function towards the worst value of the objective function.

Fig. 2 shows the flowchart for the proposed “JAYA” algorithm. It always tries to give better or closer solution of the problems and avoids the worst solution. It has always propensity to do your best victorious solution of constrained and un-constrained problems and hence it is named as “JAYA”. “JAYA” is the Sanskrit word meaning as Victory. The proposed algorithm is explained by considering the constrained function known as Sphere in the next paragraph.

The working of JAYA algorithm is explained by means of considering the Sphere constrained benchmark function. The objective function is to determine the value of control variable such that it maximizes the solution of defined function in equation no (3). Let assume the objective function and its constrained limits for x_i as follows.

Select Population size, Generate control variables (PV bus voltages and Taps of OLTC) within constraints and decide no of iterations and execution condition

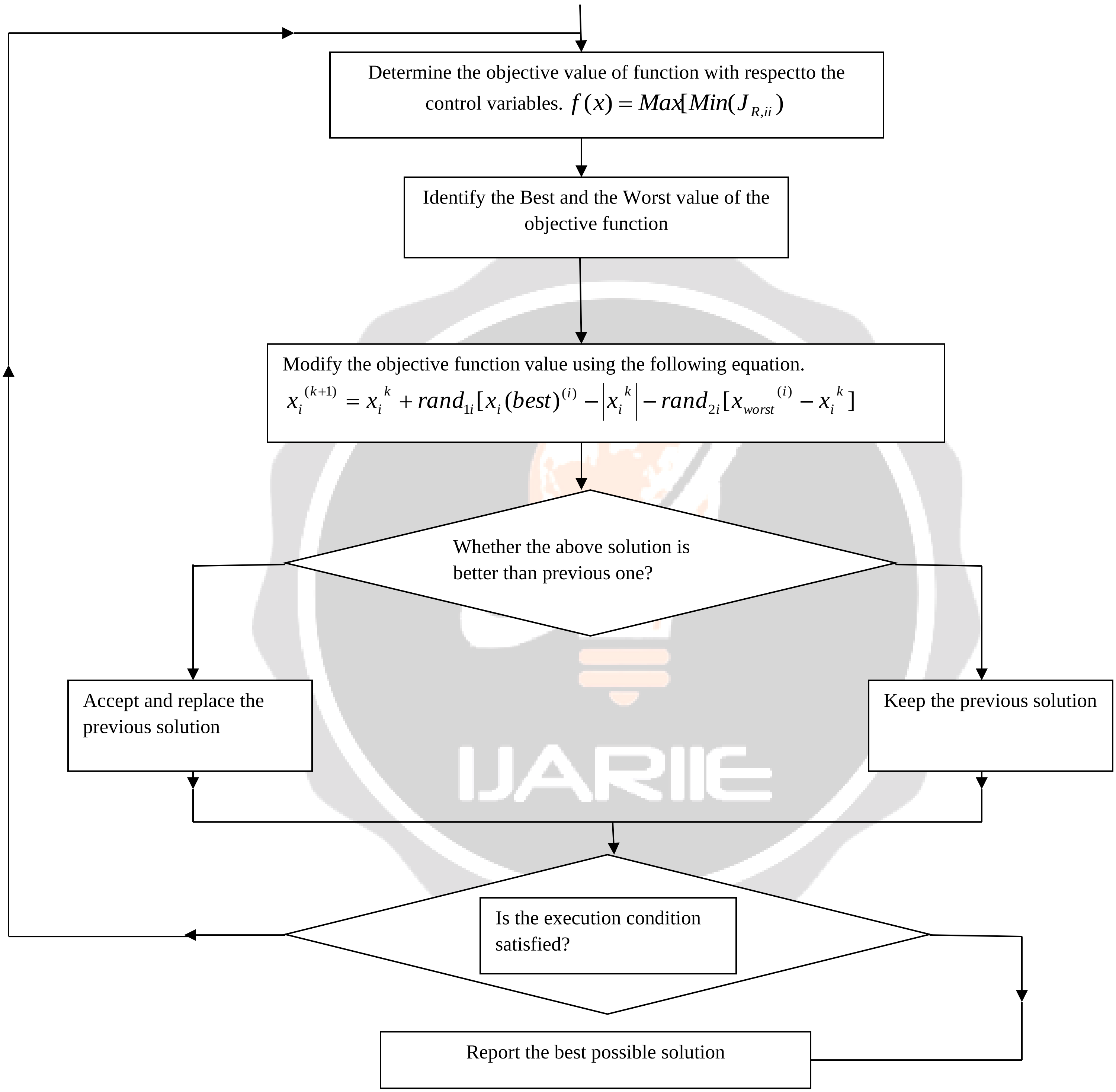

Fig -2: Flowchart of Proposed JAYA Algorithm

$$\max\ f(x)=\sum_{i=1}^{k} x_i^{\ 2} \text{ And constrained limits as } -50 \le x_j \le 50 \quad (5)$$

Let us assume population size of 5 candidates and 2 control variable. Maximum value to this function is 5000 correspond to defined 2 control variables. The value of control variables to which it gives maximum value of objective function is as (50, 50), (-50, 50),(50, -50) and (-50,-50). The initial value of control variable is randomly generated within its pre-defined constrained limits for 5 candidates and objective function value corresponding to individual candidates is shown in Table 1. The aim of problem is to determine the maximum value of objective function, so the maximum & the minimum value of objective function is considered as best & worst solution respectively. From Table 1 the best solution is corresponding to 2[nd] candidate and the worst solution is corresponding to 4[th] candidate. The random numbers are generated between 0 and 1. Assuming $rand_1$=0.36 & $rand_2$=0.72 for control variable x_1 , and

$rand_1$=0.9 & $rand_2$=0.45 for control variable x_2 .

The updated value of control variables for x_1 and x_2 are determined using the Eq.(4) and are placed in Table 2. Suppose for the 3[rd] candidate, the updated values of x_1 and x_2 are determined as shown below, during the 1[st] iteration.

$$x_i^{(k+1)} = x_i^{\ k} + rand_{1i}[x_i(best)^{(i)} - \left|x_i^{\ k}\right| - rand_{2i}[x_{worst}^{\ (i)} - \left|x_i^{\ k}\right|]$$

$$x_{1},_{3}^{(1)} = 18 + 0.36(-45-18) - 0.72(29-18)$$

$$x_{1},_{3}^{(1)} = -12.6$$

Similarly the updated values of x_2 is calculated as follows.

$$x_i^{(k+1)} = x_i^{\ k} + rand_{1i}[x_i(best)^{(i)} - \left|x_i^{\ k}\right| - rand_{2i}[x_{worst}^{\ (i)} - \left|x_i^{\ k}\right|]$$

$$x_{2},_{3}^{(1)} = 36 + 0.9(10-36) - 0.45(-17-36)$$

$$x_{2},_{3}^{(1)} = 36.45$$

Similarly, the new values of control variables x_1 and x_2 for the other candidates are calculated. Table 2 shows the updated values of control variables and corresponds its objective function value. The value of objective function $f(x)$ of Table 1 and Table 2 are compared and the best values of $f(x)$ are considered and placed in Table 3. The control variable values and function value as shown in Table 3 shows the end of iteration number 1.

From Table 3, it can be seen that the best solution is corresponding to the candidate 1[st] and worst solution is corresponding to 4[th] candidate. For the iteration number 2, assuming the random numbers for x_1 as 0.58 and 0.38 and similarly for x_2 as 0.83 & 0.67. The new values of control variables of all the candidates and the corresponding objective function values are shown in Table 4. The objective function values of Table 3 and Table 4 are compared and the best values of objective function are placed in Table 5. This ends the second iteration of JAYA algorithm.

The best and worst solution of objective function is corresponding to 1[st] candidate & 4[th] Candidate. It can be observed that value of objective function is increased from 2125 to 5000 in just two iterations. The known value of defined objective function is 5000. For this constrained problem, it can be seen that the maximum value is obtained for the 1[st] candidate in just two iterations. Similarly it can be noted that the objective function value is increased towards the solution for other candidates also. If we increase the number of iteration, the objective function values moves towards the goal speedily.

With the same method, the minimum value of objective function can also be obtained for the constrained and unconstrained problems. It concludes that the JAYA method is useful for determination of best solution of constrained and unconstrained type problems. In the constrained type problems, if the value of control variable violates, it sets to minimum or maximum limit.

Table 1: Initial value of Control Variable and Objective Function

Candidate	Control Variable x_1	Control Variable x_2	Objective function Value $f(x)$	Remarks
1	-35	20	1625	
2	-45	10	2125	Best
3	18	36	1620	
4	29	-17	1130	Worst
5	36	-27	2015	

Table 2 : Updated Value of control variable and objective function

Candidate	Control Variable x_1	Control Variable x_2	Objective function Value $f(x)$	Remarks
1	-84.68 Replaced by -50	27.65	3264.52	
2	-98.28 Replaced by -50	22.15	2990.6	Best
3	-12.6	36.45	1487.4	
4	2.36	7.3	58.85	Worst
5	11.88	1.8	144.37	

Table 3: Updated value of control variable and objective function by comparing Table 1 & Table 2 after iteration 1

Candidate	Control Variable x_1	Control Variable x_2	Objective function Value $f(x)$	Remarks
1	-50	27.65	3264.52	Best
2	-50	22.15	2990.6	
3	18	36	1620	
4	29	-17	1130	Worst
5	36	-27	2025	

Table 4: New values of control variables and objective function during second iteration

Candidate	Control Variable x_1	Control Variable x_2	Objective function Value $f(x)$	Remarks
1	-80.02 replaced by -50	57.56 replaced by 50	5000	
2	-80.02 replaced by -50	52.94 replaced by 50	5000	
3	-25.62	50	3156.4	
4	-16.82	20.05	684.91	
5	-11.22	11.65	261.61	

Table 5 : Updated value of control variable and objective function by comparing Table 1 & Table 2 after iteration 1

Candidate	Control Variable x_1	Control Variable x_2	Objective function Value $f(x)$	Remarks
1	-50	50	5000	Best
2	-50	50	5000	Best
3	-25.62	50	3156.4	
4	29	-17	1130	Worst
5	36	-27	2025	

3. IMPLEMENTATION OF "JAYA" ALGORITHM FOR VOLTAGE STABILTY Stability ENHANCEMENT

3.1 Steps for Algorithm

This portion describes a new approach of JAYA method to determine the best solution of voltage stability indices and its enhancement for IEEE-14 & IEEE-30 bus test system. The algorithm is explained in following step.

Step 1: Obtain Load flow solution at base loading condition, where VSM is inadequate.

Step:2 Generate population of suitable size (Control Variables) or individuals as unit vectors considering limits of constraints as follows.

$$V_p \le V_p \le V_p$$
$$t_p \le t_p \le t_p$$
$$0.95 \le V_p \le 1.15$$
$$0.95 \le t_p \le 1.15 \quad (6)$$

Where V_p = Voltage at Generator bus, The elements of each individuals of this group are generated by generating random digits between range say [0.95 1.15] and t_p = Tap Setting of Transformer. The elements of each individuals of Tap Setting Transformer group are generated by generating random digits between the range say [0.95 1.15]

Step 3: Obtain reduced Jacobean Matrix as per following equation number (5) & also considering control variables within the constrained limit mentioned as per above equation No (4). Obtain minimum diagonal element from Reduced Jacobean Matrix.

$$\begin{pmatrix} J_1 & J_2 \\ J_3 & J_4 \end{pmatrix}\begin{pmatrix} \Delta\delta \\ \Delta V \end{pmatrix} = \begin{pmatrix} \Delta P = 0 \\ \Delta Q \end{pmatrix} \quad (7)$$

$$J_1\Delta\delta + J_2\Delta V = 0$$
$$\Delta\delta = -J_1^{-1}J_2\Delta V$$
$$J_3\Delta\delta + J_4\Delta V = \Delta Q$$
$$[-J_3J_1^{-1}J_2 + J_4]\Delta V = \Delta Q \quad (8)$$
$$[J_R = [J_4 - J_3J_1^{-1}J_2]$$
$$[J_R][\Delta V] = [\Delta Q]$$

Where J_R is the reduced Jacobean matrix of N-R based load flow.

Step 4: Maximize the objective function Max {Min of Reduced Jii} --------(9)Where Jii is the diagonal element of Reduced Jacobean.Equation (9) is to be maximized subject to constraints mentioned in the Eq.(6). The term J_{ii} indicate the diagonal elements of Reduced Jacobean Matrix.

Step 5: Select the X_{best} & X_{worst} solution among all the individuals.

Step 6: Each individual in this phase is updated towards the maximum value using relation (4). if solution violating the bounds ,should be set to limiting values.
Step 7: Modify the solution till convergence is obtained.

4. SIMULATIONS , RESULTS AND ANALYSIS

4.1 Results of Gershgorin's Circular Theorem for Standard Test System

[A] IEEE-6 bus test system:

Table 5 (a): Results for Plotting Circular discs for 6-bus test system with different Load

Load=1.000			Load=1.050			Load=1.200		
Center	Y	Radius	Center	Y	Radius	Center	Y	Radius
0.7951	0	2.3980	0.8105	0	2.5655	0.8850	0	3.4250
0.5970	0	1.4044	0.6293	0	1.5252	0.7984	0	2.1625
0.4156	0	1.2874	0.4408	0	0 .3974	0.5746	0	1.9795
0.6853	0	1.5970	0.7022	0	1.7112	0.7839	0	2.2988
0.3951	0	1.2374	0.4071	0	1.3216	0.4645	0	1.7577
0.4229	0	0.8023	0.4381	0	0.8830	0.5170	0	1.2977
0.3115	0	0.9137	0.3259	0	0.9998	0.4028	0	1.4407
0.2566	0	0.2959	0.2582	0	0.3253	0.2660	0	0.4678
0.2323	0	0.6971	0.2369	0	0.7567	0.2607	0	1.0535

Table 5(b): Results for Plotting Circular discs for 6-bus test system with different Load

Load=1.250			Load=1.300			Load=1.350		
Center	Y	Radius	Center	Y	Radius	Center	Y	Radius
0.9300	0	3.9941	1.0037	0	5.0093	1.1812	0	7.8292
0.9119	0	2.5960	1.1155	0	3.3840	1.6831	0	5.6253
0.6659	0	2.3770	0.8315	0	3.1016	1.3012	0	5.1693
0.8337	0	2.6882	0.9162	0	3.3826	1.1209	0	5.3080
0.4992	0	2.0483	0.5564	0	2.5680	0.6982	0	4.0136
0.5697	0	1.5753	0.6640	0	2.0763	0.9262	0	3.4953
0.4554	0	1.7345	0.5511	0	2.2635	0.8235	0	3.7553
0.2709	0	0.5582	0.2791	0	0.7156	0.2999	0	1.1435
0.2761	0	1.2459	0.3029	0	1.5862	0.3751	0	2.5255

[B] IEEE-30 Bus Test System:

Table 5(c): Results for Plotting Circular discs for 30-bus test system with different Load

%Load= 1.000														
Centre	Y	Radius	Centre	Y	Radius	Centre	Y	Radius	Centre	Y	Radius	Centre	Y	Radius
0.0572	0	1.3888	0.4051	0	4.7195	0.4013	0	5.0027	0.0213	0	0.5544	0.1544	0	1.8467
0.1037	0	2.0776	0.3953	0	4.8388	0.3556	0	5.0930	0.0592	0	0.3558	0.1554	0	1.8929
0.1031	0	2.5467	0.3129	0	4.9262	0.4714	0	5.0876	0.0854	0	0.9807	0.2464	0	2.1225
0.1949	0	2.3372	0.3394	0	4.7950	0.9207	0	4.8485	0.1113	0	1.5955	0.2172	0	2.3690
0.1170	0	2.9372	0.3032	0	4.8693	0.4442	0	4.9385	0.0800	0	1.0390	0.3483	0	2.8383
0.1696	0	2.7135	0.4090	0	5.0260	0.1703	0	3.1327	0.2172	0	1.4753	0.7832	0	3.1742
0.1641	0	3.1769	0.4075	0	5.0566	0.8055	0	4.9984	0.1458	0	1.7243	0.3315	0	2.4996
0.2478	0	4.2846	0.3864	0	5.0262	0.8966	0	5.0840	0.1835	0	1.4252	0.0597	0	0.7651
0.2504	0	4.8640	0.2932	0	4.9600	0.0591	0	0.6133	0.1616	0	1.6112	0.6705	0	3.0378
0.4611	0	4.2846	0.2941	0	4.9764	0.0378	0	0.6786	0.2510	0	2.081	0.7485	0	3.1161

Table 5 (d): Results for Plotting Circular discs for 30-bus test system with different Load

%Load=1.250											
Centre	Y	Radius	Centre	Y	Radius	Centre	Y	Radius	Centre	Y	Radius
0.0607	0	1.5370	0.4634	0	5.8917	0.0642	0	0.4220	0.8542	0	3.6602
0.1129	0	2.3077	0.4630	0	5.9354	0.0902	0	1.1419	0.3628	0	2.9204
0.1141	0	2.8697	0.4382	0	5.8904	0.1184	0	1.8281	0.0644	0	0.9038
0.2256	0	2.6696	0.3332	0	5.8051	0.0839	0	1.2135	0.7396	0	3.5594
0.1314	0	3.3476	0.3341	0	5.8241	0.2286	0	1.6929	0.8322	0	3.6737
0.1945	0	3.1090	0.4551	0	5.8678	0.1543	0	1.9687			
0.1863	0	3.6511	0.4071	0	5.9954	0.1933	0	1.6371			
0.2793	0	4.9614	0.5432	0	6.0121	0.1715	0	1.8444			
0.2831	0	5.6711	1.0728	0	5.7851	0.2666	0	2.3588			
0.5077	0	4.9614	0.5119	0	5.8287	0.2722	0	2.4225			
0.2939	0	5.4854	0.1933	0	3.5746	0.2531	0	2.3426			
0.4453	0	5.4854	0.9505	0	6.0045	0.1648	0	2.1108			
0.4426	0	5.6494	1.0772	0	6.1919	0.1658	0	2.1615			
0.3533	0	5.7508	0.0626	0	0.7716	0.2621	0	2.4171			
0.3802	0	5.5884	0.0405	0	0.8323	0.2332	0	2.7047			
0.3421	0	5.6840	0.0230	0	0.6641	0.3785	0	3.2680			

Table 5(e): Results for Plotting Circular discs for 57-bus test system with different Load

%Load=1.000								
Centre	Y	Radius	Centre	Y	Radius	Centre	Y	Radius
0.0262	0	0.4734	0.1756	0	3.4852	0.0989	0	2.6213
0.0574	0	1.8965	0.1061	0	3.2187	0.1089	0	2.6638
0.1149	0	2.9383	0.2039	0	3.4744	0.2049	0	3.0650
0.1098	0	3.1767	0.2343	0	3.5296	0.9114	0	5.4145
0.0913	0	3.0722	0.3060	0	3.7181	0.2034	0	2.7945
0.0674	0	2.1449	0.4432	0	3.6052	0.1540	0	1.5311
0.0841	0	2.3127	0.2131	0	3.1412	0.0989	0	0.9438
0.1420	0	2.7689	0.1215	0	3.0108	0.0551	0	0.4852
0.1175	0	2.7164	0.1102	0	2.5610	0.9510	0	5.8601
0.0998	0	2.8472	0.1020	0	2.7828	0.9788	0	6.2616
0.1306	0	3.3732	0.1092	0	3.0553	0.8282	0	5.9008
0.0624	0	2.4496	0.1058	0	3.1052	0.8616	0	5.9371
0.0681	0	2.3553	0.1117	0	3.0787	0.2912	0	4.6254
0.0466	0	1.9184	0.1609	0	2.9859	0.2276	0	4.2832
0.0911	0	1.5503	0.1513	0	2.8560	0.1823	0	3.9365
0.0757	0	0.8215	0.2607	0	3.5661	0.1549	0	3.5991
0.2959	0	2.7773	0.2840	0	3.5014	0.0806	0	2.4418
0.5662	0	2.8865	0.2738	0	3.3715	0.1857	0	3.6306
0.5680	0	3.0091	0.1802	0	3.2814	0.2179	0	3.9434
0.2087	0	3.2196	0.3857	0	3.5627	0.2691	0	1.8776
0.1241	0	3.2683	0.5002	0	3.4792	0.4224	0	2.6962
0.1338	0	3.2848	0.0268	0	0.0372	0.1669	0	1.0748
0.2380	0	3.5493	0.0253	0	0.0133	0.0998	0	2.0443
0.8801	0	5.3558	0.0402	0	0.5489	0.0910	0	1.0716
0.2483	0	3.4904	0.0723	0	0.6041	0.0807	0	1.3640
0.2352	0	3.6126	0.0453	0	0.6812	0.0864	0	1.8284
0.1988	0	3.6604	0.0280	0	0.7461	0.0816	0	2.0217
0.1682	0	3.7005	0.0396	0	0.8819	0.0866	0	1.6564
0.9166	0	5.3568	0.0232	0	0.5291	0.1375	0	1.4204
0.9432	0	5.2854	0.0780	0	0.4184	0.1179	0	0.7996
0.8059	0	5.1314	0.0725	0	0.2348	0.1716	0	0.8177
0.8368	0	5.0977	0.2267	0	0.4581	0.2038	0	0.8572
0.3002	0	3.5781	0.5502	0	2.0841	0.2028	0	0.6331
0.2423	0	3.5418	0.5768	0	2.6027	0.1000	0	0.1549
0.2011	0	3.5288	0.1905	0	2.7332	0.3692	0	3.1998
						0.4986	0	3.4273

Table 5 (f)-: Results for Plotting Circular discs for 57-bus test system with different Load

%Load=2.000

Centre	Y	Radius	Centre	Y	Radius	Centre	Y	Radius
0.0262	0	0.4752	0.1757	0	3.4938	0.0990	0	2.6282
0.0574	0	1.9021	0.1062	0	3.2263	0.1089	0	2.6708
0.1151	0	2.9467	0.2041	0	3.4831	0.2050	0	3.0717
0.1099	0	3.1860	0.2346	0	3.5386	0.9119	0	5.4254
0.0915	0	3.0817	0.3062	0	3.7290	0.2035	0	2.8005
0.0674	0	2.1512	0.4435	0	3.6171	0.1540	0	1.5339
0.0841	0	2.3194	0.2133	0	3.1502	0.0989	0	0.9453
0.1421	0	2.7769	0.1215	0	3.0174	0.0551	0	0.4859
0.1176	0	2.7246	0.1102	0	2.5661	0.9515	0	5.8718
0.0999	0	2.8555	0.1021	0	2.7893	0.9794	0	6.2740
0.1308	0	3.3827	0.1093	0	3.0626	0.8285	0	5.9121
0.0625	0	2.4562	0.1059	0	3.1127	0.8619	0	5.9484
0.0681	0	2.3609	0.1118	0	3.0866	0.2913	0	4.6349
0.0466	0	1.9227	0.1610	0	2.9944	0.2277	0	4.2921
0.0911	0	1.5544	0.1515	0	2.8646	0.1823	0	3.9449
0.0757	0	0.8232	0.2610	0	3.5765	0.1550	0	3.6072
0.2960	0	2.7848	0.2844	0	3.5118	0.0806	0	2.4488
0.5665	0	2.8943	0.2741	0	3.3814	0.1857	0	3.6387
0.5683	0	3.0169	0.1804	0	3.2911	0.2180	0	3.9518
0.2089	0	3.2276	0.3860	0	3.5745	0.2691	0	1.8822
0.1243	0	3.2761	0.5006	0	3.4912	0.4225	0	2.7022
0.1339	0	3.2928	0.0268	0	0.0376	0.1669	0	1.0784
0.2382	0	3.5593	0.0253	0	0.0134	0.0998	0	2.0510
0.8810	0	5.3771	0.0402	0	0.5542	0.0910	0	1.0773
0.2485	0	3.5003	0.0723	0	0.6079	0.0807	0	1.3700
0.2354	0	3.6233	0.0453	0	0.6842	0.0864	0	1.8349
0.1990	0	3.6708	0.0280	0	0.7506	0.0817	0	2.0283
0.1684	0	3.7108	0.0396	0	0.8867	0.0866	0	1.6625
0.9177	0	5.3788	0.0232	0	0.5333	0.1375	0	1.4260
0.9444	0	5.3071	0.0781	0	0.4244	0.1180	0	0.8039
0.8065	0	5.1481	0.0725	0	0.2394	0.1716	0	0.8186
0.8375	0	5.1144	0.2267	0	0.4594	0.2039	0	0.8582
0.3006	0	3.5876	0.5503	0	2.0881	0.2028	0	0.6338
0.2426	0	3.5510	0.5769	0	2.6080	0.1000	0	0.1551
0.2013	0	3.5376	0.1905	0	2.7399	0.3693	0	3.2066
						0.4987	0	3.4347

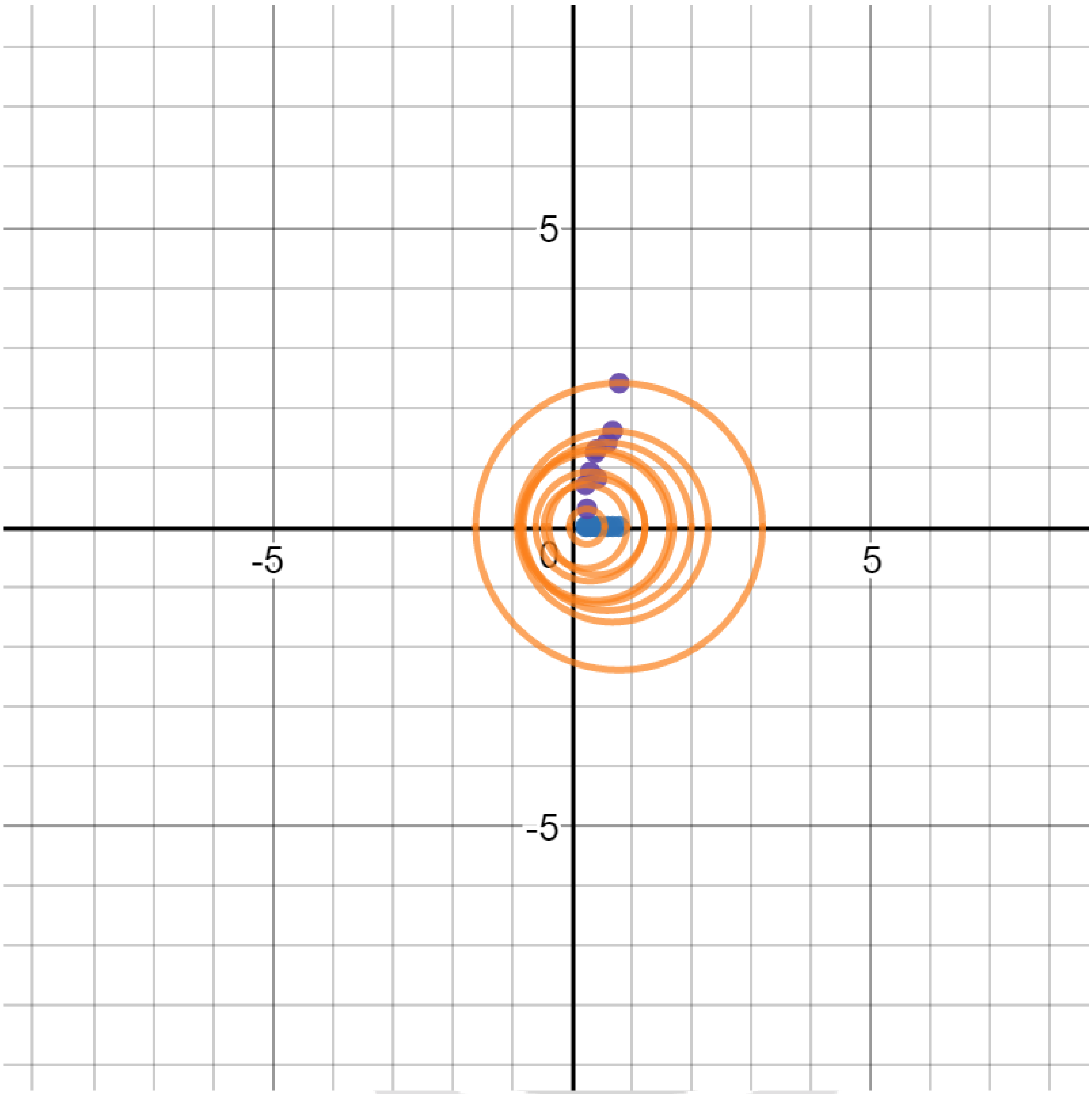

Fig-2 (a) : Georschrin's Circle for 6-Bus Test System (Load=1.00)

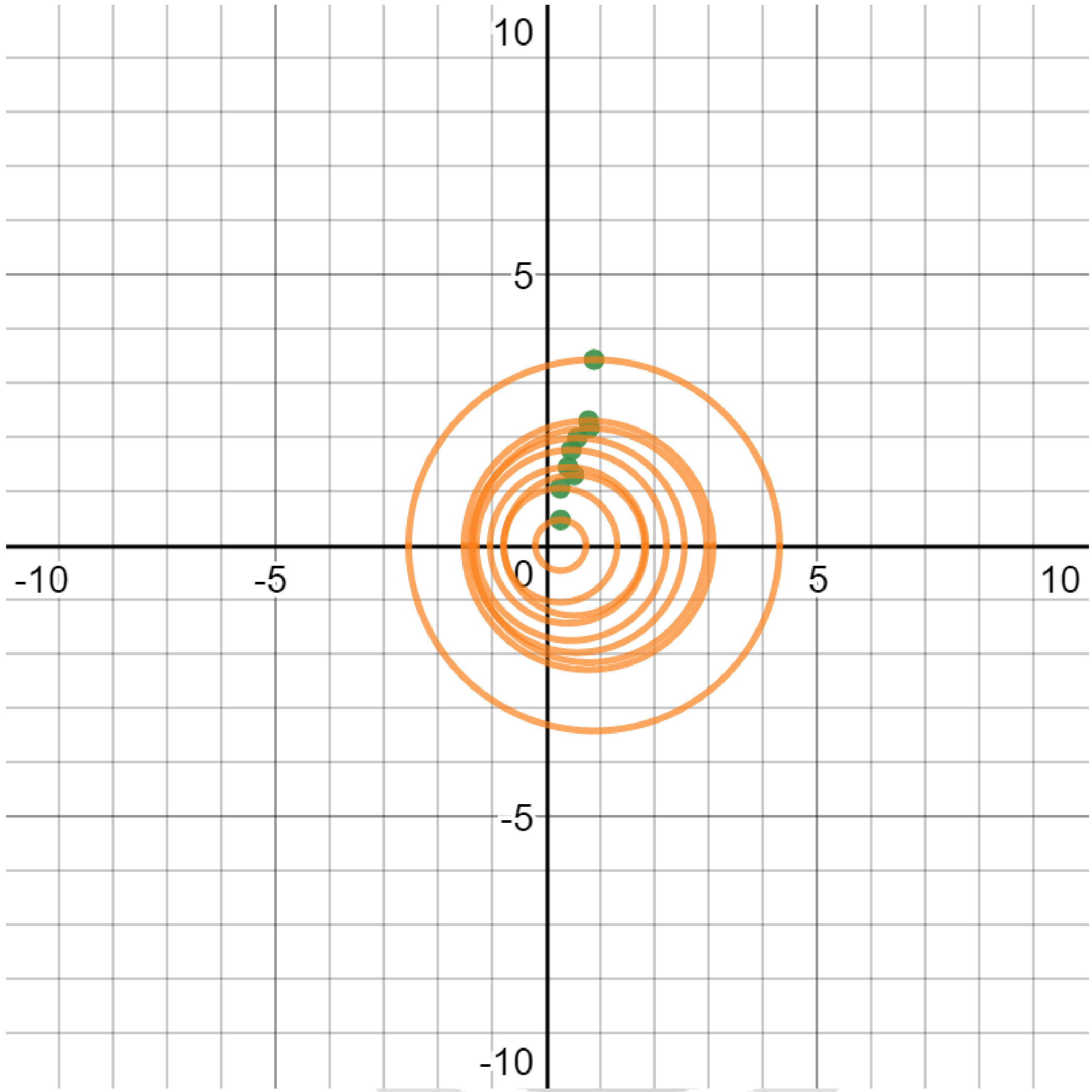

Fig-2 (b): Georschrin's Circle for 6-Bus Test System (Load=1.2)

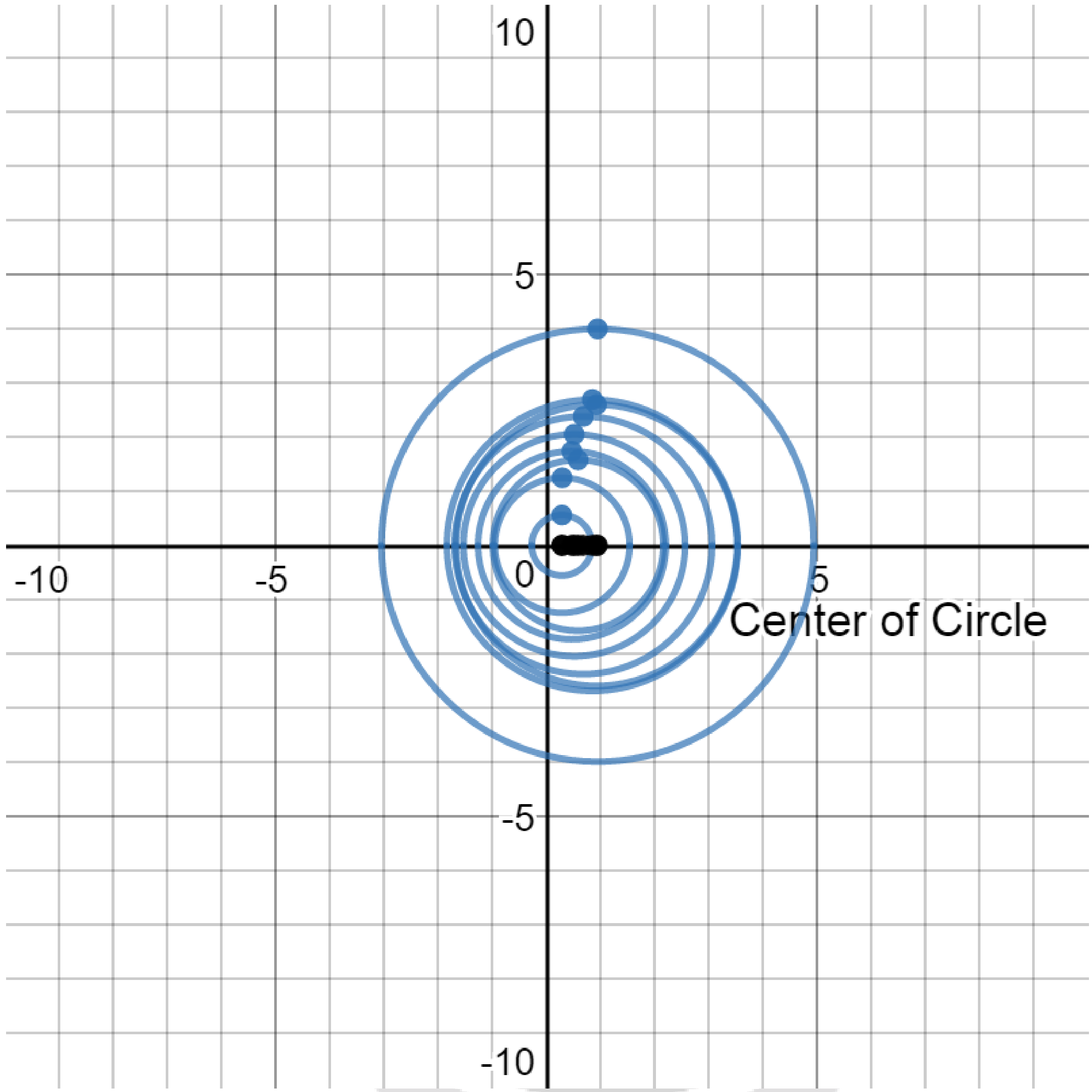

Fig-2 (c): Georschrin's Circle for 6-Bus Test System (Load=1.25)

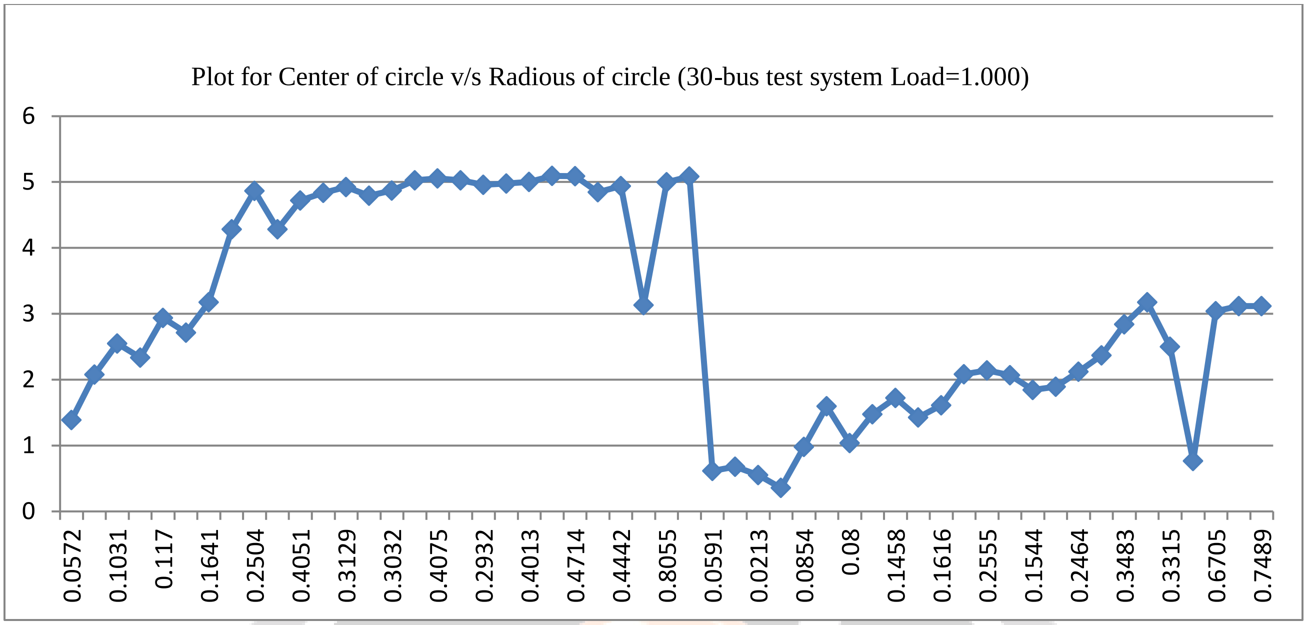

Fig-2 (d): Effect of Variation in Load on Center of Circle & Radius of Circle

(30-Bus Test System Per unit Load= 1.000)

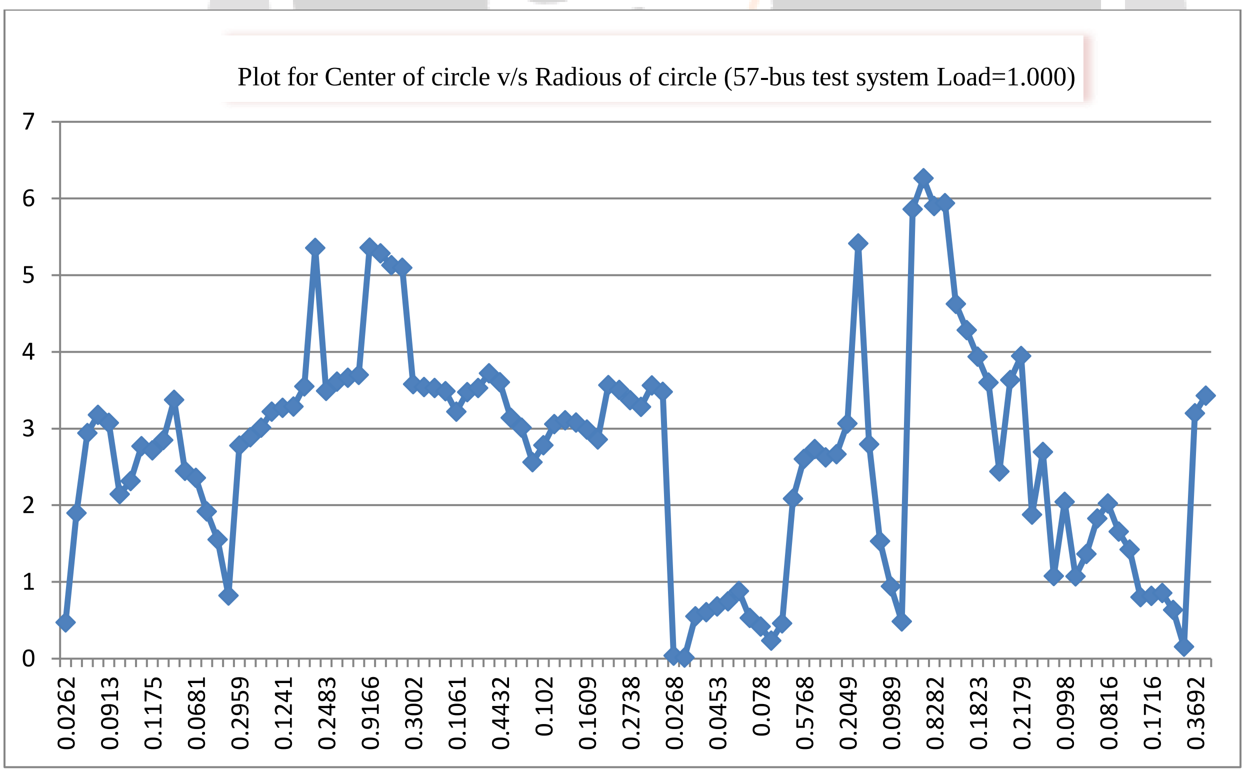

Fig- 2 (e): Effect of Variation in Load on Center of Circle & Radius of Circle (57-Bus Test System Per unit Load= 1.00

4.2 Results of JAYA Method

[C] IEEE-14 bus test system

Table-6: Initial Best Value of Centre of Circle (JAYA-14 Bus Test System)

Sr. No	Control Variables of Voltage at Generator buses					Control Variables of Tap Changing Transformer			Min. Eigen Value	Remarks
	V_2	V_3	V_6	V_7	V_8	T_7	T_9	T_6		
1	1.0450	1.0100	1.0700	1.0000	1.0000	0.9780	0.9690	0.9320	5.6770	
2	1.0315	1.0406	0.9627	1.0413	1.0132	1.0146	1.0209	1.0255	5.5378	Worst
3	1.0457	0.9985	1.0300	0.9642	0.9912	0.9663	0.9619	0.9918	5.4310	
4	1.0349	1.0434	1.0179	1.0258	1.0243	0.9724	1.0251	0.9755	5.8488	Best
5	1.0266	1.0295	0.9687	0.9990	0.9946	0.9754	1.0314	0.9744	5.5620	
6	1.0490	1.0094	1.1247	0.9836	1.0078	0.9500	0.9676	0.9500	5.6277	
7	1.0340	1.0430	1.0076	1.0280	1.0220	0.9802	1.0240	0.9845	5.8054	
8	1.0490	0.9969	1.0810	0.9500	0.9982	0.9500	0.9599	0.9500	5.3532	
9	1.0379	1.0459	1.0679	1.0117	1.0343	0.9500	1.0289	0.9500	5.9411	
10	1.0289	1.0307	1.0142	0.9825	1.0190	0.9500	1.0350	0.9500	5.5886	
11	1.0450	1.0100	1.0700	1.0000	1.0000	0.9780	0.9690	0.9320	5.6770	
12	1.0340	1.0430	1.0076	1.0280	1.0220	0.9802	1.0240	0.9845	5.8054	
13	1.0457	0.9985	1.0300	0.9642	0.9912	0.9663	0.9619	0.9918	5.4310	Worst
14	1.0379	1.0459	1.0679	1.0117	1.0343	0.9500	1.0289	0.9500	5.9411	Best
15	1.0289	1.0307	1.0142	0.9825	1.0190	0.9500	1.0350	0.9500	5.5886	

Table-7: Updated Best and Worst Value of Centre of Circle (JAYA-14 Bus Test System)

Sr. No	Control Variables of Voltage at Generator buses					Control Variables of Tap Changing Transformer			Min. Eigen Value	Remarks
	V_2	V_3	V_6	V_7	V_8	T_7	T_9	T_6		
16	1.0434	1.0250	1.1060	1.0340	1.0124	0.9851	0.9830	0.9500	5.7776	
17	1.0238	1.0840	0.9947	1.0842	1.0510	0.9890	1.0810	0.9734	5.8296	
18	1.0447	1.0045	1.0348	0.9702	0.9966	0.9642	0.9704	0.9864	5.4897	Worst
19	1.0307	1.0890	1.1025	1.0550	1.0730	0.9500	1.0900	0.9500	6.3123	Best
20	1.0146	1.0620	1.0065	1.0029	1.0157	0.9500	1.1000	0.9500	5.7340	
21	1.0434	1.0250	1.1060	1.0340	1.0124	0.9851	0.9830	0.9500	5.7776	
22	1.0238	1.0840	0.9947	1.0842	1.0510	0.9890	1.0810	0.9734	5.8296	
23	1.0447	1.0045	1.0348	0.9702	0.9966	0.9642	0.9704	0.9864	5.4897	Worst
24	1.0307	1.0890	1.1025	1.0550	1.0730	0.9500	1.0900	0.9500	6.3123	Best
25	1.0146	1.0620	1.0065	1.0029	1.0157	0.9500	1.1000	0.9500	5.7340	
26	1.0352	1.0674	1.1107	1.0535	1.0522	0.9649	1.0518	0.9500	6.1197	
27	1.0261	1.0949	1.0589	1.0768	1.0702	0.9667	1.0974	0.9573	6.1221	
28	1.0358	1.0579	1.0776	1.0238	1.0449	0.9552	1.0460	0.9633	6.0661	
29	1.0293	1.0972	1.1091	1.0632	1.0804	0.9500	1.1016	0.9500	6.2995	
30	1.0218	1.0846	1.0644	1.0390	1.0538	0.9500	1.1063	0.9500	6.1010	

Table-8: Final Best and Worst Value of Centre of Circle (JAYA-14 Bus Test System)

Sr. No	Control Variables of Voltage at Generator buses					Control Variables of Tap Changing Transformer			Min. Eigen Value	Remarks
	V_2	V_3	V_6	V_7	V_8	T_7	T_9	T_6		
166	1.1215	1.0311	1.1500	1.0831	1.1470	0.9500	0.9500	0.9500	6.8919	Best solution
167	1.1215	1.0311	1.1500	1.0830	1.1470	0.9500	0.9500	0.9500	6.8919	
168	1.1215	1.0311	1.1500	1.0830	1.1470	0.9500	0.9500	0.9500	6.8916	
169	1.1215	1.0311	1.1500	1.0830	1.1470	0.9500	0.9500	0.9500	6.8916	
170	1.1214	1.0311	1.1499	1.0830	1.1469	0.9500	0.9500	0.9500	6.8916	

The 14-bus test system has five generator buses, eight load buses and three tap changing transformer. The control variables with respect to voltage of PV generator buses were selected in the range of between [0.95 1.15].The control variables with respect to tapping of Tap changing transformer were selected between [0.95 1.05]. Five initial solutions (search direction) were assumed as per given in Table 6 for JAYA method. It shows the initial best and worst value as 5.8488 and 5.5378 respectively. Value of centre of circle which determines the minimum approximate eigen value.Table 7 shows the updated value of control variables and objective function after implementation of JAYA method. It shows the best and worst value of objective function as 6.3123 and 5.5378 respectively. Table 7 gives the best value of objective function as 6.3123. Maximum number of iterations was set equal to 100. Table 8 also shows the updating solution after JAYA convergence at iteration number eighteen. The minimum objective value is updated from 5.4897 to 6.8919. It is obvious that lesser numbers of iterations are required if initial control variable are randomly generated near to the optimal solution. Similarly Table 9 ,10 and table 11 show the result of 30 bus test system.

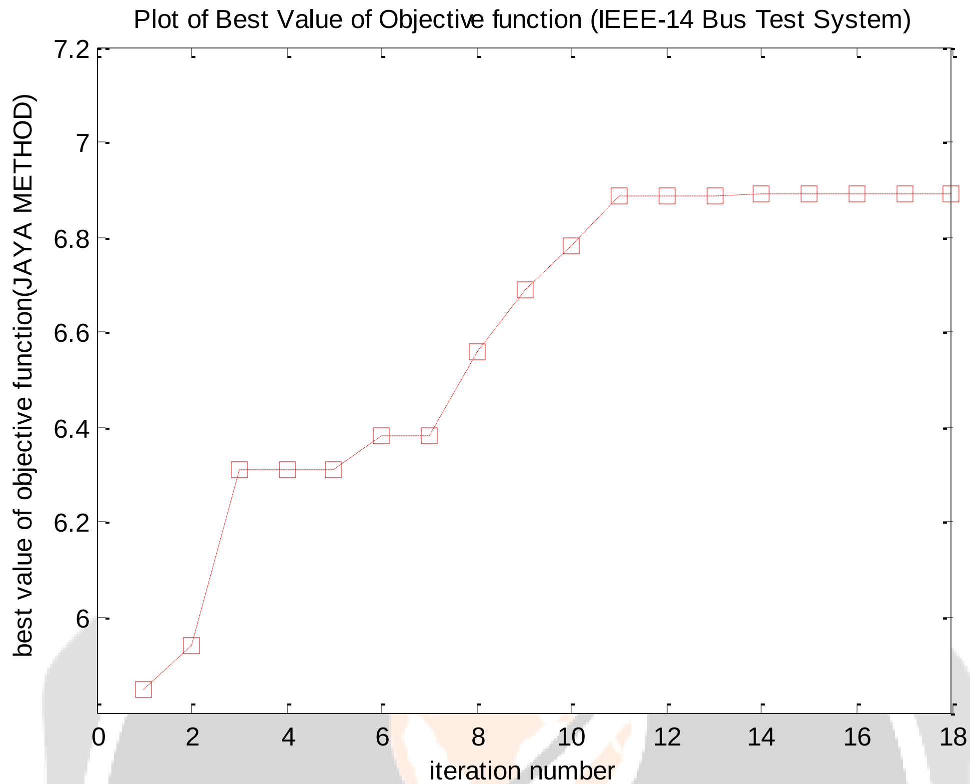

Fig-3: Best Value of Centre of Gershgorin'sCircular Disk (JAYA-Method)

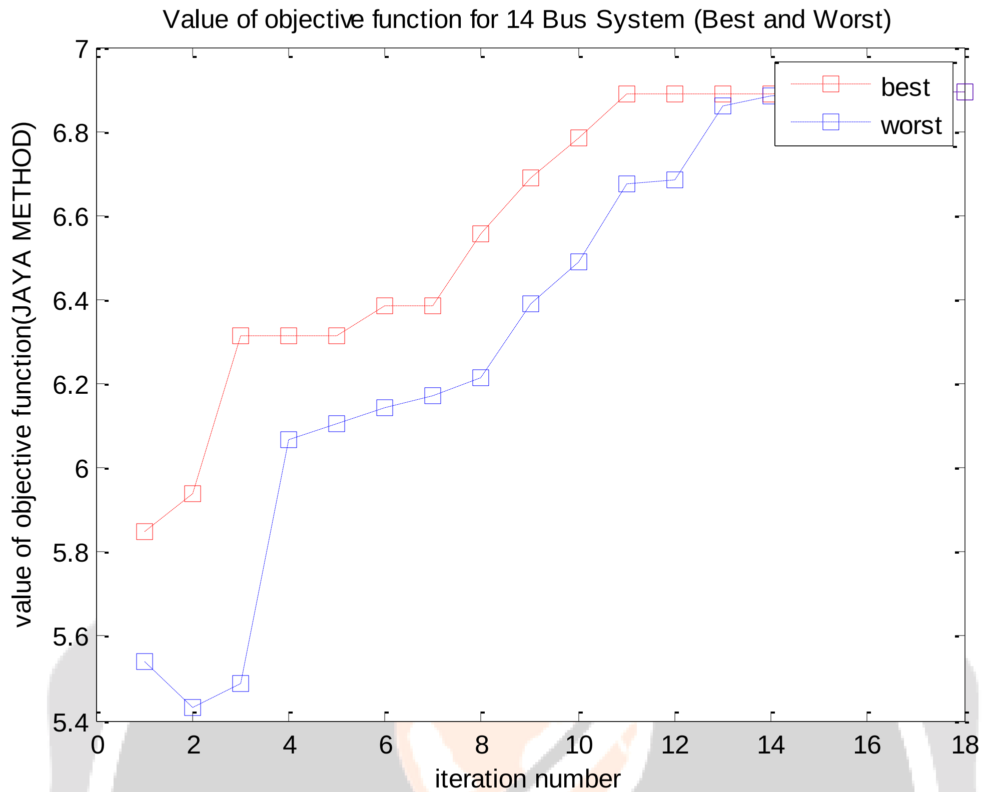

Fig-4: Best & Worst Value of Centre of Gershgorin'sCircular Disk (JAYA-Method)

[D] JAYA Method (IEEE-30 bus test system)

Table-9: Initial Best and Worst Value of Centre of Circle (JAYA-30 Bus Test System)

Sr. No	Control Variables of Voltage at Generator buses					Control Variables of Tap Changing Transformer				Min. Eigen Value	Remarks
	V2	V_5	V_8	V_{11}	V_{13}	T_9	T_{10}	T_{12}	T_{27}		
1	1.0980	1.0410	1.0780	1.0690	1.0840	0.9780	0.9678	0.9530	0.9546	2.6546	Best
2	1.1040	1.0910	1.0680	1.0540	1.0640	0.9800	0.9538	0.9521	0.9561	2.6267	
3	1.1120	1.0820	1.0980	1.0860	1.0320	0.9512	0.9880	0.9870	0.9912	2.4658	
4	1.0720	1.1200	1.1010	0.9897	1.0910	0.9761	0.9531	0.9780	0.9612	2.4459	Worst
5	1.0810	1.0890	1.0730	0.9794	1.0930	0.9526	0.9600	0.9512	0.9550	2.5029	
6	1.1022	1.0282	1.0743	1.0819	1.0829	0.9783	0.9702	0.9500	0.9535	2.6580	
7	1.1034	1.0384	1.0722	1.0788	1.0788	0.9787	0.9673	0.9500	0.9538	2.6597	
8	1.1051	1.0366	1.0784	1.0854	1.0722	0.9728	0.9743	0.9559	0.9610	2.6281	
9	1.0969	1.0444	1.0790	1.0656	1.0843	0.9779	0.9672	0.9541	0.9549	2.6522	
10	1.0987	1.0380	1.0732	1.0635	1.0847	0.9731	0.9686	0.9500	0.9536	2.6622	
11	1.1022	1.0282	1.0743	1.0819	1.0829	0.9783	0.9702	0.9500	0.9535	2.6580	
12	1.1034	1.0384	1.0722	1.0788	1.0788	0.9787	0.9673	0.9500	0.9538	2.6597	
13	1.1051	1.0366	1.0784	1.0854	1.0722	0.9728	0.9743	0.9559	0.9610	2.6281	Worst
14	1.0969	1.0444	1.0790	1.0656	1.0843	0.9779	0.9672	0.9541	0.9549	2.6522	
15	1.0987	1.0380	1.0732	1.0635	1.0847	0.9731	0.9686	0.9500	0.9536	2.6622	Best

Table-10: Initial Best and Worst Value of Centre of Circle (JAYA-30 Bus Test System)

Sr. No	Control Variables of Voltage at Generator buses					Control Variables of Tap Changing Transformer				Min. Eigen Value	Remarks
	V2	V_5	V_8	V_{11}	V_{13}	T_9	T_{10}	T_{12}	T_{27}		
16	1.0967	1.0286	1.0697	1.0637	1.0941	0.9790	0.9652	0.9500	0.9500	2.6700	
17	1.0980	1.0397	1.0674	1.0604	1.0896	0.9795	0.9620	0.9500	0.9500	2.6629	
18	1.0999	1.0377	1.0742	1.0676	1.0824	0.9730	0.9697	0.9511	0.9550	2.6557	
19	1.0909	1.0463	1.0748	1.0460	1.0956	0.9786	0.9619	0.9500	0.9500	2.6352	
20	1.0929	1.0393	1.0685	1.0437	1.0960	0.9734	0.9634	0.9500	0.9500	2.6342	
21	1.0967	1.0286	1.0697	1.0637	1.0941	0.9790	0.9652	0.9500	0.9500	2.6700	Best
22	1.0980	1.0397	1.0674	1.0604	1.0896	0.9795	0.9620	0.9500	0.9500	2.6629	
23	1.0999	1.0377	1.0742	1.0676	1.0824	0.9730	0.9697	0.9511	0.9550	2.6557	
24	1.0969	1.0444	1.0790	1.0656	1.0843	0.9779	0.9672	0.9541	0.9549	2.6522	
25	1.0987	1.0380	1.0732	1.0635	1.0847	0.9731	0.9686	0.9500	0.9536	2.6622	Worst
26	1.0967	1.0271	1.0688	1.0635	1.0951	0.9791	0.9650	0.9500	0.9500	2.6695	
27	1.0973	1.0322	1.0677	1.0620	1.0930	0.9793	0.9635	0.9500	0.9500	2.6663	
28	1.0982	1.0313	1.0709	1.0653	1.0896	0.9763	0.9671	0.9501	0.9518	2.6674	
29	1.0968	1.0344	1.0739	1.0644	1.0905	0.9786	0.9659	0.9515	0.9518	2.6635	
30	1.0976	1.0314	1.0704	1.0634	1.0907	0.9764	0.9666	0.9500	0.9512	2.6675	

Table-11: Final Best and Worst Value of Centre of Circle (JAYA-30 Bus Test System)

Sr. No	Control Variables of Voltage at Generator buses					Control Variables of Tap Changing Transformer				Min. Eigen Value	Remarks
	V2	V_5	V_8	V_{11}	V_{13}	T_9	T_{10}	T_{12}	T_{27}		
76	1.0983	1.0235	1.0671	1.0652	1.0933	0.9758	0.9672	0.9500	0.9500	2.6734	
77	1.0983	1.0245	1.0671	1.0649	1.0931	0.9761	0.9668	0.9500	0.9500	2.6736	
78	1.0984	1.0239	1.0670	1.0651	1.0931	0.9758	0.9671	0.9500	0.9500	2.6735	
79	1.0983	1.0237	1.0672	1.0652	1.0932	0.9758	0.9672	0.9500	0.9500	2.6734	
80	1.0993	1.0199	1.0638	1.0640	1.0935	0.9731	0.9681	0.9500	0.9500	2.6740	
81	1.0983	1.0244	1.0671	1.0649	1.0931	0.9761	0.9668	0.9500	0.9500	2.6736	
82	1.0983	1.0244	1.0671	1.0649	1.0931	0.9761	0.9668	0.9500	0.9500	2.6736	
83	1.0984	1.0239	1.0670	1.0651	1.0931	0.9758	0.9671	0.9500	0.9500	2.6735	
84	1.0983	1.0237	1.0672	1.0652	1.0932	0.9758	0.9672	0.9500	0.9500	2.6734	Worst
85	1.0993	1.0199	1.0638	1.0640	1.0935	0.9731	0.9681	0.9500	0.9500	2.6740	Best
86	1.0992	1.0207	1.0640	1.0639	1.0934	0.9735	0.9677	0.9500	0.9500	2.6738	
87	1.0992	1.0208	1.0640	1.0639	1.0934	0.9735	0.9677	0.9500	0.9500	2.6738	
88	1.0993	1.0204	1.0640	1.0640	1.0934	0.9733	0.9680	0.9500	0.9500	2.6740	
89	1.0992	1.0202	1.0641	1.0641	1.0935	0.9733	0.968	0.9500	0.9500	2.674	
90	1.0999	1.0175	1.0616	1.0632	1.0937	0.9714	0.9687	0.9500	0.9500	2.6738	

TLBO constant is selected as 1.Five initial solutions (search direction) were assumed and are given in Table 12. It shows the initial best value of centre of circle which determines the minimum approximate eigen value. Table 12 gives the best value of objective function as 5.8964. Maximum number of iterations was set equal to 100. Table 13 shows the final solution after TLBO convergence and the initial minimum objective value 5.6371 (Table 12) is increased up to 5.9896 after iteration eleven.

Similar results have been obtained for 30-bus system. The 30-bus test system has five generator buses, twenty four load buses and four tap changing transformer. TLBO constant is selected as 1. Five initial solutions (search direction) were assumed and are given in Table 14. It shows the initial best value of centre of circle which determines the minimum approximate eigen value. Table 15 gives the best value of objective function as 2.6546. Maximum number of iterations was set equal to 100. Table 16 also shows the updating and final solution after TLBO convergence after iteration number eight and it also indicates the updating of objective value from 2.4459 to 2.6821.

4.3 Results of TLBO Method

[E] IEEE-14 Bus Test Systems

Table-12: Initial Best Value of Centre of Circle (TLBO-14 Bus Test System)

Sr.No	Voltage at Generator Buses					Tap Setting			Min. Eigen Value	Remark
	V_2	V_3	V_6	V_7	V_8	T_7	T_9	T_6		
1	1.0433	1.0124	1.0773	1.0125	1.0019	0.9755	0.9818	0.95	5.6954	
2	1.0324	1.0472	0.9885	1.0366	1.0291	0.9823	1.0299	0.9964	5.8310	
3	1.0280	1.0461	0.9968	0.9847	1.0084	0.9624	1.0388	0.9848	5.6371	
4	1.0337	1.0467	1.0236	1.0264	1.0297	0.9720	1.0274	0.9719	5.8964	Best
5	1.0305	1.0471	1.0191	1.0130	1.0230	0.9712	1.0414	0.9726	5.8236	

Table 13: Final Best Value of Centre of Circle (TLBO-14 Bus Test System)

Sr.No	**Voltage at Generator Buses**					**Tap Setting**			**Min. Eigen Value**	**Best value**
	V_2	V_3	V_6	V_7	V_8	T_7	T_9	T_6		
1	1.0290	1.0508	1.0239	1.0127	1.0408	0.9657	1.0458	0.9623	5.9836	5.988
2	1.0288	1.0508	1.0241	1.0133	1.0409	0.9611	1.0459	0.9612	5.9878	
3	1.0290	1.0507	1.0241	1.0143	1.0402	0.9612	1.0461	0.9626	5.9896	
4	1.0290	1.0507	1.0240	1.0223	1.0402	0.9884	1.0461	0.9629	5.9785	
5	1.0285	1.0507	1.0226	1.0129	1.0414	0.9666	1.0465	0.9634	5.9883	

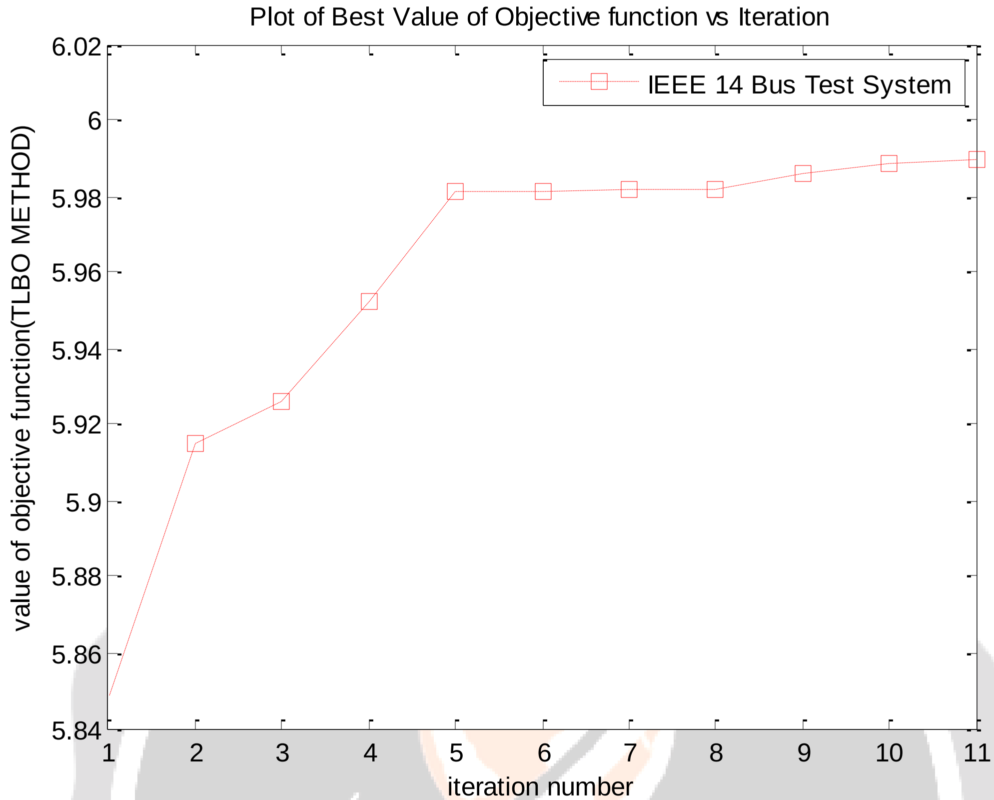

Fig-5 : Best Value of Centre of Gershgorin's Circular Disk

[F] IEEE-30 Bus Test Systems

Table 14: Initial Best Value of Centre of Circle (TLBO-30 Bus Test System)

Voltage at Generator Buses					Tap Setting				Min. Eigen Value	Remark
V_2	V_5	V_8	V_{11}	V_{13}	T_9	T_{10}	T_{12}	T_{27}		
1.098	1.041	1.078	1.069	1.084	0.978	0.9678	0.953	0.9546	2.6546	Best
1.104	1.091	1.068	1.054	1.064	0.980	0.9538	0.9521	0.9561	2.6267	
1.112	1.082	1.098	1.086	1.032	0.9512	0.988	0.987	0.9912	2.4658	
1.072	1.120	1.101	0.9897	1.091	0.9761	0.9531	0.978	0.9612	2.4459	
1.081	1.089	1.073	0.9794	1.093	0.9526	0.960	0.9521	0.9550	2.5029	

Table 15: Final Best Value of Centre of Circle (TLBO-30 Bus Test System)

Voltage at Generator Buses					Tap Setting				Min. Eigen Value	Remark
V_2	V_5	V_8	V_{11}	V_{13}	T_9	T_{10}	T_{12}	T_{27}		
1.0902	1.0734	1.0606	1.1013	1.0728	0.9882	0.9504	0.95	0.95	2.6828	Best Value 2.683
1.0920	1.0725	1.0616	1.0979	1.0814	0.9860	0.9542	0.95	0.9502	2.6797	
1.0747	1.0638	1.0678	1.0742	1.0827	0.9868	0.9528	0.9501	0.9504	2.6799	
1.0865	1.0637	1.0603	1.1061	1.0798	0.9876	0.9515	0.95	0.95	2.6821	
1.0887	1.0727	1.0605	1.1041	1.0755	0.9886	0.9503	0.95	0.95	2.6827	

Table 16. Shows the statistical analysis of the results obtained from TLBO and JAYA for 14-bus & 30 bus test system. It shows the better performance of TLBO compared to JAYA as deviation in control variables is very less in TLBO method. JAYA has better performance with respect to maximize the objective value compared to TLBO. TLBO requires less iterations but time per iteration is more compared to JAYA.

Table 17 & 18 shows the results of voltage and load angle at each bus on IEEE-14 & IEEE-30 bus test system respectively. Table 18 shows the load flow results for IEEE-30 bus test system considering the objective function value as 2.6730. Voltages at each bus are within constrained limit as well as reactive power limit is not violated with reference to the bus data of 30 bus standard test system. Load flow results obtained for 14-bus test system with active power loading of 2.59 per unit & reactive power loading of 0.813 per unit as per bus data of system. Also, Load flow results obtained for 30-bus test system with active power loading of 2.834 per unit & reactive power loading of 1.262 per unit as per bus data of the system.

Table 16: Statistical Analysis for 14-Bus & 30-Bus Test System (TLBO-JAYA-Method)

Sr No	Parameters	TLBO 14-Bus	JAYA(14-Bus)
1	Max. value of Objective function	5.988	6.8916
2	Worst Value of Objective function	5.4310	5.4310
3	Standard Deviation (V_2)	1.96E-04	0
4	Standard Deviation (V_3)	4.898E-05	1.095E-04
5	Standard Deviation (V_6)	0.0005755	3.9971E-05
6	Standard Deviation (V_7)	0.003646	3.52E-05
7	Standard Deviation (V_8)	0.000456	0
8	No of iterations	11	18
Sr.No	Parameters	TLBO (30-Bus)	JAYA(30-Bus)
1	Max. value of Objective function	2.6828	2.725
2	Worst Value of Objective function	2.4658	2.4658
3	Standard Deviation (V_2)	6.12E-03	2.73E-04
4	Standard Deviation (V_3)	4.46E-03	1.2E-03
5	Standard Deviation (V_6)	2.86E-03	9.7E-04
6	Standard Deviation (V_7)	1.16E-02	0.000953
7	Standard Deviation (V_8)	0.00371	1.1E-04
8	No of iterations	5	9

Table 17: Results of Voltage and Angle at Bus (14 Bus System at Best value)

Value of Objective Function =6.8916					
Bus No	Voltage	Angle	Bus No	Voltage	Angle
1	1.060	0	8	1.121	-13.172
2	1.056	-5.125	9	1.063	-14.725
3	1.031	-12.829	10	1.059	-14.913
4	1.026	-10.265	11	1.067	-14.688
5	1.031	-8.817	12	1.067	-15.042
6	1.082	-14.216	13	1.062	-15.102
7	1.083	-13.172	14	1.045	-15.871

Table 18: Results of Voltage and Angle at Bus (30 Bus System at Best value)

Value of Objective Function = 2.6827					
Bus No	Voltage	Angle	Bus No	Voltage	Angle
111	1.060	0	16	11.032.032	- --16.05016.050
2	1. 1.044044	--5. -5.507507	161117719	1.033	-16.388
3	1.027	-8.049	18	1.016	-17.060
4	1.019	-9.701	19	1.016	-17.246
5	1.014	-14.416	20	1.022	-17.051
6	1.012	-11.386	21	1.028	-16.644
7	1.005	-13.149	22	1.028	-16.620
8	11.023.023	-12.14212.142	23	1.011.0144	-16.748-16.748
9	1.028	-14.584	24	1.012	-16.835
10	1.041	-16.227	25	1.021	-16.515
11	1.074	-14.584	26	1.004	-16.931
12	1.037	-15.413	27	1.035	-16.048
13	1.069	-15.413	28	1.012	-12.057
14	1.024	-16.308	29	1.016	-17.249
15	1.021	-16.414	30	1.004	-18.110

6. CONCLUSIONS

A methodology has been developed and implemented on three standard test systems t o obtain approximate eigen values for the analysis of voltage stability .It is the easiest way to find voltage stability critical point by means of approximate eigen values rather than eigen value of Reduced Jacobean matrix. One of the advantages of this technique is that there is better chance of obtaining optimal solution very quickly. The eigen value based analysis for voltage stability indices require more calculation rather than proposed algorithm. The developed new algorithm JAYA technique has been compared with one of the best optimization TLBO method. Final Optimized value of Gershgorin'scircular disk (movement of centre of circle) which gives minimum distance to voltage collapse has been obtained using JAYA & TLBO. It has been observed that although TLBO is slightly inferior in terms of execution time but less standard deviation in control parameters is observed. This type of index is used for voltage stability enhancement by means of Generator bus voltage and tapings of tap changing transformer.

New algorithms JAYA have been implemented on the IEEE-14 bus test system and IEEE 30 Bus System to obtain maximum values of minimum value of diagonal element of Reduced Jacobean Matrix. It enhances voltage stability limit and its margin. The Georgeoschgorin's Theorem is very useful mathematical tool for determining voltage stability indices by quick observation of Reduced Jacobean Matrix. It is also observed that, Voltage and angle at all the buses are within limit and also reactive power constrains are also maintained within the limit. .The performance of TLBO algorithm is compared with that of JAYA algorithm, So far as computation time is concerned, TLBO takes slightly more time than JAYA algorithm even if it requires less iteration.. JAYA gives better result than TLBO algorithm. As far as Standard deviation in control variables, TLBO algorithm has smaller deviation than JAYA. JAYA has better performance with respect to maximize the objective value compared to TLBO. JAYA requires only one phase per iteration as two phases per iterations are required by TLBO. JAYA is very simple to implement as compared to TLBO. JAYA algorithm is effectively handled mathematical model and proved its capabilities in the field of parameters optimization in the area of voltage stability studies compared to TLBO Method. The JAYA algorithm gives better result and satisfactory performance than TLBO for the constrained optimization problem. The statistical analysis also has supported the performance superiority of the JAYA compared to TLBO.

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