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Comparative Study and Performance Analysis of PSO, ABC, BFO and Cuckoo Search Optimization Techniques on UPFC Device for Voltage Stability Margin Improvement

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Abstract:- This paper investigates the enhancement of voltage stability margin using UPFCdevice tuned with PSO, ABC, BFO and Cuckoo Search techniqueson Nigerian 330KV 56-bus practical network. In order to have avoltage stable power system it is goodto keep voltages within the acceptable limits. This is achieved using continuation power flow embedded in Power System Analysis Toolbox (PSAT).The optimal location and tuning of the UPFC device is determined using line stability index and the met – heuristics techniques. The effects of UPFC on voltage stability margin are examined. The results so obtained for tuning PSO, ABC, BFO and Cuckoo Search with UPFC device are compared to know the technique that yields the best loading parameter for Nigerian 56- bus power system for voltage stability margin enhancement. It is found thatUPFC tuned with Cuckoo Search outperforms the other techniques in terms of the increased loading parameter of the Nigerian power system which gives room for voltage stability margin improvement.The tuned UPFC device has provedbeyond reasonable doubt that it can improve voltagestability margin of the entire Nigerian 330KV Network.

***Keywords**:- Artificial Bee Colony, Bacterial Foraging Algorithm, Cuckoo Search Algorithm, Particle Swarm Optimization, Voltage stability margin, UPFC.*

I. INTRODUCTION

Power Transmission lines are loaded heavily nowadays because of the considerable amount of time and heavy capital cost of building new lines. New installations of power stations and other facilities are primarily determined based on environmental and economic reasons. Due to these reasons power transmission has to rely on the existing transmission system. This results in deteriorating voltage profiles and voltage instability which leads to system black out [1].

As power system reaches voltage stability limit, voltage of several buses in the network diminishesquickly for small growthsin load. Designated control measures or Human operators could not be able to avertvoltage decline. Often times the response of control measures or operating personnel might worsen the condition and the eventualconsequence is voltage collapse.Reactive power provision increases load ability of a bus in the power system. Real and reactive power losses increase rapidlywhen the system approaches the maximum loading point or voltage collapse point.

Operational problems in power transmission system are mitigated by promising device known as Flexible AC Transmission (FACTS). This device has the capability for quick response and injection of active and reactive power to control the flow of electric power via transmission corridors. The voltage levels are enhanced as a result and the voltage stability margin is increased correspondingly.Though, position and parameters of FACTS devices should be optimized to exploit the resulting benefits. FACTS technology is very expensive and therefore must be deployed and tuned best possible in electric grid network. Optimal location and tuning of FACTS technology in power system network is key for voltage stability marginimprovement [2][3].Rest of the paper is organized as follows: Section II introduces Voltage stability Phenomenon; Section III presents mathematical representation of Power Systems. Section IV shows line stability index to detect the weakest bus in the Nigerian 330kV network. Section V discusses continuation power flow analysis and optimization techniques used, algorithms considered for optimizing FACTS devices are presented in section VI, modeling of UPFC device, problem formulation, test system and analysis tools are presented in section VII, in section VIII, some interesting results are presented along with detailed discussion and finally; contribution and conclusion are summarized in Section IX.

II. VOLTAGE STABILITY

The ability of the system to maintain the satisfactory voltages at all the buses before and after being subjected to a disturbance is termed voltage stability. The reactive power injection at a bus in power system is key to voltage control and enhancement. Shortage of reactive power at any a bus in the networkis the key reason for voltage instability [4]. Reactive power insufficiency in the system causes voltage instability. It is not easy to estimate the reactive power margin required to achieve a certaindegree of voltage security, in this way it is different from the active power.

The voltage collapse studycan be realized from dynamic and static methods. For the purpose of this paper, only static method will be discussed. Static or Steady state method is analyzed in detail from load flow studies [5]. Determination of the voltage stability margin can be achieved from the PV curves. As the system loading is varied two different solution emerges. Maximum load ability occurs when these two solution coalesce at a point[6].

III. MATHEMATICAL REPRESENTATION OF POWER SYSTEMS

A power system can be mathematically formulated as follows:

$M\dot{Z}$ = f (z, u,λ)

0 = g(z, u,λ) 1

Where:

$z\epsilon\mathcal{R}^n$ shows the system state variables suchas the dynamic states of generators, loads, etc...,$u\mathcal{R}^n$ represents the algebraic variablescorresponding to the steady state element models,$\lambda\epsilon\,\Re^1$ represents a set of uncontrolled variablethat drive the system to voltage collapse,f (z,u, λ) represents a vector function of thedifferential equations, g (z, u, λ) groups all termsrepresenting algebraic equations.

M: is a constant positive definite matrix.

The system model can be reduced by the term

$M\dot{Z}$ = f (z,h(z,λ), λ) = s(z,λ) 2

A saddle node bifurcation of the system (2) when the jacobian D,s(z,λ) z is singular at equilibrium point ($Z_{0,}\lambda_0$) where two solutions of the system, stable and unstable, merge and then disappear as the parameter λ , i.e. system load changes. At the bifurcation point ($Z_{0,}\lambda_0$)the jacobian$D_z s(z,\lambda)$ has a simple and unique zero eigenvalue with normalized right eigenvector v and left eigenvector *w*.

D_zs ($Z_{0,}\lambda_0$)v =0

$W^T D_z$s ($Z_{0,}\lambda_0$)v =0^T

$W^T \frac{\partial s}{\partial \lambda}/(Z_{0,}\lambda_0$)≠ 03

$W^T\left[D_z^2\text{s}\ (Z_{0,}\lambda_0)\text{v}\right]v \neq 0$**[7]**

IV. LINE STABILITY INDEX (LMN)

Voltage stability analysis can be carried out using various indices. This paper considers line stability index to identify the weak buses in Nigerian 56-bus Network.

A. A mathematical representation of the line stability index is as follows:

The line stability index is given as

$L_{mn} = \frac{4Q_m X}{[V_k \sin(\theta-\delta)]2}$ 4

When L_{mn} values of a line approaches unity it means that the line is approaching its stability limits. The L_{mn} values of all the lines must be lower than 1 to assure the stability of power system.

Voltage stability index L

$L_j = 1 - \sum_{i=1}^{i=g} F_{ji}\frac{V_i}{V_j}$

Voltage stability index L is used for monitor the voltages of the buses. P. Kessel **and Glavitsch H. (1986),** derived L index **Kessel P., based** on load flow results. L index is given as

Where g= no of generators

$V_i$is the ith bus voltage

$V_j$is the jth bus voltage

$F_{ji}$is the element of F matrix

The L-indices are calculated for all load buses. L-index calculation is simple and results are consistent [8][9].

V. CONTINUATION POWER FLOW (CPF)

Determination of the proximity to saddle node bifurcations can be achieved with continuation methods.

Continuation power flows trace the solution of the power flow equations (z,λ) = 0, where the parameter λ stands for the loading factor. The method can be summarized in two steps: [10].

Predictor Step:

At a generic equilibrium point p, the followingrelation applies:

f (X_p,λ_p) = 0 ⇒$\frac{df}{d\lambda_p}$=0 = $D_z f_p \frac{dx}{d\lambda_p}$ + $\frac{df}{d\lambda_p}$5

And the tangent vector can be approximated by:τ_p=$\frac{dx}{d\lambda_p} \approx \frac{\Delta x_p}{\Delta\lambda_p}$6

From 5 and 6

$\tau_p = D_z f_p \frac{df}{d\lambda_p}$ 7

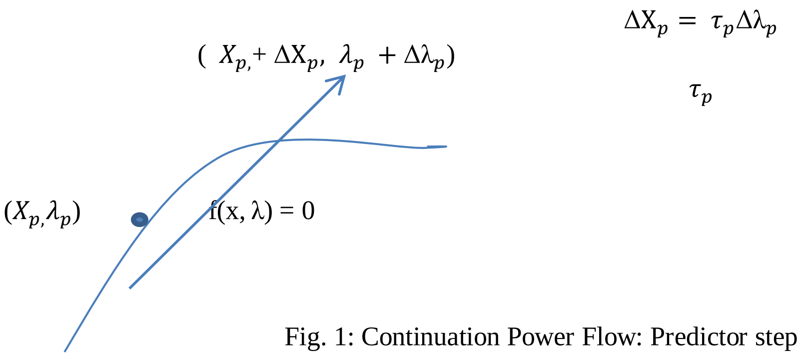

Fig. 1: Continuation Power Flow: Predictor step obtained by means of tangent

At this point a step size control k has to be chosen for determining the increment ΔX_p and $\Delta\lambda_p$along with a normalization to avoid large steps when $\|\tau_p\|$ is large**:**

$$\Delta\lambda_p \triangleq \frac{k}{\|\tau_p\|} \Delta X_p \triangleq \frac{k\tau_p}{\|\tau_p\|}$$
8

where $\|.\|$is the Euclidean norm and K= ±1 .The sign of k determines the increase or the decrease ofλ. Figure 1 presents a pictorial representation of the predictor step.

Corrector Step:
In the corrector step, a set of n+ 1 equation is solved:

$f(x, \lambda) = 0$
$\eta(x, \lambda) = 0$ 9

Where the solution of f must be in the bifurcation manifold and η is an additional equation toguarantee a non-singular set at the bifurcation point. For the choice of η there are two options: the perpendicular intersection $\eta$and the local parameterization [10]. In case of perpendicular intersection, whose pictorial representation is depicted in Figure 2, the expression of ηbecomes:

$$\eta(x, \lambda) = \begin{bmatrix} \Delta X_p \\ \Delta\lambda_p \end{bmatrix}^T \begin{bmatrix} x_c - (x_p + \Delta X_p) \\ \lambda_c - (\lambda_p - \Delta\lambda_p) \end{bmatrix} = 0 \quad 10$$

Whereas for the local parameterization, either the parameter λor a variable x_i is forced to be a fixed value:
$\eta(x, \lambda) = \lambda_c - \lambda_p - \Delta x_p$ 11

Or $\eta(x, \lambda) = x_{c\,i} - x_{pi} - \Delta x_{pi}$

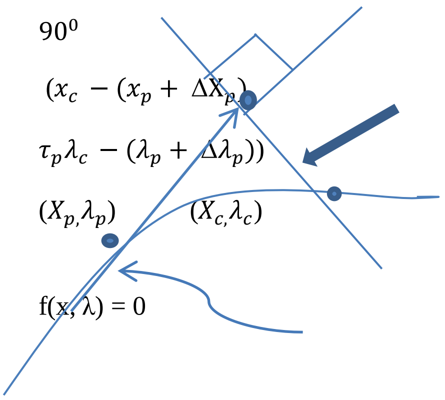

Fig. 2: Continuation Power Flow: Corrector Step Obtained by Means of Perpendicular Intersection.

The choice of the variable to be fixed depends on bifurcation manifold of f, as depicted in Fig3 3

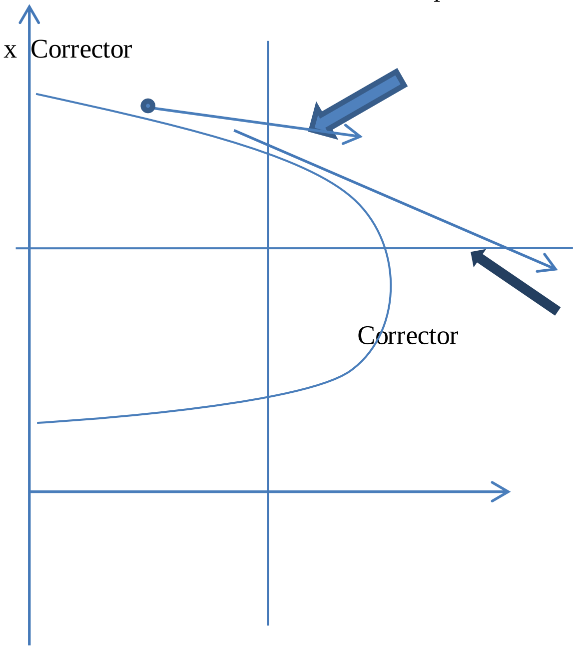

Fig. 3: Continuation Power Flow: Corrector Step Obtained by Means of Local Parameterization Intersection

VI. ALGORITHMS CONSIDERED FOR OPTIMIZING OF FACTS DEVICES

A. Particle Swarm Optimization

Social science and computer science are two the field of knowledge that gave birth to PSO.PSO uses swarm intelligencemodel as well, whereby the cooperative behaviors of agents interact locally with their surroundingsand formcoherent global patterns.

In the real number space, each discrete possible solution can be modeled as a particle that navigates through the problem hyperspace. The position of each particle is determined by the vector $X_i \epsilon R^n$and its movement by the velocity of the particle$V_i \in R^n$, as shown in (12).

$$x_i^{\rightarrow}(t) = x_{(i)}^{-}(\text{t-1}) + V_I^{\rightarrow}(t)12$$

The intelligence available for each individual is based on its own experience and the knowledge of the performance of other individuals in its neighborhood. Since the relative importance of these two factors can vary from one decision to another, it is rational to apply random weights to each factor, and therefore the velocity will be determined by:

$$v_i^{\rightarrow}(\text{t}) = v_i^{\rightarrow}(\text{t - 1}) + \varphi_1 . rand_1 .(P_i^{\rightarrow} - x_i^{\rightarrow}(t-1)) + \varphi_2 . rand_2 .(P_g^{\rightarrow} - x_i^{\rightarrow}(t-1))13$$

Where:φ_1,φ_2 are two positive numbers, called acceleration constants*rand1*, *rand2* are two random numbers with uniform distribution in the range of [0.0, 1.0].

$P_i$is the best position that the corresponding particle has found so far, $P_g$is the best position of the entire swarm[11][12][13].

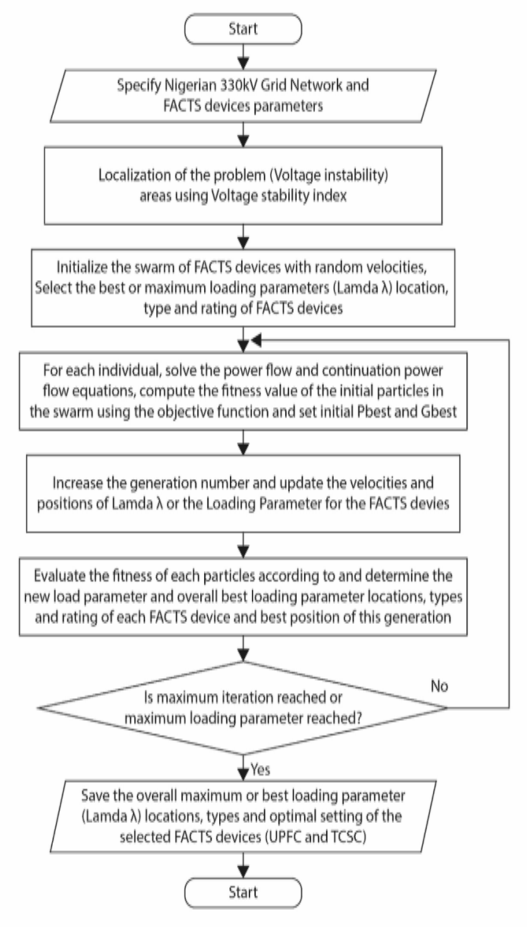

Fig. 4: Proposed Particle Swarm Optimization Flowchart

B. *Cuckoo Search Algorithm*

Aninnovative fact-finding optimization algorithm known as cuckoo search is stimulated by some species of a bird family called cuckoo because of their special lifestyle and aggressive reproduction strategy. CSA uses fewer parameters namely: the number of nests (N_p), maximum number of iterations ($Iter_{max}$) and the probability of an alien egg to be discovered (pa). It can have its value chosen in the range [0, 1]. These parameters have to be predetermined; the stopping criterion for the algorithm is the maximum number of iterations. In addition, solution quality of the algorithm depends largely on the number of nests and the higher number of N_p is chosen, the higher probability for a better optimal solution to be obtained. CSA uses Lévy flights; a sequence of straight flight paths with sudden 900 turn [18][19] [20][21]. The step lengths are generally distributed based on longlikelihood distribution. A lévy flight is performed, if new solution (X^{t+1}) is to be generated and is given by;

$X_i^{(t+1)} = X_i^t + \alpha \oplus$ Levy (λ)14

Where;
α= step size (usually α > 0)
$\oplus$ = entry wise multiplications.

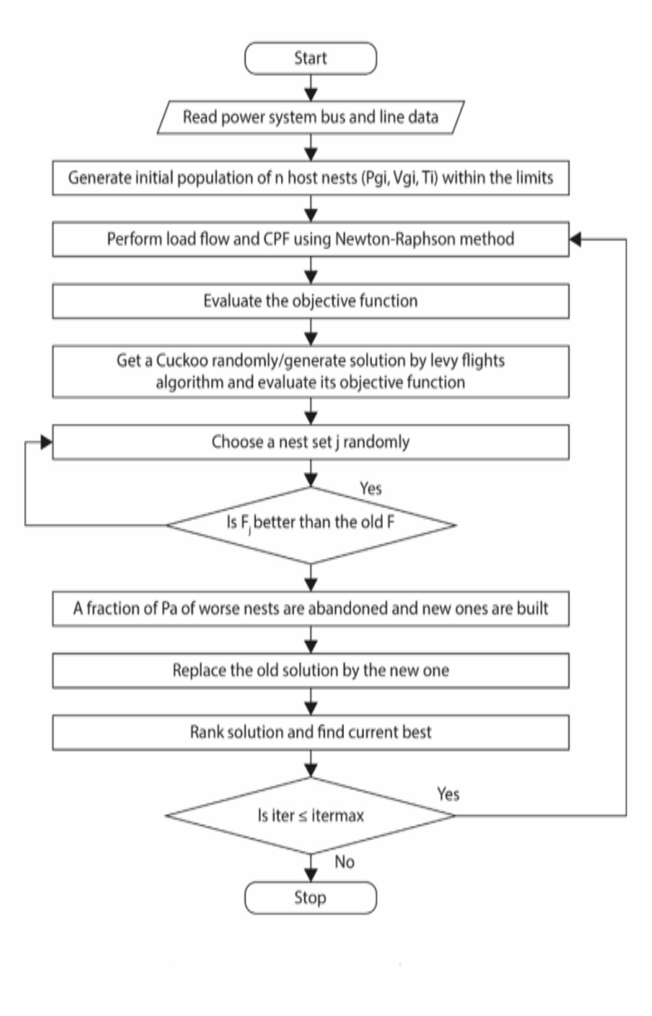

Fig. 5: Proposed Cuckoo Search Optimization Flowchart

C. *Bacterial Foraging Algorithm*

The BFA is focused on the movement patterns of E. coli in the intestines. Each individual, in this case a bacterium, represents a possible solution to the problem. The algorithm considers four sequential processes: Chemotaxis, Swarming, and Reproduction and Elimination dispersal[18][19].

The bacteria moving towards better nutrient foci can be represented by:

$J(\text{ i, k, l}) + J_{cc}(\theta, P\ )$ 15

Where
J(i, k, l) is the fitness function

c) Reproduction: after *Nc*chemotactic steps, the population of bacteria is allowed to reproduce. *Sr*(*Sr=S/2*) bacteria having the worst fitness function value die and the remaining *Sr*are allowed to split into two thus keeping the population size constant.

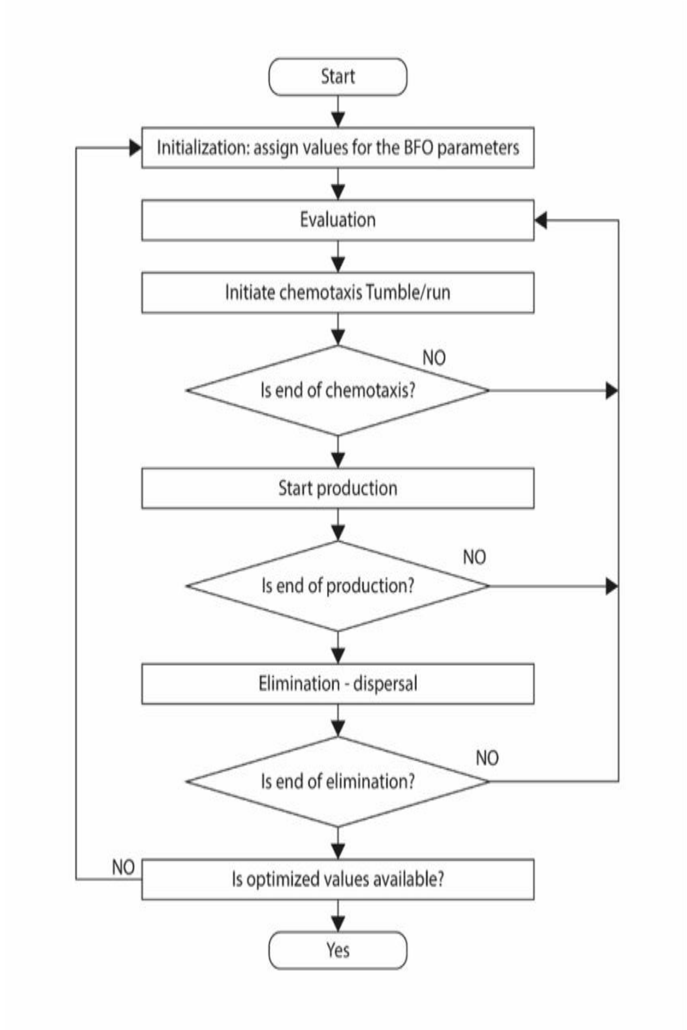

Fig. 6: Proposed Bacterial Foraging Optimization Flowchart

D. Artificial Bee Colony

Food foraging techniques ofreal honey bees is what ABC uses in carrying out the optimizing method. The colony of artificial bees comprises of three groups of bees: employed bees, onlookers and scouts. Every employed bee is connected with only one food source. The number of employed bees is equal to the number of food sources which correspond to solutions of a given problem. Both onlookers and scouts are also called unemployed bees. Onlooker bees watch the dance of employed bees within the hive to choose a food source. Scout bees search for food sources in random fashion. The nectar of food sources is exploited by employed bees and onlooker bees. If the existing nectar quality is better than the previous value then it discards the earlier nectar and adopts new one.

The employed bees move towards the food source from its original position to new position. The new food source position is given by

$$X_{ij} = X_j^{min} + \text{rand } (0,1)*(X_j^{max} - X_j^{min} \quad (16)$$

X_j^{max} , X_j^{min} are upper and lower limits of the food source position in dimension j, The new food source position is determined for all the constraints accordingly. If any one of the limitations is disregarded, at that point max limit is set [20][21].

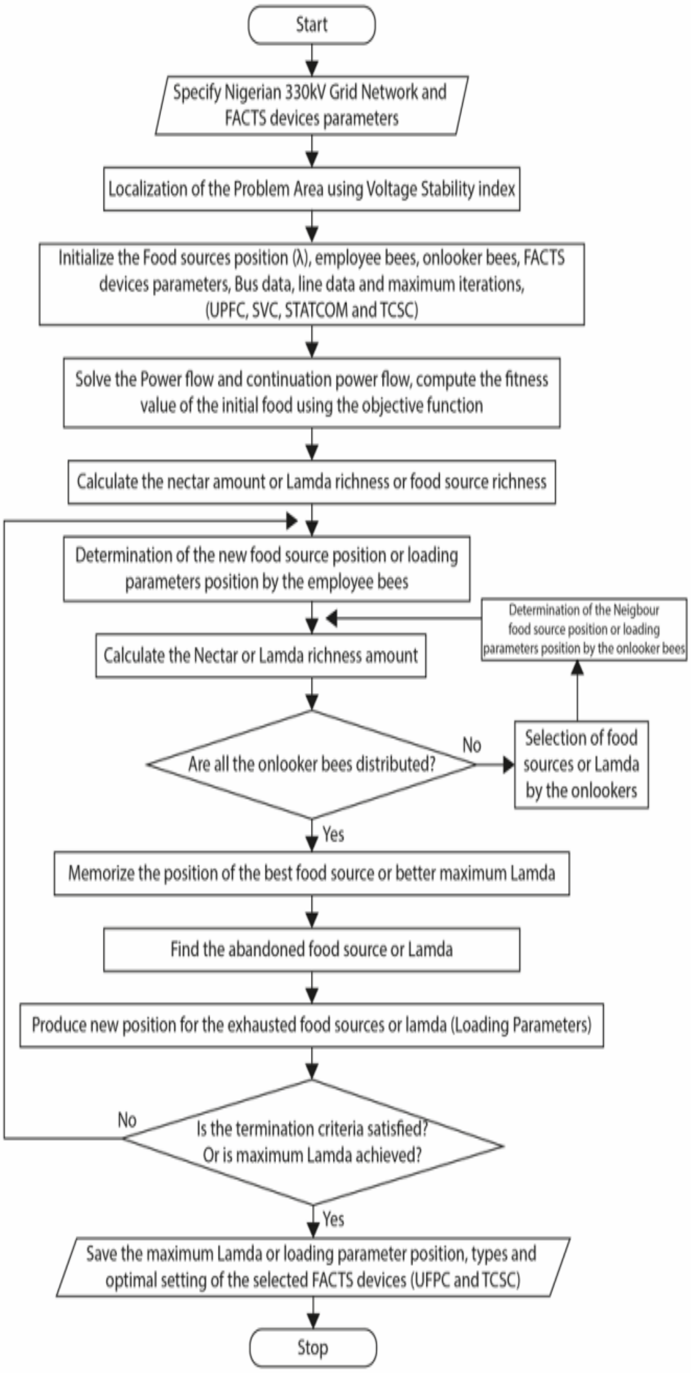

Fig. 7: Proposed Artificial Bee Colony Optimization Flowchart

S/N	Techniques	Strength	Weaknesses
1	Particle Swarm Optimization	It has speed of convergence	It is prone to premature convergence
2	Artificial Bee Colony Optimization	Premature convergence problems are prohibited	Slow to obtain accurate solutions
3	Cuckoo Search Colony Optimization	Global convergence is guaranteed	Slow to obtain accurate solutions.
4	Bacteria Foraging Optimization	It is characterized with less computational burden, Also, global convergence is guaranteed.	Reaching the global solution is delayed.

Table 1: Comparison among PSO, ABC, BFO and CS Techniques

Sr. N0.	Parameter	Values
1	Dimension	2
2	Number of Bacteria	20
3	Maximum number of steps,N	10
4	Maximun Number of chemotactic steps	20
5	Number of Chemotactic Steps, Nc	10
6	Number of reproduction Steps Nre	20
7	Number of Elimination Dispersal Steps Ned	100
8	Probability, Ped	0.9
9	Size of Step, C(i)	0.01

Table 2: Bacteria Foraging Parameters

Sr. N0.	Parameter	Values
1	Dimension	4
2	Number of Runs	20
3	Number of Population	20
4	Food Number	10
5	Limit	100
6	maxCycle	100
7	Ub (Upper Bound)	50
8	lb (Lower Bound)	1

Table 3: Artificial Bee Colony Parameters

Sr. N0.	Parameter	Values
1	npar	100
2	Varlo	-5
3	Number of Population	10
4	varHi	5
5	nC	5
6	maxCycle	100
7	Min Egg	2
8	Max Egg	4
9	N0. Clusters	1
10	Lambda var	9
11	Control of Egg	5

Table 4: Cuckoo Search Parameters

Sr. N0.	Parameter	Values
1	Acceleration Const. 1	2
2	Acceleration Const. 2	2
3	Max. Veocity	4
4	Number of Population	24
5	Limit	100
6	maxCycle	2000
7	Number of Runs	150
8	Initial weight	0.9
9	Final weight	0.4

Table 5: Particle Swarm Optimization Parameters

VII. UPFC MODEL, PROBLEM FORMULATION, TEST SYSTEM AND ANALYSIS TOOLS

The unified power flow controller (UPFC) is the most all-encompassing device to have sprungup so far from the FACTS ingenuity. UPFC device offers new prospects in terms of power system control, with the potential to independently control three power system parameters such as bus voltage, line active and reactive power. Provided no operating limits are violated, the UPFC regulates all three variables simultaneously or any combination of them. UPFC control can change line flow in such a way that thermal limits are not violated and stability margin increased [22] [23].

The configuration of UPFC and its model for representing power flow are depicted in Fig. 8. UPFC is used to control the real power flow in the power transmission line using its both voltage source converters (VSCs)[24].

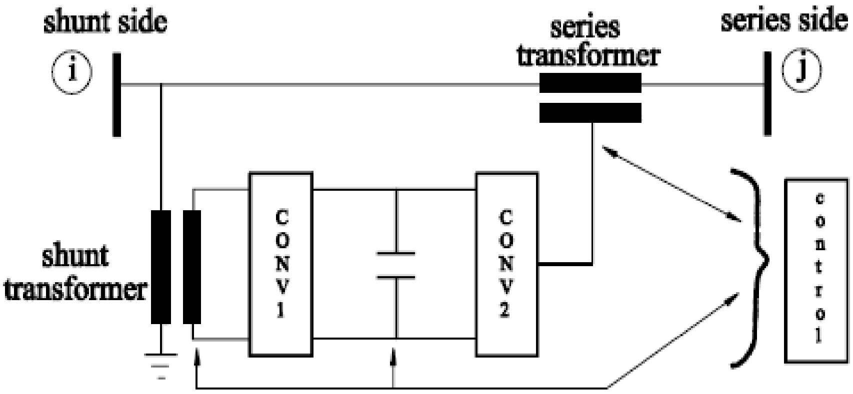

Fig. 8: The UPFC device circuit arrangement [14]

(UPFC) with injection model is connected at suitable location in the system. The UPFC injection model is shown is figure9

$V_i < \theta_i V_j < \theta$

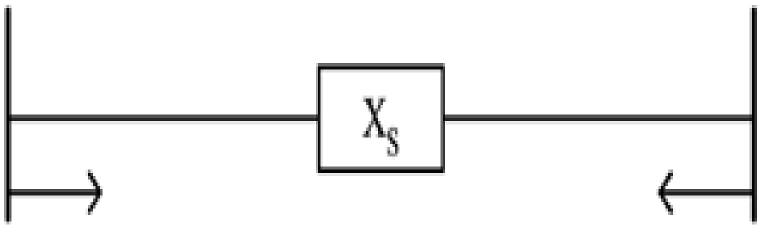

Fig. 9: UPFC injection model. [25]

$P_{si} = r_{bs} V_i V_j \sin(\theta_{ij} + \gamma)$
$Q_{si} = r_{bs} V_i^2 \cos\gamma$
$P_{sj} = - r_{bs} V_i V_j \sin(\theta_{ij} + \gamma)$ 17
$Q_{sj} = - r_{bs} V_i V_j \cos((\theta_{ij} + \boldsymbol{\lambda})$

The UPFC components are stored in the structure UPFC in PSAT which has the following fields:

- con: UPFC data.
- n: total number of UPFC.
- bus1: bus numbers k (from).
- bus2: bus numbers m (to).
- dat: UPFC parameters.
- Vdc: indexes of the state variable Vdc.
- alpha: indexes of the state variable α.
- Gamma ($\boldsymbol{\gamma}$)
- Voltage ratio (**r**)[22].

The objective is the maximization of the loading parameter λ to improve voltage stability.

From the load flow solutions of the developed model stated above L-index is obtained to identify the weakest bus which is subsequently loaded to a maximum loading limit.

In continuation power flow, the power flow equations are expressed as a function of voltage V, angle of the buses δ and load parameter λ. Reformulated power flow equations at a bus i are$\Delta P_{i=} P_{Gi}(V, \delta, \lambda) - P_{Li}(V, \delta, \lambda) - P_{Inji=}0)$ 18

$\Delta Q_{i=} Q_{Gi}(V, \delta, \lambda) - Q_{Li}(V, \delta, \lambda) - Q_{Inji=}0)$ 19

Where

$P_{inji} = \sum_{j=1}^{n} V_i V_j y_{ij} \cos(\delta_i - \delta_j - \theta_i))$
20

$Q_{Inji=} \sum_{j=1}^{n} V_i V_j y_{ij} \sin(\delta_i - \delta_j - \theta_i))$
21

And $0 \leq \lambda \leq \lambda_{cr}$

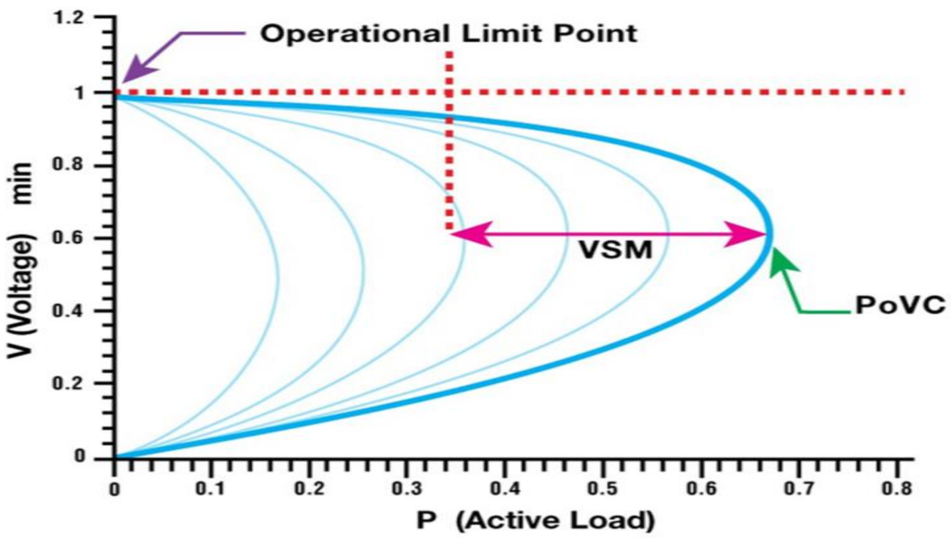

Fig. 10: Voltage Stability Margin Curve [26]

For simulating different load change scenarios, loads are modified as

$P_{Li}(\lambda) = P_{Lio}[1 + \lambda K_{Li}])$ 22

$Q_{Li}(\lambda) = P_{Lio} \tan(\Phi_i) [1 + \lambda K_{Li}]$ 23

where P_{Lio}, Q_{Lio} are the base real and reactive load at bus i. $K_{Li}$is multiplier designating the rate of load change at bus i as λ changes. $\Phi_i$is power factor of load at bus i.

The real power generation is modified to

$P_{Gi}(\lambda) = P_{Gio}[1 + \lambda K_{Gi}]$24

VIII. TEST SYSTEM AND ANALYSIS TOOLS

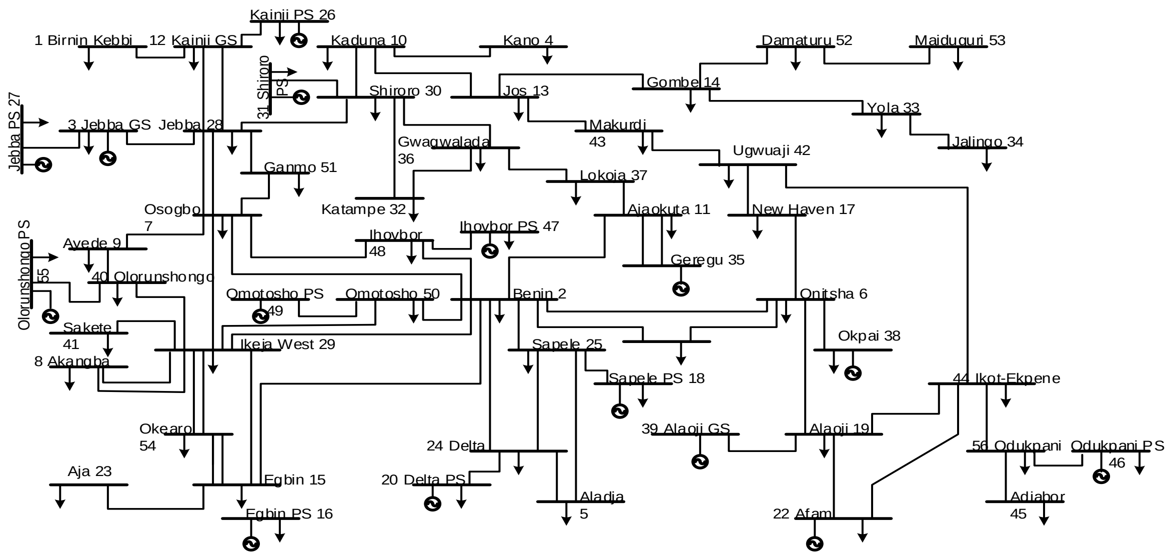

Fig. 11: Single line diagram of 56-bus Nigerian National Grid

Simulations were carried on Nigerian 56- bus practical test system. This network has 14 generators busbars, 42 load busesand 67 lines. The network data is obtained from Transmission Company of Nigeria data bank. The aim of the simulations is to compare the performance of the four different meta-heuristic techniques ontuning UPFC device for voltage stability improvement. All the results are produced with the helpof a program developed in PSAT. PSAT is a Matlab toolbox for electric power system analysis and control. Once the power flow has been solved, further static and/or dynamic analysis can be performed.

IX. RESULTS AND DISCUSSIONS

A. Weak Bus and L-Index

The best location for reactive power compensation for the improvement of static voltage stability margin is the weakest bus of the system. The most vunerable bus of the system can be identified by using the line stability index as shown inequation 4 abovefor a given load condition, and is computed for all load buses. The estimated value of L-index is varying between 0 and 1. Based on this value, we can able to identify the weakest bus in the system.The main purpose of line stability index is to find out the point of voltage instability and weak buses in the system. The analysis and study of system is done for detecting the weakest area of the system. This analysis was done on the Nigerian 56 bus System. The weakest bus is ranked the most severity because it can only handle a minimum load. If the load rises, the voltage collapses. Today, there is no venture in power businesswithout the hope of return and there is no energy supplied if it is not gainful [27]. The analytical result obtained from the index, helps to avoid voltage collapse and prevent the system from voltage instability.It is shown from Table below that the most susceptible line, which is line 49 is between bus 44 (Ikot-Ekpene) – bus 56 (Odukpani). Therefore, the optimal location for placement of UPFC device will be in line 49 between bus 44 (Ikot-Ekpene) **-** bus 56 (Odukpani).

Line no.	**From Bus**	**To Bus**	**Voltage Stability Index**
1	12	1	0.05681
2	3	12	0.02865
3	15	23	0.01289
4	3	30	0.02307
5	10	4	0.02224
6	10	13	0.02249
7	14	13	0.00476
8	2	11	0.19739
9	6	17	0.06288
10	19	6	0.12533
11	24	2	0.03591
12	25	5	0.01360
13	24	5	0.00406
14	9	29	0.17578
15	33	14	0.03538
16	34	33	0.05227
17	30	32	0.00141
18	28	3	0.00582
19	36	37	0.15673
20	32	36	0.04459
21	29	41	0.01042
22	42	17	0.01044
23	43	13	0.13231
24	22	19	0.03231
25	2	48	0.01293
26	7	48	0.07025
27	50	2	0.18203
28	30	10	0.00321
29	2	25	0.07360
30	51	7	0.03922
31	51	3	0.04665
32	15	54	0.00437
33	2	15	0.22900
34	29	50	0.16311
35	30	36	0.09802
36	7	29	0.25073
37	29	8	0.00522
38	42	44	0.23956
39	43	42	0.01570
40	3	7	0.07358
41	45	44	0.01492
42	52	14	0.00276
43	52	53	0.00356
44	7	9	0.12041

45	9	55	0.02881
46	29	55	0.24796
47	56	45	0.05943
48	22	44	0.10939
49	44	56	0.30368
50	2	6	0.14534
51	37	11	0.03440
52	15	29	0.01511
53	29	54	0.01335
54	16	15	0.09910
55	39	19	0.05981
56	40	55	0.01816
57	46	56	0.05454
58	47	48	0.08676
59	49	50	0.01375
60	26	12	0.00754
61	27	28	0.12140
62	21	22	0.00292
63	31	30	0.04632
64	20	24	0.00527
65	18	25	0.03002
66	35	11	0.03323
67	38	6	0.03337

Table 6: Line Stability Index Result for 56-bus Nigerian National Grid

Table 6: Cont'd

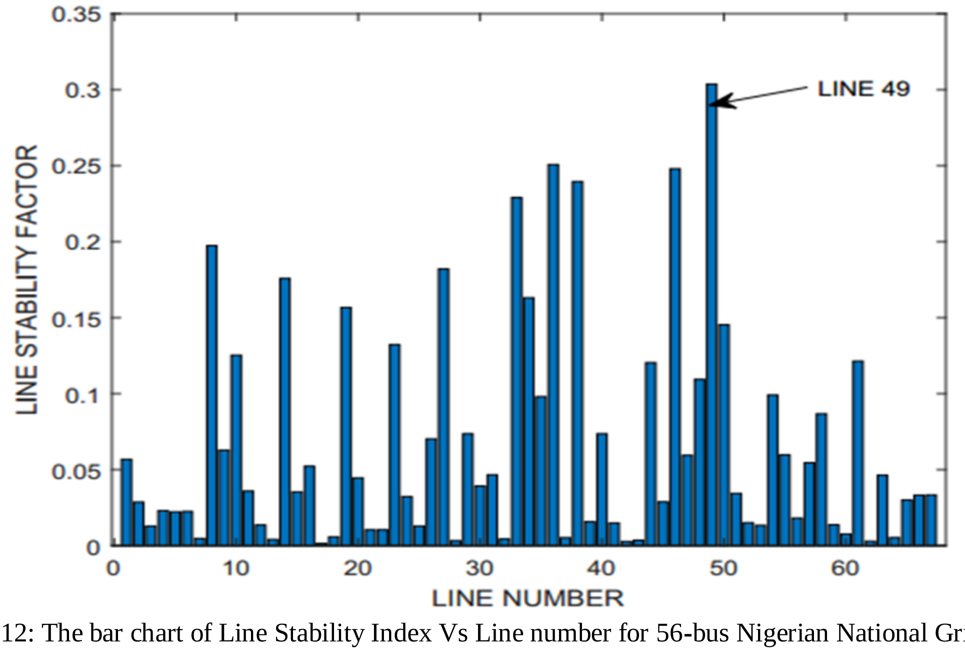

Fig. 12: The bar chart of Line Stability Index Vs Line number for 56-bus Nigerian National Grid.

B. Simulation for the tuning of UPFC device using PSO, ABC, BFO and Cuckoo Search Algorithmson Nigerian 330KV Network

The simulation started with Particle Swam Optimization algorithm then followed sequentially byArtificial Bee Colony,Bacterial Foraging and Cuckoo Search algorithms.The developed UPFC model in figures 8 and 9 above,for real and reactive power injections into the system was used to carry out the load flow studies in MATLAB environment with the aid of PSAT software by keeping the voltage ratio(r) of the system and UPFC constant while varying the gamma (γ) of the UPFC between 0 to 2π on the 330KV Nigerian network. The relationship amongvoltage ratio (r) of the UPFC and the system, Gamma $(\gamma)\ of\ the$UPFC device and loading parameter $(\lambda)$of the system is represented in equation 17 above.All the simulations results are shown below:

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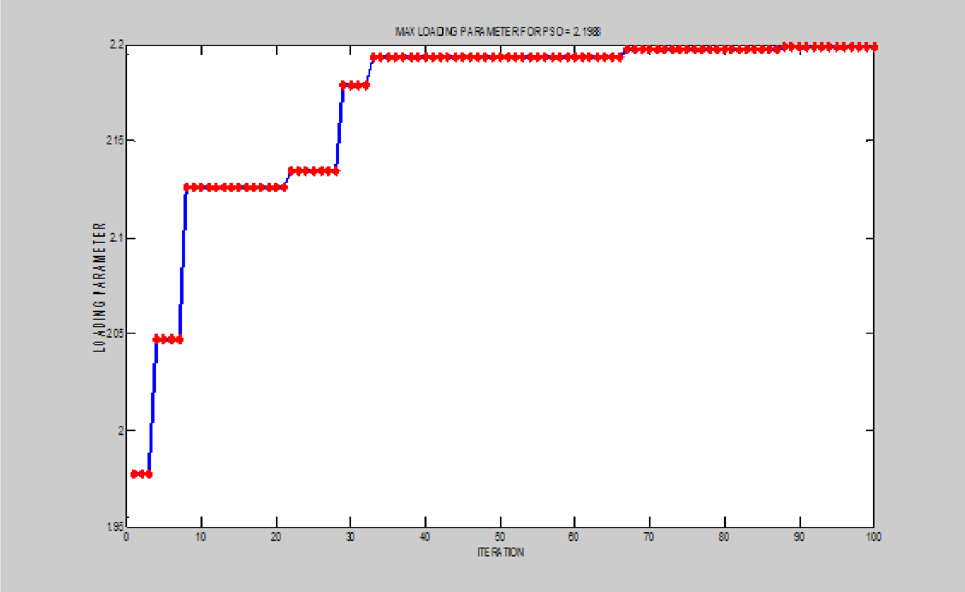

Fig. 13: This graph shows Particle Swarm Optimisation Algorithm Generation Versus Loading Parameter.

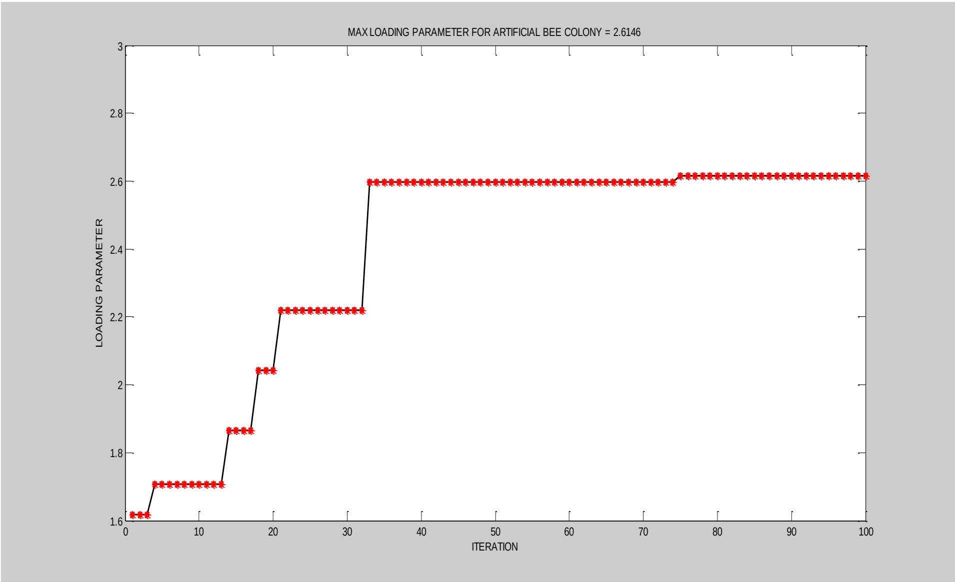

Fig. 14: This graph shows Artificial Bee Colony Algorithm Generation Versus Loading Parameter

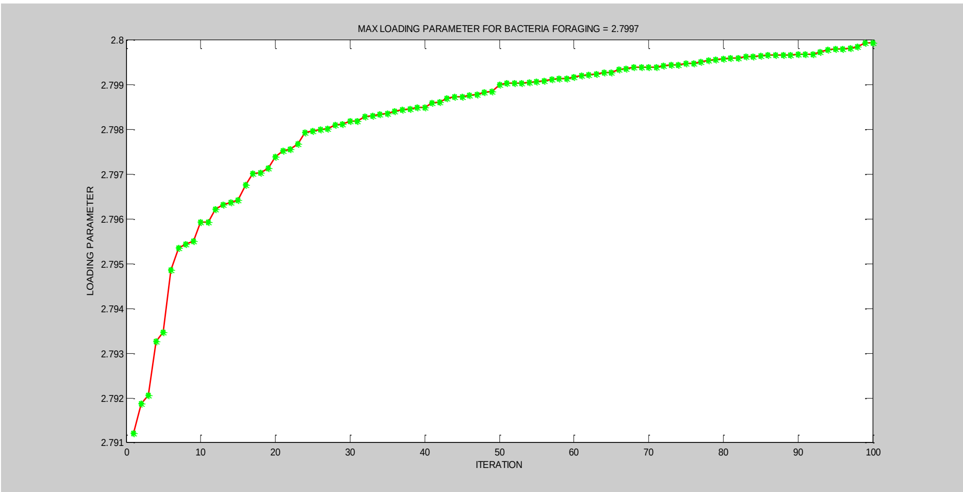

Fig. 15: This graph shows Bacterial Foraging Algorithm Generation Versus Loading Parameter

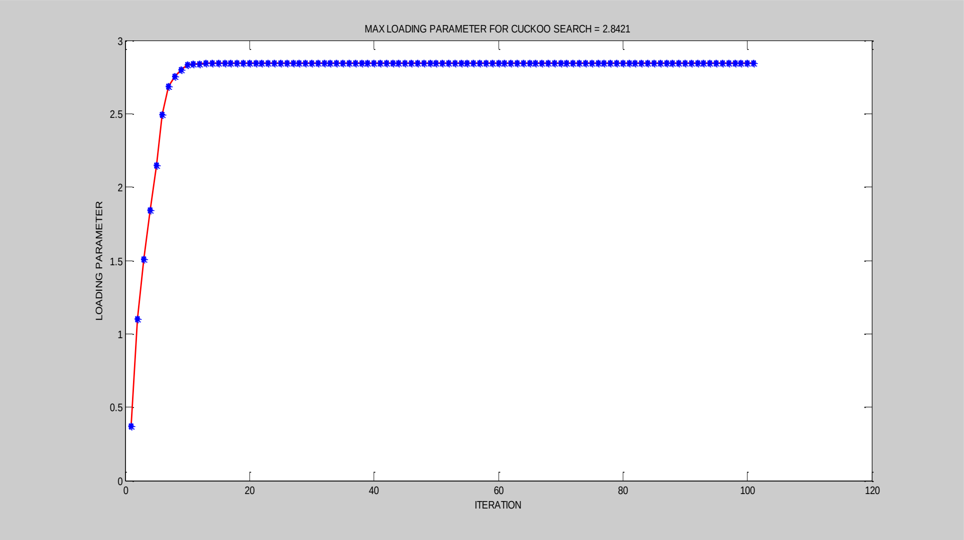

Fig. 16: This graph shows Cuckoo Search Algorithm Generation Versus Loading Parameter

From figures 13, 14, 15 and 16 above, the values of the loading parameter and corresponding gamma values are tabulated as shown below:

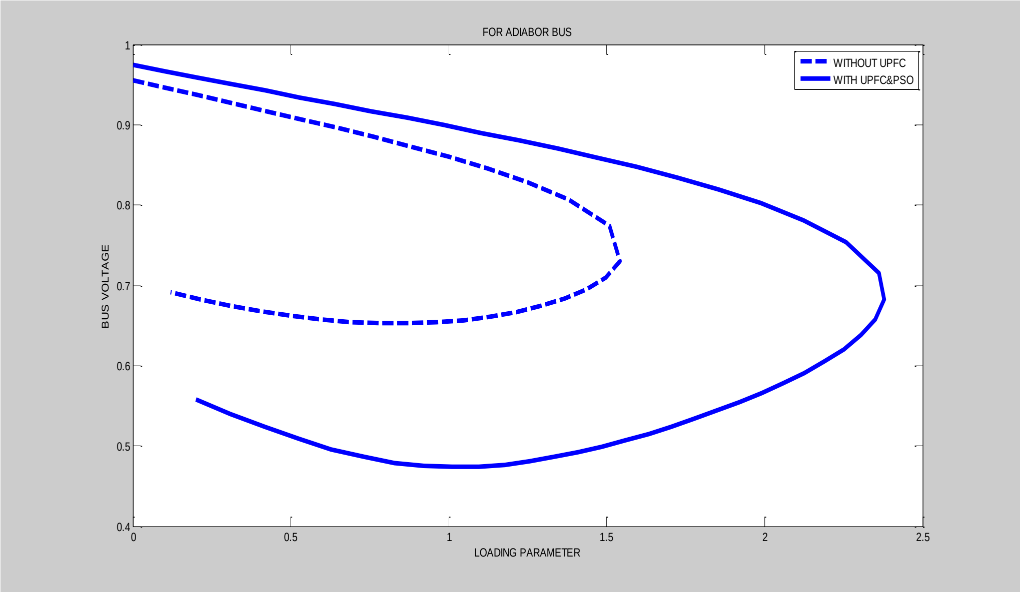

Fig. 17: Nose Curve for Adiabor buswithPSO

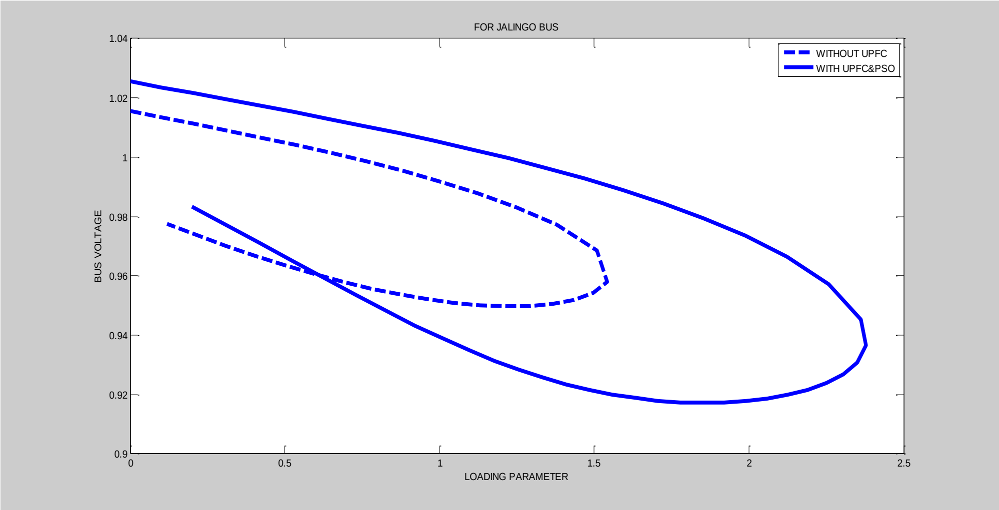

Fig. 18: Nose Curve forJalingo bus with PSO

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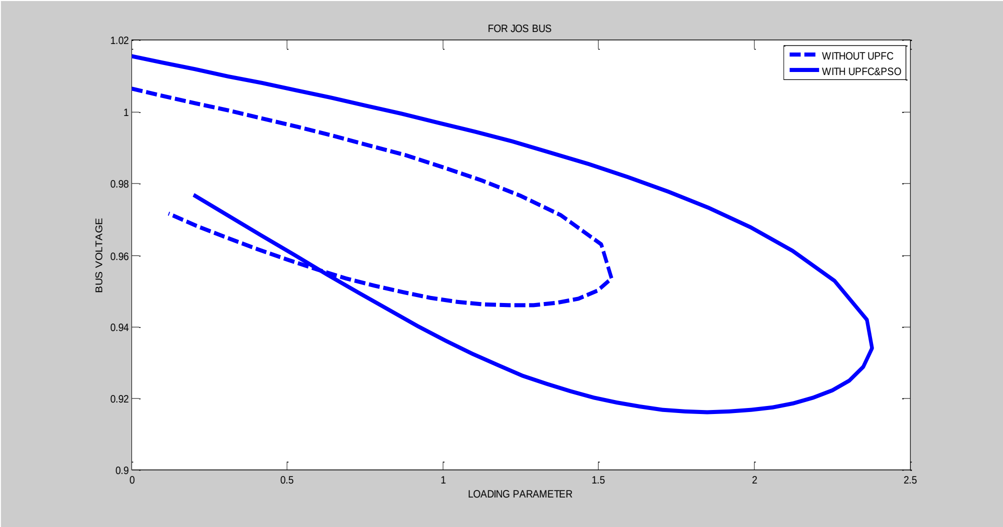

Fig. 19: Nose Curve for Jos buswith PSO

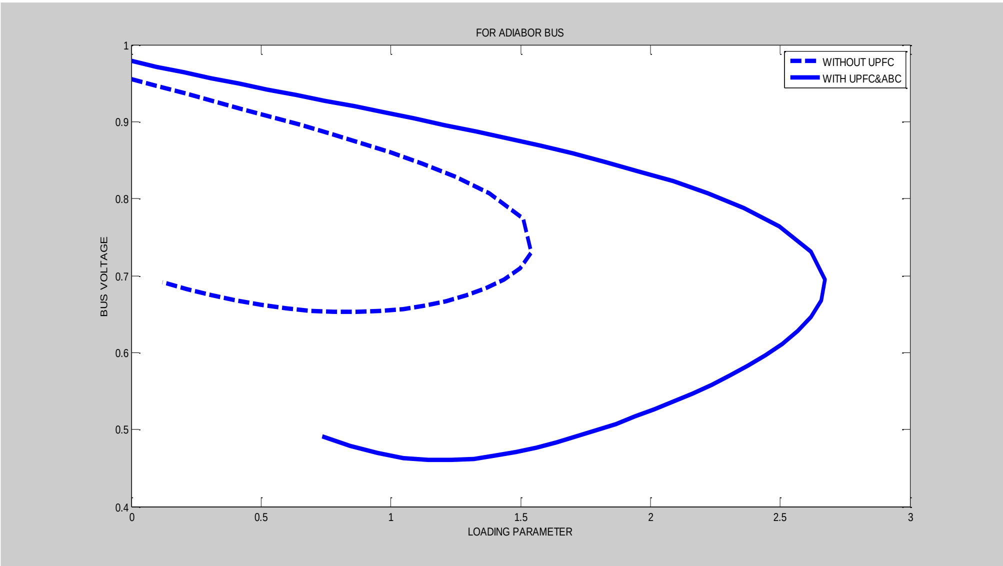

Fig. 20: Nose Curve for Adiabor bus with ABC

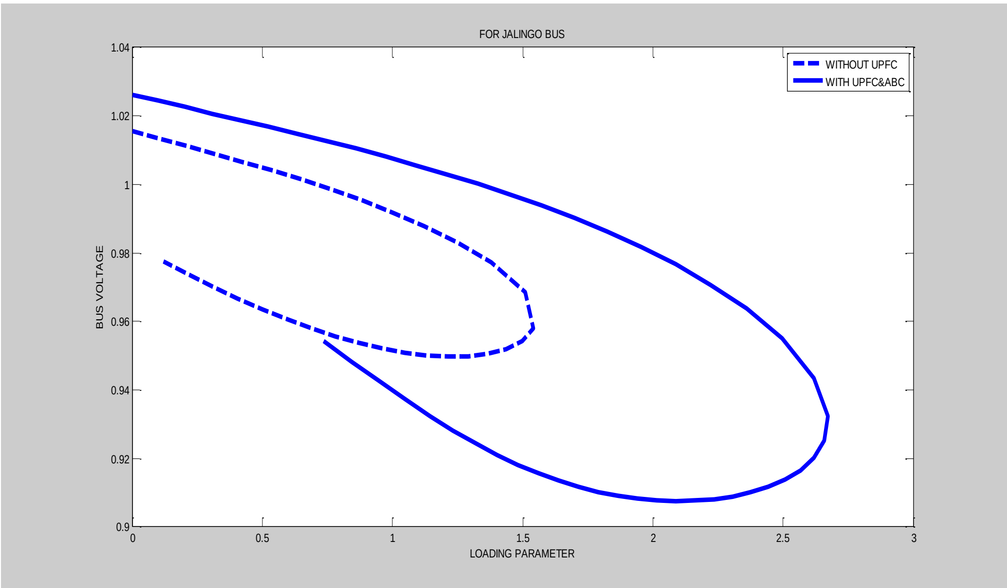

Fig. 21: Nose Curve for Jalingo buswith ABC

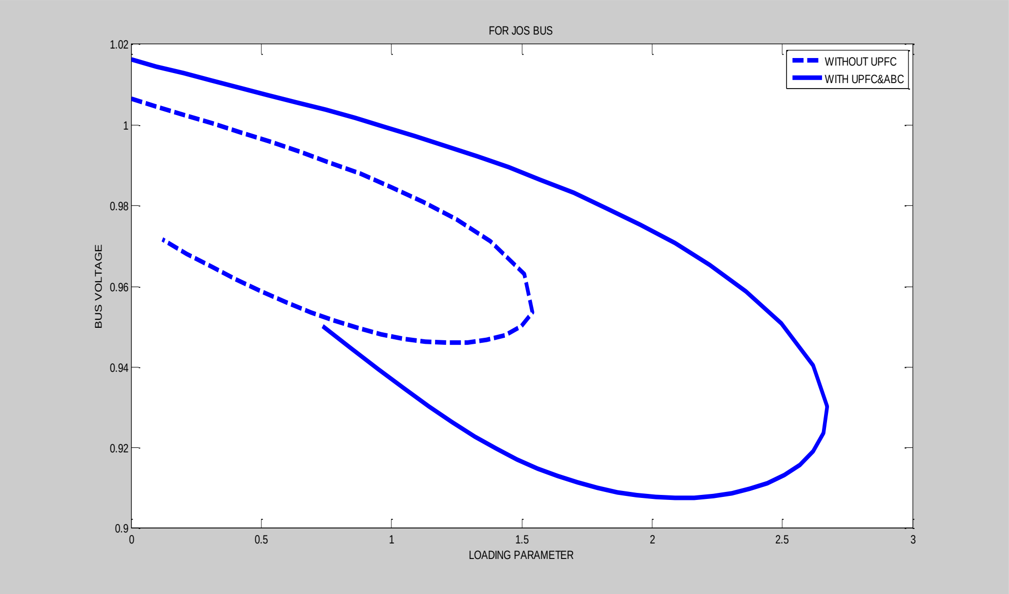

Fig. 22: Nose Curve forJos buswith ABC

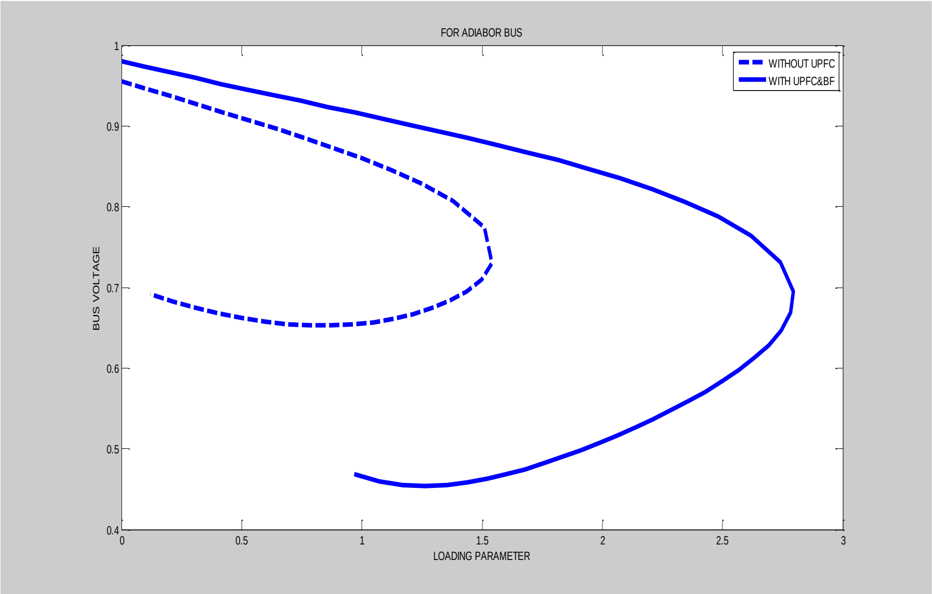

Fig. 23: Nose Curve for Adiaborwith BFO

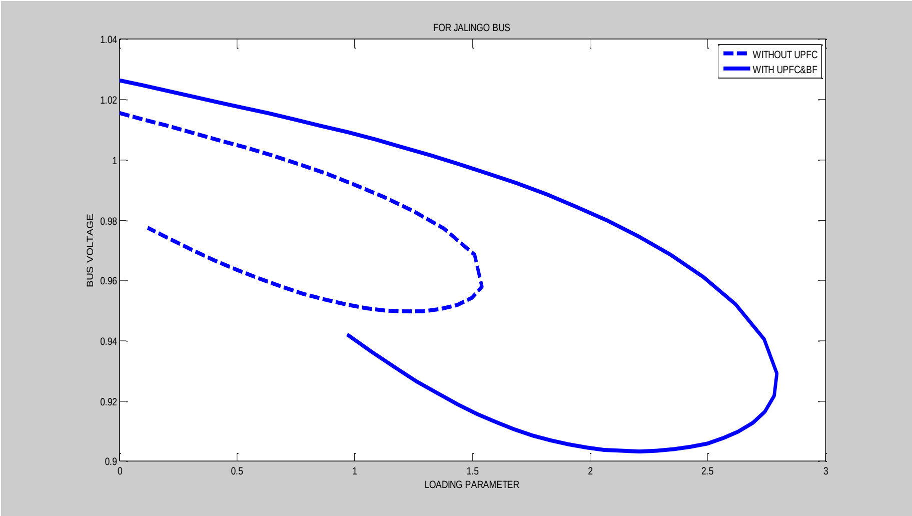

Fig. 24: Nose Curve for Jalingo buswith BFO

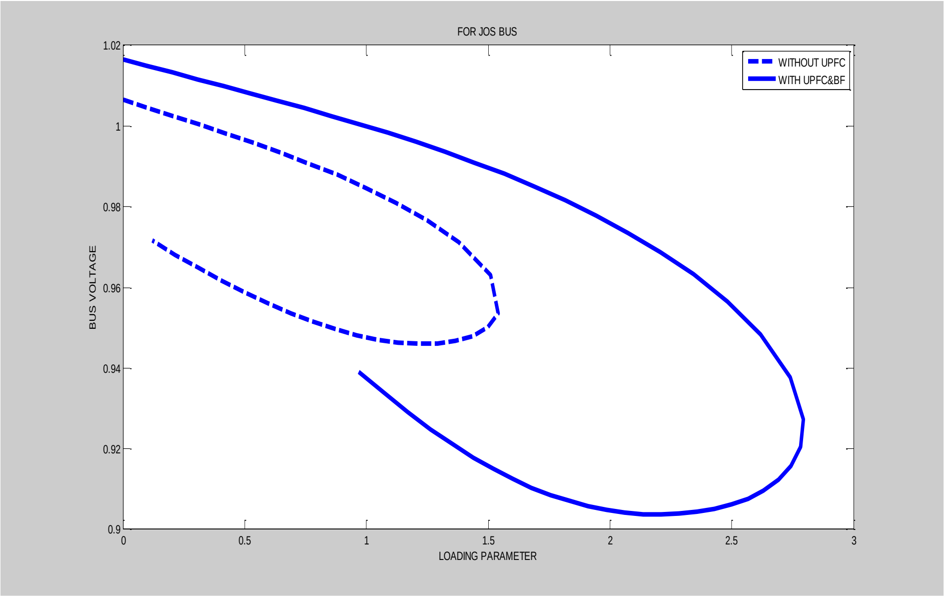

Fig. 25: Nose Curve for Jos bus with BFO

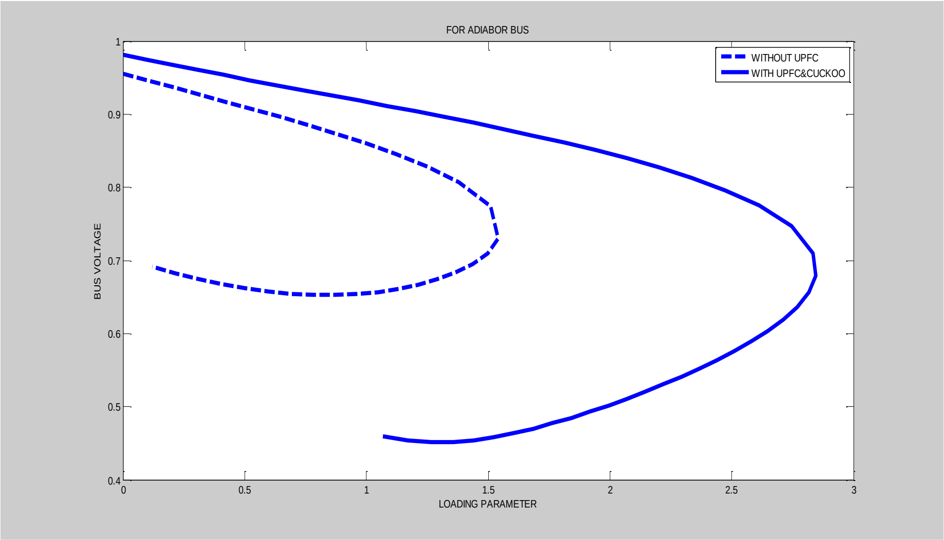

Fig. 26: Nose Curve for Adiabor bus with Cuckoo

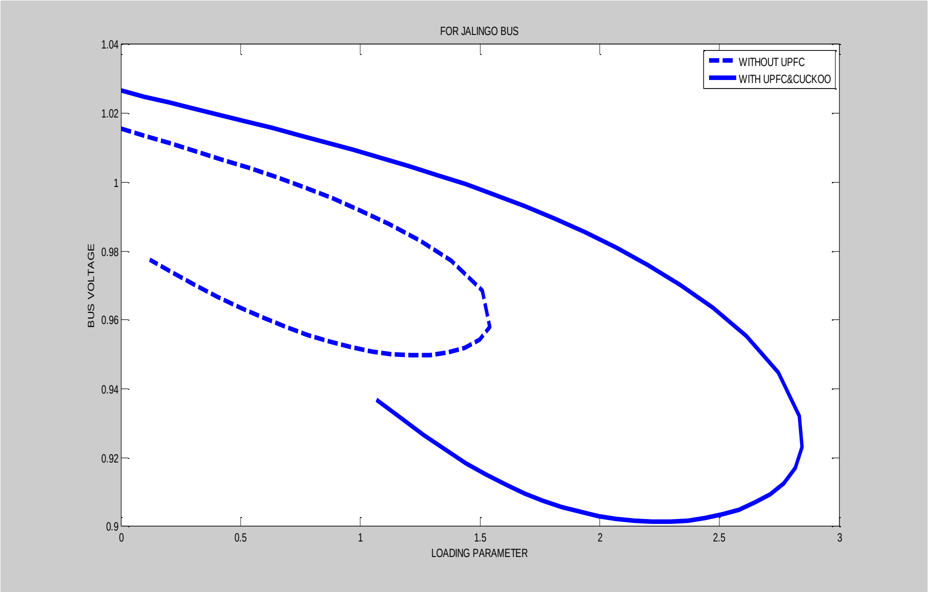

Fig. 27: Nose Curve for Jalingowith Cuckoo

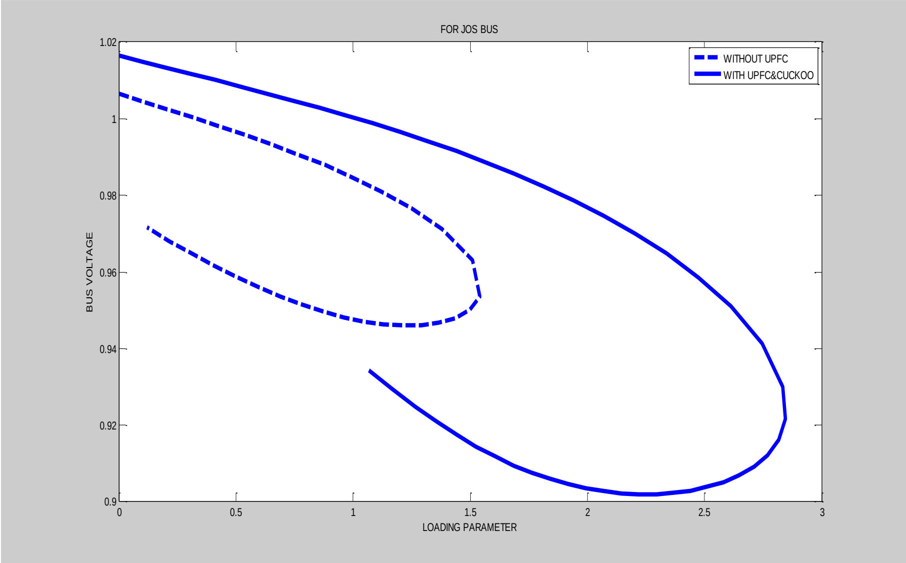

Fig. 28: Nose Curve for Jos bus with Cuckoo

S/N	Algorithm/Technique	Loading Parameters values (λ)	Gamma Values
1	Particle Swarm Optimisation	2.1988	1.41497
2	Artificial Bee Colony	2.6146	1.22649
3	Bacterial Foraging	2.7997	1.14976
4	Cuckoo Search	2.8421	1.11912

Table 7: Loading Parameters versus Gamma Values

The parameters of the UPFC are chosen based on static behavior of the UPFC. With the control variables r and γ, an improvement in the loading parameter as well as voltage stability of the Power system is achieved. The r is kept constant while γ is tuned with PSO, ABC, BFO and Cuckoo Search algorithms until the best value is gotten that yield the maximum voltage improvement. It is Gamma that determines the contribution of UPFC to the power system network improvement.

The PSO, ABC, BFO and Cuckoo Search techniques are used in turn to tune UPFC device Parameters on Nigerian 330KV Network. From figures 13, 14, 15 &16 and table 7 above it can be seen that the cuckoo Search has the highest and best loading parameter and smallest gamma values. This implies that the cuckoo Search algorithm outperforms all the three algorithms, followed sequentially by BFO, ABC and lastly PSO. The smaller the Gamma values, the better the UPFC contribution to voltage stability margin improvement of the Nigerian 330KV Network.

UPFC	Location	(λ_0) without UPFC	(λ_{max}) with UPFC and PSO	$(LMI) = \frac{(\lambda_{max} - \lambda_0)}{\lambda_0} \times 100\%$
1	Adiabor (Bus 45)	1.5000	2.3900	59.3%
1	Jalingo (Bus 34)	1.5000	2.4200	61.3%
1	Jos (Bus 13)	1.5000	2.4100	60.6%

Table 8: Loadability Margin for the selected Nigerian bus Network

UPFC	Location	(λ_0) without UPFC	(λ_{max}) with UPFC and ABC	$(LMI) = \frac{(\lambda_{max} - \lambda_0)}{\lambda_0} \times 100\%$
1	Adiabor (Bus 45)	1.5000	2.6100	74%
1	Jalingo (Bus 34)	1.5000	2.6300	75.3%
1	Jos (Bus 13)	1.5000	2.6400	76.0%

Table 9: Loadability Margin for the selected Nigerian bus Network

UPFC	Location	(λ_0) without UPFC	(λ_{max}) with UPFC and BFO	$(LMI) = \frac{(\lambda_{max} - \lambda_0)}{\lambda_0} \times 100\%$
1	Adiabor (Bus 45)	1.5000	2.7700	84.6%
1	Jalingo (Bus 34)	1.5000	2.8300	88.6%
1	Jos (Bus 13)	1.5000	2.8000	86.6%

Table 10: Loadability Margin for the selected Nigerian bus Network

UPFC	Location	(λ_0) without UPFC	(λ_{max}) with UPFC and Cuckoo	$(LMI) = \frac{(\lambda_{max} - \lambda_0)}{\lambda_0} \times 100\%$
1	Adiabor (Bus 45)	1.5000	2.8000	86.6%
1	Jalingo (Bus 34)	1.5000	2.8500	90%
1	Jos (Bus 13)	1.5000	2.8300	88.6%

Table 11: Loadability Margin for the selected Nigerian bus Network

From the result obtained as tabulated above it can be seen that the cuckoo search algorithm outperforms all the other three algorithms in terms of voltage stability margin improvement. For example, buses 45, 34 and 13 of Nigerian 330KV Network were tested with PSO, ABC, BFO and Cuckoo Search techniques respectively. The voltage margin percentage improvement is highest with cuckoo search technique. This analysis shows the superiority of cuckoo search over the other algorithms in improving the voltage stability of power system network.

X. CONTRIBUTION AND CONCLUSION

A. *Contribution of this work to knowledge is summarized as follows:*

This paper analyzes and compares the performance of PSO, ABC, BFO and Cuckoo Search techniques for voltage stability margin improvement. The performance of these techniques has revealed that the smaller the gamma values, the better the loading parameter and of course voltage margin improvement of power system network. It is gamma that determines the contribution of UPFC for voltage stability improvement.

B. *Conclusion*

This paper presents a comparative study and performance analysis of PSO, ABC, BFO and Cuckoo Search Techniques on voltage stability margin improvement of Nigerian 330KV Network. The above results have shown that cuckoo search is a superior algorithm to the other three algorithms in improving loadability or voltage stability margin of power system network. These results are very encouraging since voltage collapse phenomenon will be reduced to the barest minimum.

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