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Investigation of the impact of PSO, ABC, BFO and Cuckoo search optimization techniques on UPFC device for sustainable voltage stability margin improvement

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Abstract

This paper investigates the enhancement of voltage stability margin using Unified Power Flow Control (UPFC) device tuned with Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), Bacterial Foraging Optimization (BFO) and Cuckoo Search techniques (CS) on Nigerian 330 kV 56-bus practical network. In order to have a voltage stable power system, it is good to 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 and the proposed optimizing techniques 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 that UPFC tuned with Cuckoo Search outperforms the other techniques in terms of the increased loading parameter of the Nigerian power system with margin improvement of 86.6%, 90% and 88.6% for Adiabor (Bus 45), Jalingo (Bus 34) and Jos (Bus 13). The tuned UPFC device has proved beyond reasonable doubt that it can improve voltage stability margin of the entire Nigerian 330 kV Network as envisaged from results before and after optimization.

Keywords: Artificial Bee Colony, Bacterial foraging optimization, Cuckoo search algorithm, Particle Swarm optimization, Voltage stability margin, UPFC

Introduction

Safe and secure network operation with acceptable voltage level has become a challenging task for Power utilities nowadays. Voltage stability margin or Load margin analysis is one of the important measurements in voltage stability studies. It is defined as the amount of additional allowable load from a particular operating point in a specific pattern of load increase before the occurrence of voltage collapse [1]. The bus that has the lowest load margin in the system is considered as the weakest bus.

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Voltage instability phenomenon is one of the operational problems in power transmission system and it can be mitigated by promising family of device known as Flexible AC Transmission (FACTS). 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 margin improvement [2]. Rest of the paper is organized as follows: Section II introduces Voltage stability Phenomenon; Section III presents some of the previous work done on Load margin or Voltage Stability Margin Improvement using nature inspired Techniques. Section IV shows algorithms considered for optimizing of FACTS devices, in Section V UPFC Model, Problem formulation, test system and analysis tools were discussed, in section VI, some interesting results is presented along with detailed discussion and finally; contribution and conclusion are summarized in Section VII.

Voltage stability

The ability of the power system to maintain 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 network is the key reason for voltage instability [4]. It is not easy to estimate the reactive power margin required to achieve a certain degree of voltage security, in this way it is different from the active power. The voltage collapse study can be realized from dynamic and static methods. For the purpose of this paper, only static method is considered. Static or Steady state method is analyzed in detail from load flow studies [3].

Previous work done on load margin or voltage stability margin improvement using nature inspired techniques

Jin Xing and Zeping Gang [4] proposed the use of nonlinear programming method based on dynamic power flow to improve voltage margin of power system network. This technique was validated using IEE-30 system and Liaoning power system since the margin improved by a certain amount.

The use of genetic algorithm technique to tune FACTS devices for the improvement of voltage stability margin of power system network was validated on IEEE 14 and 118 bus systems [5]. The results obtained revealed that the proposed technique increased the voltage stability margin significantly.

In [6] Adaptive tumbling bacteria foraging technique was applied on IEEE 57 bus system to achieve load margin expansion. The result gotten was encouraging as load margin improvement was achieved.

PSO was first used in [7] to find the optimal location of UPFC device and then GSA was used to tune the device. These were tested on IEEE-14bus and IEEE 30 bus system in MATLAB environment. The results obtained show that stability margin improved. Evolutionary Programming technique was employed in [8] for optimal reactive power

dispatch to improve voltage stability margin of power system. This technique was validated using IEEE 26-bus reliability.

Different types of nature inspired optimizing techniques such as Wolf optimization algorithm, Bat optimizing algorithm, and Harmony search algorithm have been already been used to optimize FACTS device for voltage stability enhancement. Why this research paper is unique is that no journal as for today has compared and analyzed simultaneously the impact of PSO, ABC, BFO and Cuckoo search techniques on UPFC device for the enhancement of voltage stability margin of power system network using loading parameter and Gamma as an index or measure. The number of research related to the system load margin is gaining much momentum due to its importance in power system security.

Algorithms considered for optimizing of FACTS devices

My choice of PSO, ABC, Cuckoo Search and BFO for this research paper was borne out of the fact that these algorithms are result driving and enterprising: ABC has high global search ability and ease of implementation. BFO has a very good swarming mechanism that guarantees a rapid and accurate solution. In PSO, initial solutions do not affect its computational behavior and it provides fast convergence, also its behavior is not highly affected by increase in dimensionality. Cuckoo Search provides platform for an interesting and aggressive reproduction strategy, coupled with levy flight random walk which guarantees an accurate solution. Their strengths and weaknesses are shown in Table 1.

Particle Swarm optimization

Social science and computer science are two the fields of knowledge that gave birth to PSO. 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 $X_i R^n$ and its movement by the velocity of the particle $V_i \in R^n$, as shown in (1) [9].

$$\overrightarrow{x_i}(t) = \overline{x_{(i)}}(t-1) + \overrightarrow{V_I}(t) \tag{1}$$

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:

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

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

$$\vec{v_i}(t) = \vec{v_i}(t-1) + \varphi_1\ rand_1\ \left(\vec{P_i} - \vec{x_i}(t-1)\right) + \varphi_2\ rand_2\ \left(\vec{P_g} - \vec{x_i}(t-1)\right) \tag{2}$$

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] (Table 2).

P_i is the best position that the corresponding particle has found so far, P_g is the best position of the entire swarm [9].

The sequence of operation of PSO is depicted in Fig. 1.

Cuckoo search algorithm

Cuckoo search is an algorithm 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 [10, 11]. The step lengths are generally distributed based on long likelihood distribution. A lévy flight is performed, if new solution $\left(X^{t+1}\right)$ is to be generated and is given by;

$$X_i^{(t+1)} = X_i^t + \alpha \oplus \text{Levy}(\lambda) \tag{3}$$

where α = step size (usually $\alpha > 0$), $\oplus$ = entry wise multiplications.

Table 2 Optimization Values for PSO, Cuckoo Search, BFO and ABC Techniques

S/N	BFO parameters names	BFO values	Cuckoo parameters names	Cuckoo search values	ABC parameters names	ABC values	PSO parameters names	PSO values
1	Number of Bacteria	20	nPar	100	Dimension	4	Acceleration Const. 1	2
2	Maximum number of steps, N	10	Varlo	− 5	Number of Runs	20	Acceleration Const. 2	2
3	Maximum Number of Chemotactic steps	20	Number of Population	10	Number of population	20	Max. Velocity	4
4	Number of chemotactic steps, Nc	10	VarHi	5	Food Number	10	Number of Population	24
5	Number of reproduction Steps Nre	20	nC	5	Limit	100	Limit	100
6	Number of Elimination Dispersal Steps Ned	100	Max Cycle	100	Max Cycle	100	maxCycle	2000
7	Probability, Ped	0.9	Min Egg	2	Ub (Upper Bound)	50	Number of Runs	150
8	Size of Step, C(i)	0.01	Max Egg	4	Lb (Lower Bound)	1	Initial weight	0.9
9			N0. Clusters	1			Final weight	0.4
10			Lambda	9				
11			Control of Egg	5				

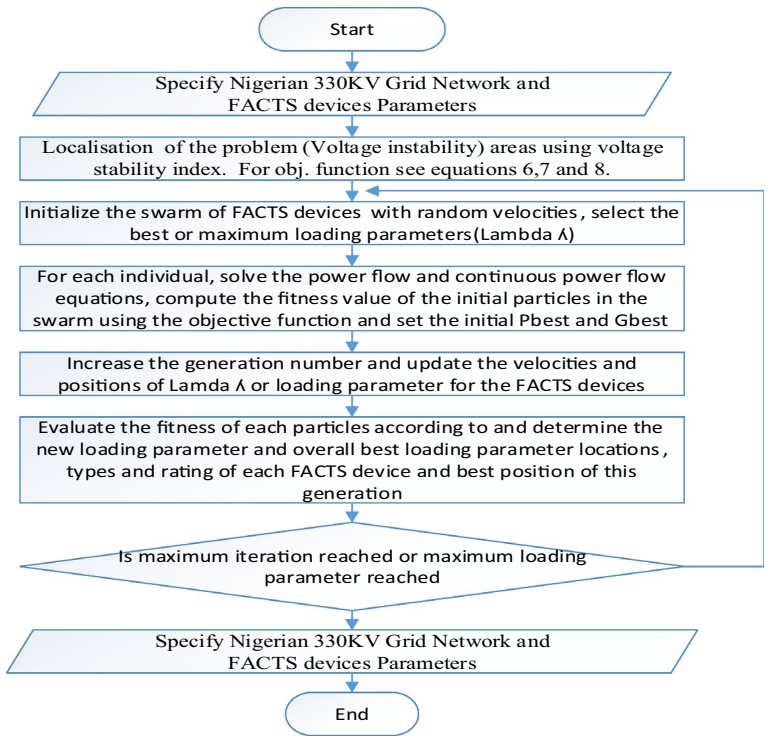

Fig. 1 Particle Swarm optimization flowchart

The sequence of operation of CS is depicted in Fig. 2.

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 [12, 13].

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

$$J(i,k,l) + J_{cc}(\theta, P) \tag{4}$$

where J(i, k, l) is the fitness function.

The sequence of operation of BFO is depicted in Fig. 3.

Artificial bee colony

The colony of artificial bees comprises of three groups of bees: employed bees, onlookers and scouts. The number of employed bees is equal to the number of food sources which correspond to solutions of a given problem. 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.

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

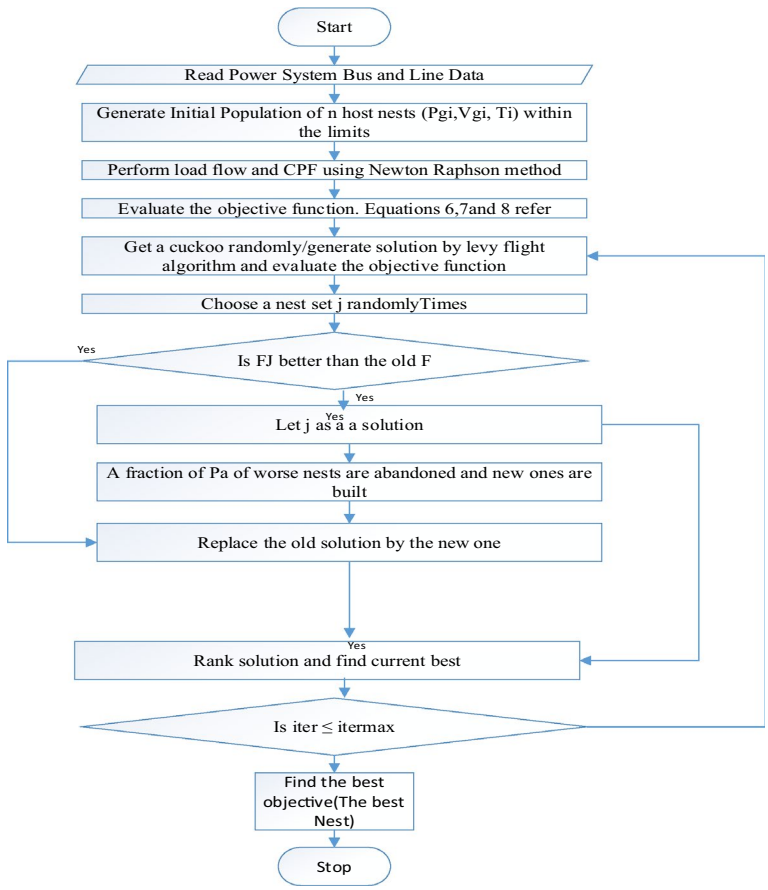

Fig. 2 Cuckoo search optimization flowchart

$$X_{ij} = X_j^{min} + rand(0,1) * \left(X_j^{max} - X_j^{min}\right) \tag{5}$$

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 [14, 15]. The sequence of operation of ABC is depicted in Fig. 4.

UPFC model, problem formulation, test system and analysis tools

The unified power flow controller (UPFC) is the most all-encompassing device to have sprung up 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 [16, 17].

The configuration of UPFC and its model for representing power flow are depicted in Fig. 5. UPFC is used to control the real power flow in the power transmission line using its both voltage source converters (VSCs) [13].

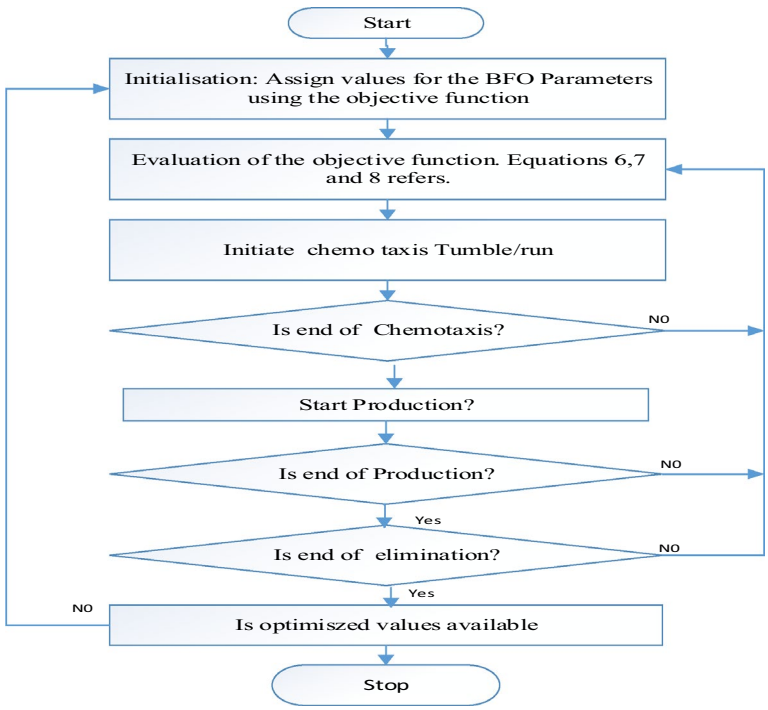

Fig. 3 Bacterial foraging optimization flowchart

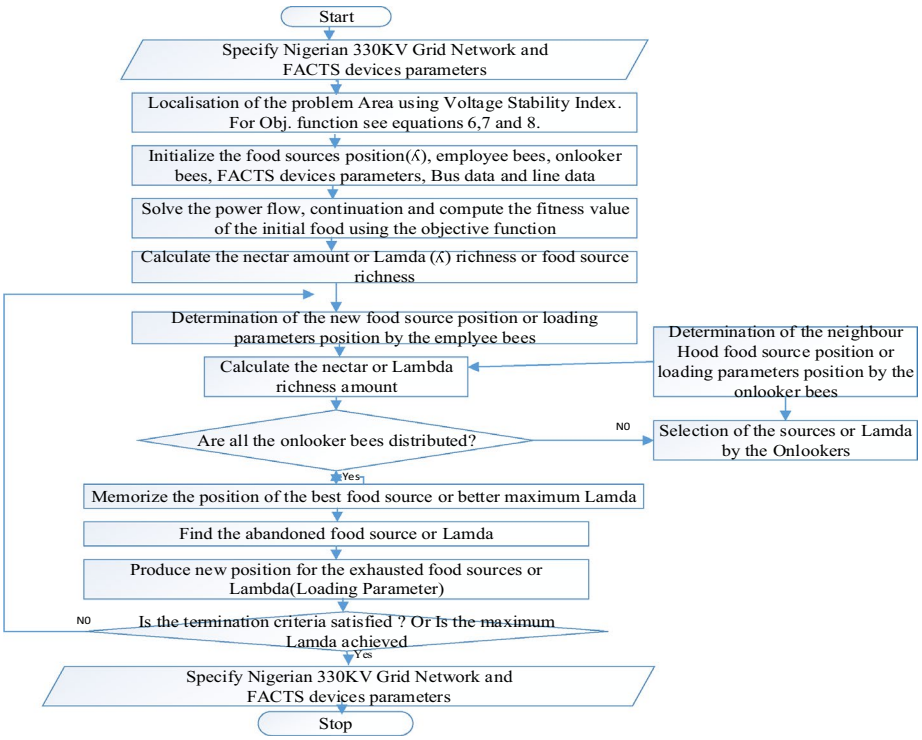

Fig. 4 Artificial Bee colony optimization flowchart

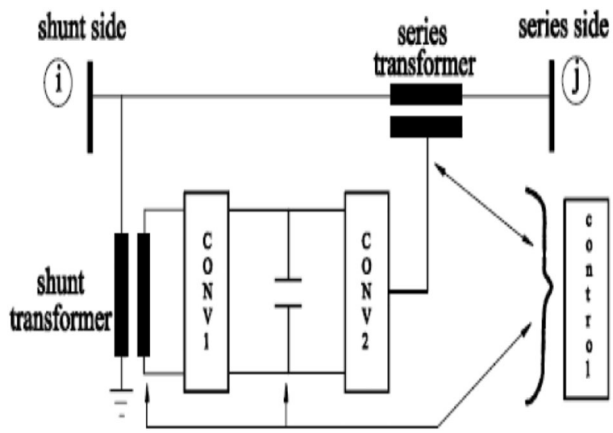

Fig. 5 The UPFC device circuit arrangement [18]

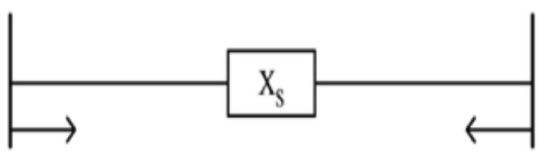

Fig. 6 UPFC injection model. [18]

(UPFC) with injection model is connected at suitable location in the system. The UPFC injection model is shown in Fig. 6

$$V_i < \theta_i \; V_j < \theta$$

$$\begin{aligned} P_{si} &= r_{bs} V_i V_j \sin\left(\theta_{ij} + \gamma\right) \\ Q_{si} &= r_{bs} V_i^2 \cos\gamma \\ P_{sj} &= -r_{bs} V_i V_j \sin\left(\theta_{ij} + \gamma\right) \\ Q_{sj} &= -r_{bs} V_i V_j \cos\left(\theta_{ij} + \boldsymbol{\lambda}\right) \end{aligned} \tag{6}$$

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

1. con: UPFC data.
2. n: total number of UPFC.
3. bus1: bus numbers k (from).
4. bus2: bus numbers m (to).
5. dat: UPFC parameters.
6. Vdc: indexes of the state variable Vdc.
7.alpha: indexes of the state variable α.
8. Gamma (γ).
9. Voltage ratio (**r**) [16].

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

$$\Delta P_i = P_{Gi}(V,\delta,\lambda) - P_{Li}(V,\delta,\lambda) - \left(P_{Inji} = 0\right) \tag{7}$$

$$\Delta Q_i = Q_{Gi}(V,\delta,\lambda) - Q_{Li}(V,\delta,\lambda) - \left(Q_{Inji} = 0\right) \tag{8}$$

where

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

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

and

$$0 \le \lambda \le \lambda_{cr}$$

For simulating different load change scenarios, loads are modified as

$$P_{Li}(\lambda) = P_{Lio}[1 + \lambda \mathrm{K}_{Li}] \tag{9}$$

$$Q_{Li}(\lambda) = P_{Lio}\tan(\Phi_i)[1 + \lambda \mathrm{K}_{Li}] \tag{10}$$

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. Φ_i is power factor of load at bus i.

The real power generation is modified to

$$P_{Gi}(\lambda) = P_{Gi0}[1 + \lambda \mathrm{K}_{Gi}] \tag{11}$$

Test system and analysis tools

Simulations were carried on Nigerian 56- bus practical test system. This network has 14 generators bus bars, 42 load buses and 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 on tuning UPFC device for voltage stability improvement. All the results are produced with the help of 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.

Results and discussions

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 vulnerable bus of the system

Table 3 Line Stability Index Result for 56-bus Nigerian National Grid

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

Table 3 (continued)

Line no	From bus	To bus	Voltage Stability Index
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

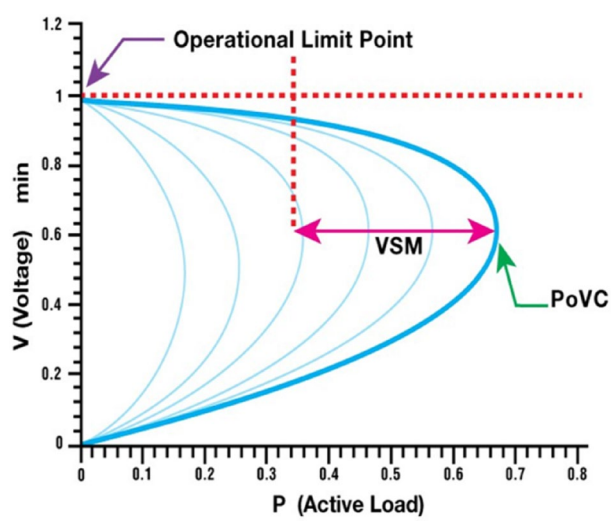

Fig. 7 Voltage Stability Margin Curve [19]

can be identified by using the line stability index (embedded in the power system analysis tool box) for 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

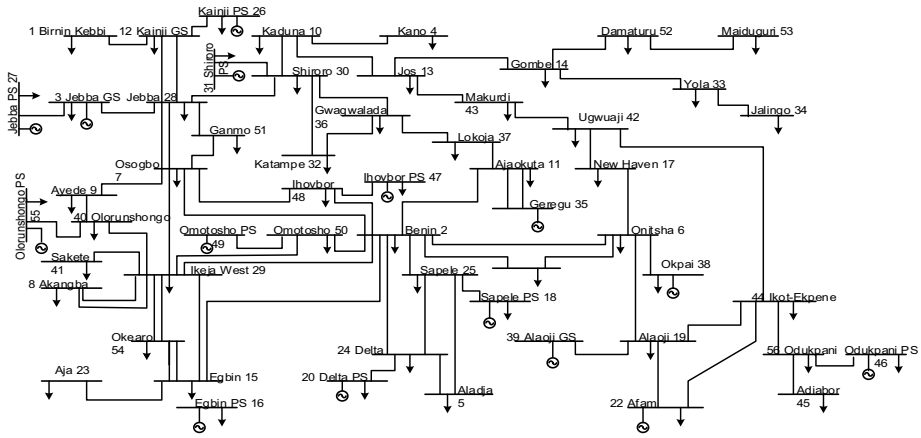

Fig. 8 Single line diagram of 56-bus Nigerian National Grid

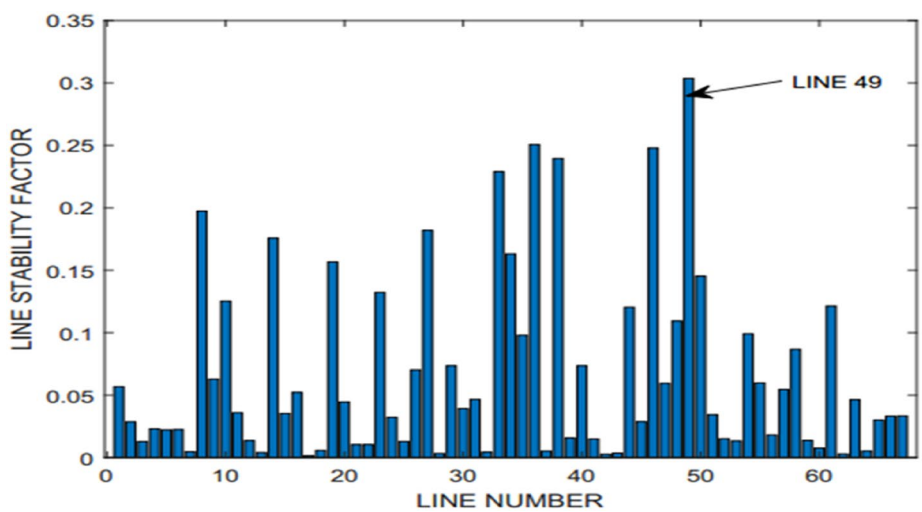

Fig. 9 The bar chart of Line Stability Index Vs Line number for 56-bus Nigerian National Grid

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 business without the hope of return and there is no energy supplied if it is not gainful [20]. The analytical result obtained from the index, helps to avoid voltage collapse and prevent the system from voltage instability. It is shown from Table 3 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).

Simulation for the tuning of UPFC device using PSO, ABC, BFO and Cuckoo search algorithms on Nigerian 330 kV network

The simulations were carried out simultaneously with particle swam optimization algorithm, artificial bee colony**,** bacterial Foraging and cuckoo search algorithms. The developed UPFC model in Figs. 5 and 6, for real and reactive power injections into the system was used to carry out the load flow studies in MATLAB environment with the

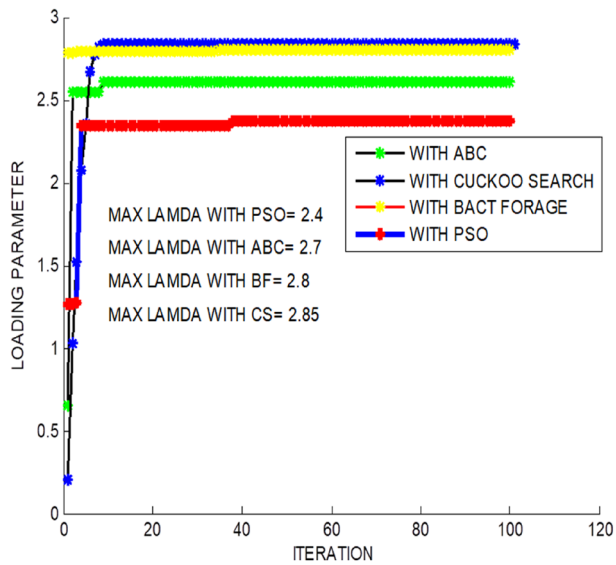

Fig. 10 Conversion curves of PSO, ABC, CK and BFO Optimization algorithms

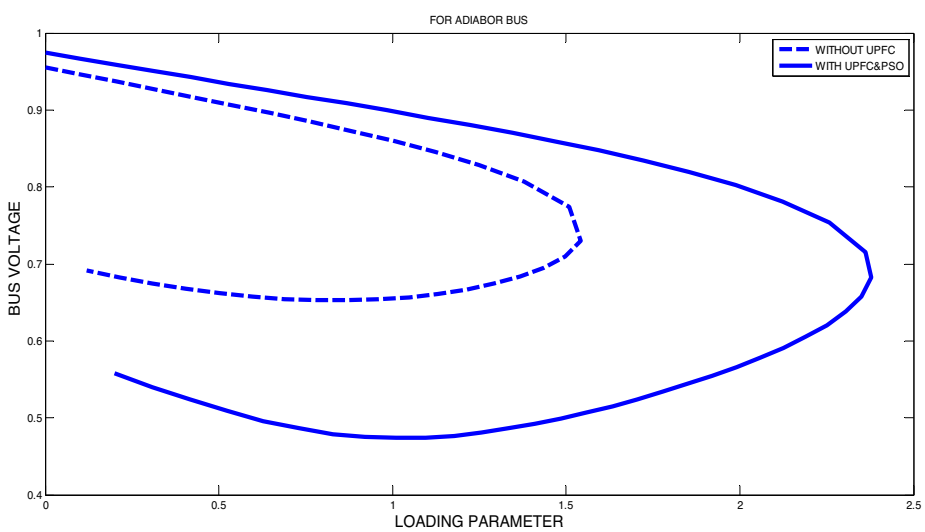

Fig. 11 Nose Curve for Adiabor bus with PSO

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 330 kV Nigerian network. The relationship among voltage ratio (r) of the UPFC and the system, Gamma (γ) of the UPFC device and loading parameter (λ) of the system is represented in Eq. 5.

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 (Figs. 7, 8, 9).

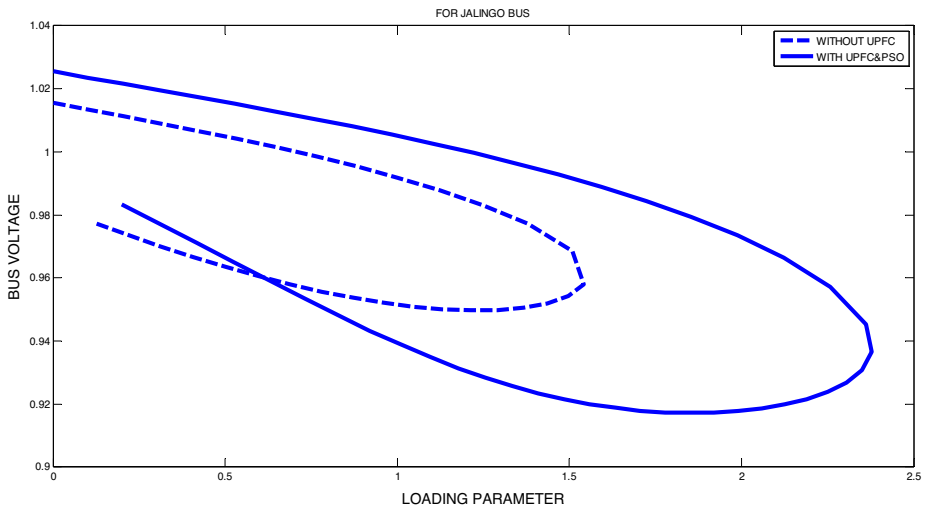

Fig. 12 Nose Curve for Jalingo bus with PSO

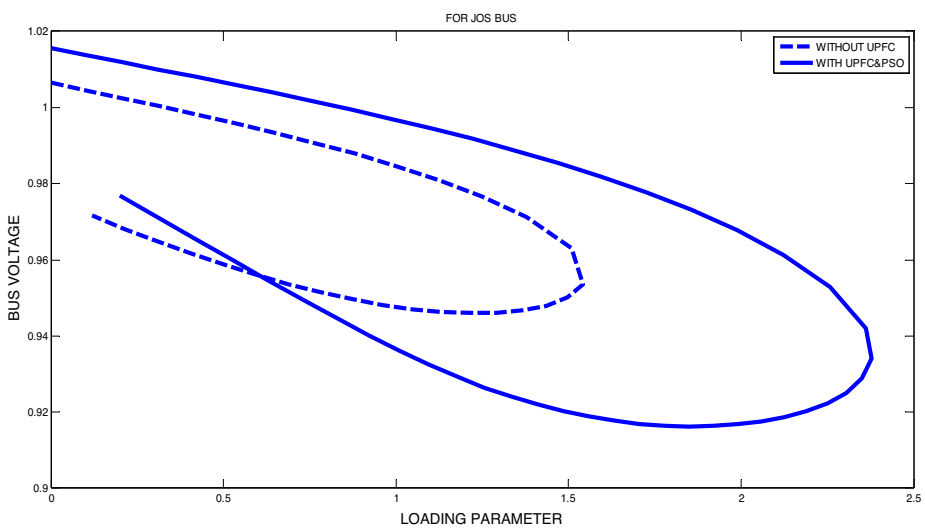

Fig. 13 Nose Curve for Jos bus with PSO

The PSO, ABC, BFO and Cuckoo Search techniques are used in turn to tune UPFC device Parameters on Nigerian 330 kV Network. From Figs. 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and Table 4 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 330 kV 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 330 kV Network were tested with PSO, ABC, BFO and Cuckoo Search techniques respectively. The voltage margin

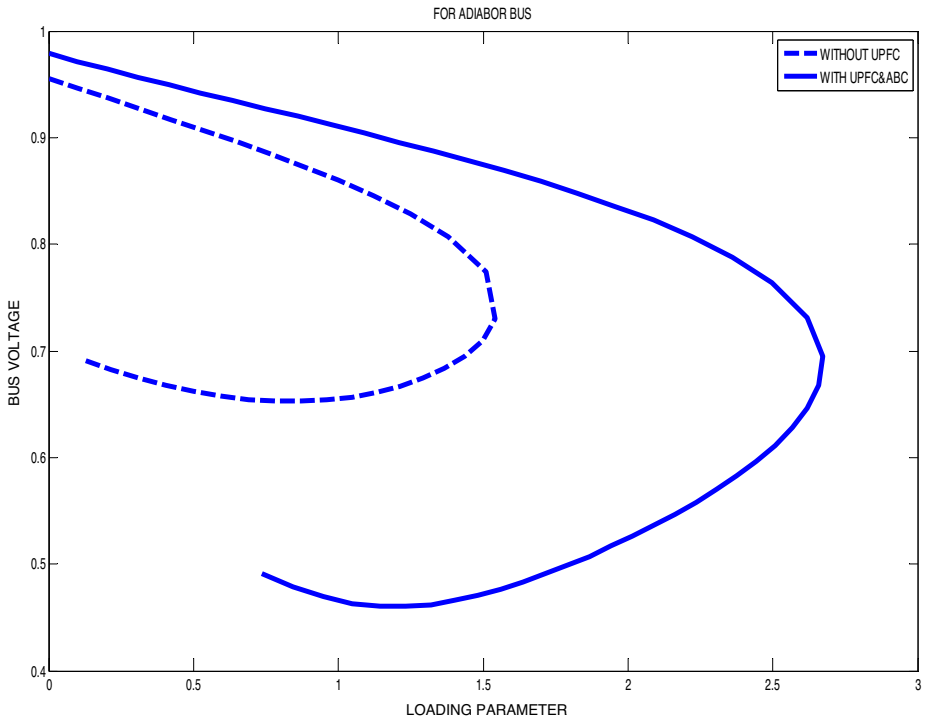

Fig. 14 Nose Curve for Adiabor bus with ABC

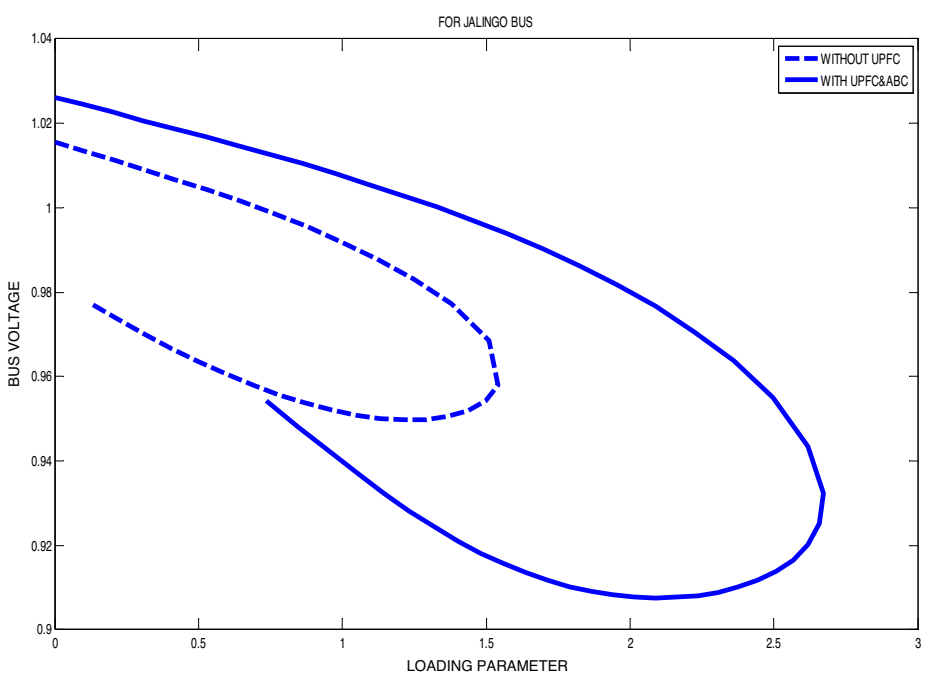

Fig. 15 Nose Curve for Jalingo bus with ABC

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 (Table 5).

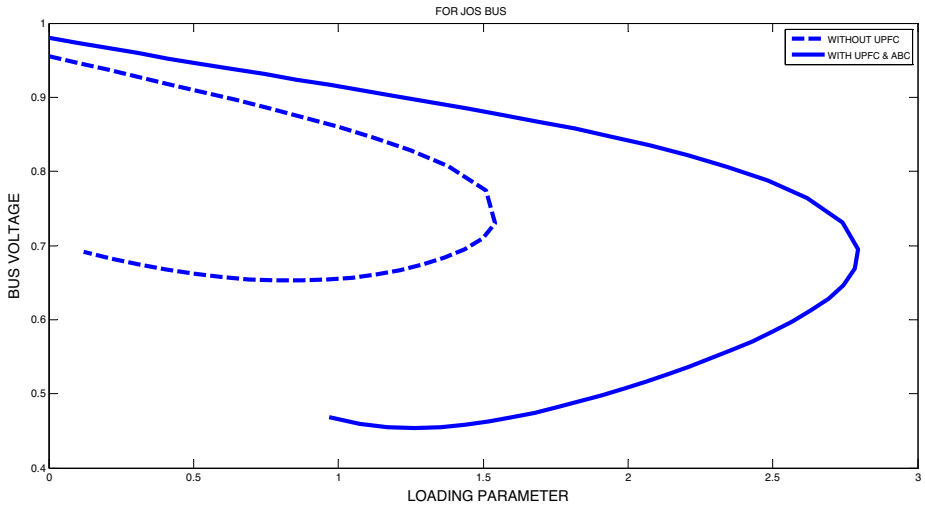

Fig. 16 Nose Curve for Jos bus with ABC

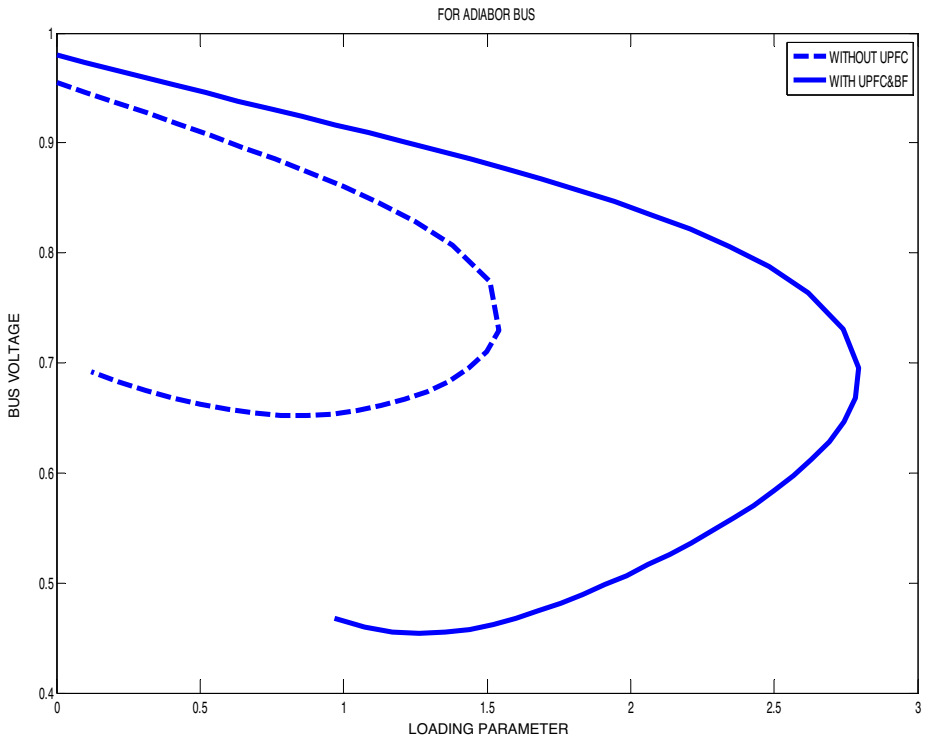

Fig. 17 Nose Curve for Adiabor with BFO

Contribution and conclusion

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

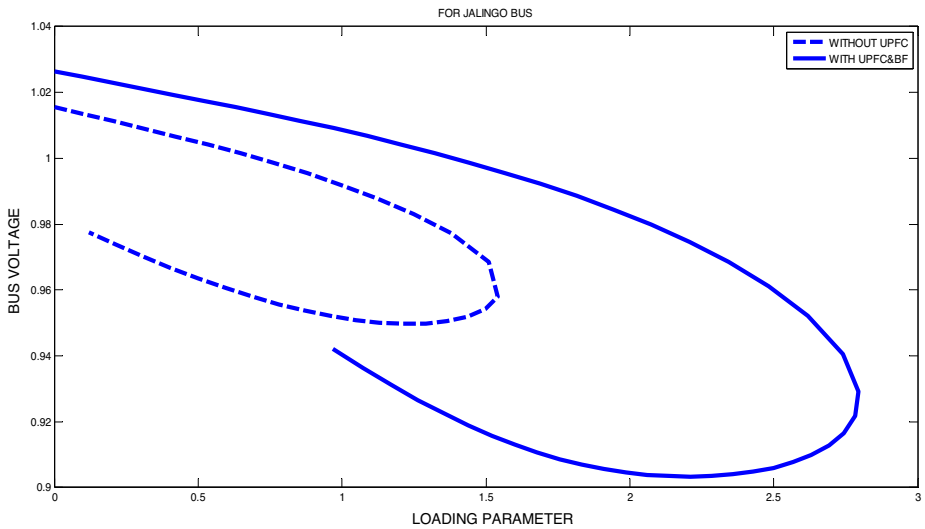

Fig. 18 Nose Curve for Jalingo bus with BFO

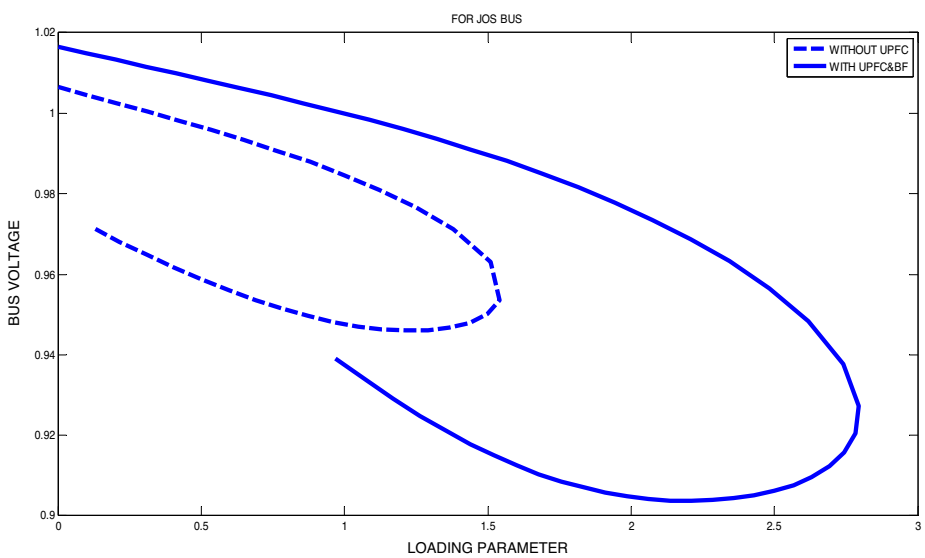

Fig. 19 Nose Curve for Jos bus with BFO

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 evident that gamma determines the contribution of UPFC for voltage stability improvement.

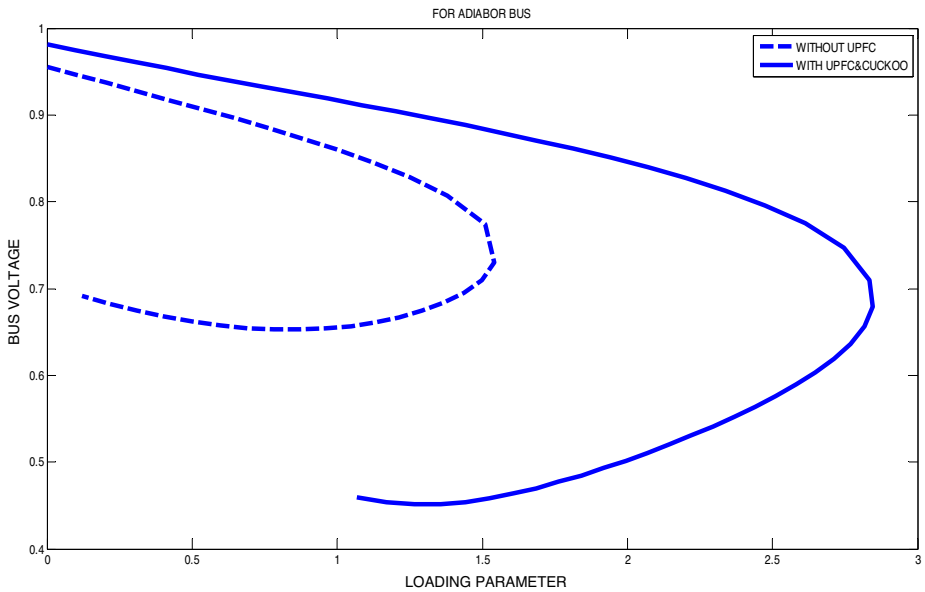

Fig. 20 Nose Curve for Adiabor bus with Cuckoo

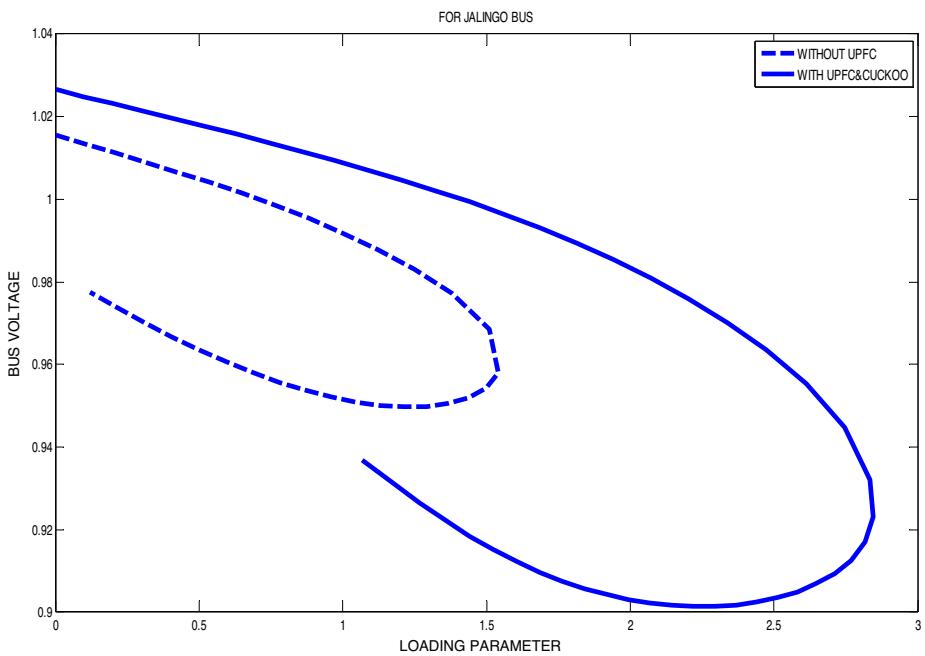

Fig. 21 Nose Curve for Jalingo with Cuckoo

Conclusion

This paper investigated the performance impact of PSO, ABC, BFO and Cuckoo Search Techniques on UPFC for voltage stability margin improvement of Nigerian 330 kV Network. Cuckoo search algorithm performs better than the other three algorithms in improving voltage stability margin of power system network. Cuckoo Search Technique

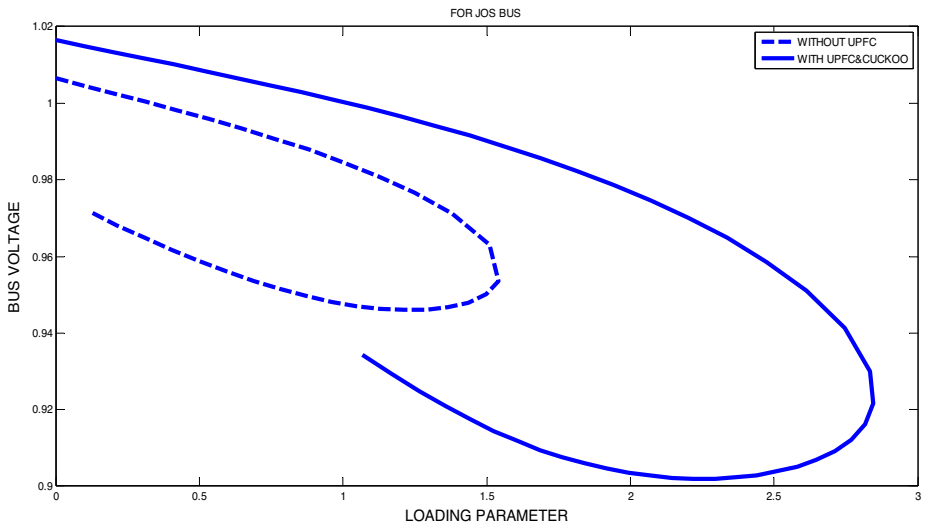

Fig. 22 Nose Curve for Jos bus with Cuckoo

Table 4 Loading Parameters versus Gamma Values

S/N	Algorithm/technique	Loading parameters values (λ)	Gamma values
1	Particle Swarm Optimisation	2.35	1.41497
2	Artificial Bee Colony	2.55	1.22649
3	Bacterial Foraging	2.79	1.14976
4	Cuckoo Search	2.84	1.11912

Table 5 Loadability Margin for the selected Nigerian bus Network Particle Swarm Optimisation

UPFC	Location	NO Optimisation	Optimisation	Load Margin Improvement (LMI) = $\frac{(\lambda_{max}-\lambda_0)}{\lambda_0}$ × 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%
UPFC	**Location**	**Without Optimisation**	**Optimisation**	**Load Margin Improvement (LMI) = $\frac{(\lambda_{max}-\lambda_0)}{\lambda_0}$ × 100%**
	Artificial Bee Colony			
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%
UPFC	**Location**	**Without Optimisation**	**Optimisation**	**Load Margin Improvement (LMI) = $\frac{(\lambda_{max}-\lambda_0)}{\lambda_0}$ × 100**
	Bacteria Foraging Optimisation			
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%
UPFC	**Location**	**Without Optimisation**	**Optimisation**	**Load Margin Improvement (LMI) = $\frac{(\lambda_{max}-\lambda_0)}{\lambda_0}$ × 100%**
	Cuckoo Search Optimisation			
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%

yielded better value of loading parameters generation (2.8421) than PSO, ABC and BFO respectively. Also, the percentage of load margin yield for cuckoo search technique (86.6%, 90% and 88.6%) for Adiabor (Bus 45), Jalingo (Bus 34) and Jos (Bus 13 was higher than the yield for ABC, PSO, BFO. These results were very encouraging since voltage collapse phenomenon was reduced to the barest minimum.

List of symbols

(λ_0)	Loading parameter minimum
(λ_{max})	Loading parameter maximum
LMI	Load margin improvement
UPFC	Unified power flow control
CPF	Continuation power flow
VSM	Voltage stability margin
GSA	Gravitational search algorithm
γ	Gamma
V	Voltage
δ	Angle difference
θ_{ij}	Theta between i and j

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Author contributions
The roles of the authors are listed below: NHI: Conceptualization, Methodology, Visualization, Writing—Original Draft Presentation, Methodology, Data Curation, Formal Analysis. E. C. A: Supervision, Validation, Writing—Reviewing and Editing. IIA: Formal Analysis, All authors have read and approved the manuscript.

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Availability of data and materials
The data is available at the data bank of Transmission Company of Nigeria. I do not have the permission to share the data.

Declarations

Competing interests
We have no conflict of interest associated with this publication, and there has been no grant or financial support that could have influenced its outcome. The publication of this article is approved by all authors and that, if accepted, it will not be published elsewhere in the same form, in English or any other language.

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