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The Effect Pso/Abc, Abc/Bfo, Pso/Bfo and Cs/Bfo Hybrid Techniques on Power System Buses for Voltage Stability Margin Improvement

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Abstract
This paper presents and investigates new approaches inspired by nature to determine the optimal placement of UPFC for enhancing voltage stability margin of power system network. Voltage collapse phenomenon has remained an operational problem yet to be solved by power system engineers. To improve the voltage stability of the power system network, new optimisation techniques viz: PSO/ABC, ABC/BFO, PSO/BFO AND CS/BFO hybrids are investigated for their performance on power system buses for voltage stability improvement. The performance of the proposed hybrid methods are examined on the practical Nigerian 56 - bus network for voltage stability improvement. The simulation results has shown that ABC/BFO technique is better than BFO/PSO by ***3.44*** *in improving voltage stability of margin of power system, gives additional improvement of* ***4.07****, totalling* ***7.51****% and lastly BFO/CS technique improved voltage stability margin of power system further by* ***5%*** *totalling* ***12.51****%. Also this research revealed that the smaller the gamma value the better the UPFC contribution to voltage stability enhancement. BFO/CS technique yielded the smallest gamma values of 0. 74532 and 0.830913 in both Nigerian practical network and IEEE – 14 bus network as shown in the analysis.*

Keywords: Artificial Bee Colony, Bacteria Foraging Optimisation, Cuckoo Search, Particle Swarm Optimisation, Continuation Power Flow, Voltage Stability Margin.

1. Introduction and Description of Challenges

The demand of electricity in the world is increasing at alarming rate. This has made the smooth operation of power system difficult. Optimal placement of this technology can reduce overloading and improve voltage stability in the electrical network. The problem of voltage stability is mainly caused by overloading condition of the system [1].

Several techniques have been proposed by many authors to reduce stress loading and improve voltage stability of the existing power systems. In heuristics methods based on genetics was used to determine the optimal locations of FACTS devices in the electrical network to improve stress loading and voltage stability [2]. This was validated on standard 14-node IEEE network in the MATLAB environment.

In Bacteria foraging was used to allocate transformer taps and UPFC to simultaneously minimize the real power loss and maximize the Voltage stability (VSL) of the system [3]. This was validated using IEEE-39 bus test system. PSO adaptive GSA technique was applied to find the optimal location and the power rating of the FACTS devices to improve voltage stability and reduce power loss in power system. This was demonstrated using IEEE 30 bus benchmark system [4].

In GA (Genetic Algorithm) and GSA (Gravitational Search Algorithm) hybrid was formulated to maximize the voltage stability of the system by proper setting of IPFC controller [5]. This was tested on IEEE-30 bus benchmark system. The optimal location and setting of FACTS devices to enhance the loadability of power system was carried out in using PSO and DE techniques [6]. It was found that DE performs better than PSO in terms of maximum loadability improvement. All simulations are tested on IEEE 118 bus system. Improved Particle Swarm Optimization (IPSO) was used in to solve the problem of optimal allocation of STATCOM units in a 30-bus system to enhance voltage stability [7]. When compared with other techniques, it was proved that IPSO outperforms classical optimization techniques, such as Benders' decomposition and B&B in terms of the ability to find the optimal solution, the computational effort and voltage stability improvement.

The remainder sections of this paper is organised as follows: section II show the problem formulation, section III presents optimisation algorithms used for this research work while section IV discuses UPFC Model, test system and analysis tools, section V presents results and discussions and finally section VI shows the contribution and conclusion of the research work.

2. Problem Formulation

In this research paper, the optimal placement of FACTS device is based on maximizing the load ability of the existing Nigerian 330KV 56 – bus networks to improve its performance. The network load ability is maximised and represented by lambda factor (λ). All parameters will be penalised by load factor (lambda) with respect to the stop criterion of the used algorithms: PSO, ABC, CS and BFO and their hybrids. All the simulation is done with the aid continuation power flow in PSAT MATLAB environment.

2.1 Objective Function

The objective function is to maximize the power system loadability so as to improve voltage stability. It could be formalized as follows:

$$F = max\{\lambda\}$$

where, (λ) is the load factor

To simplify the enforcement of the process constraints where the FACTS devices is placed at line 49 which is the weakest location as identified using line stability index [8,9]. The fitness function F_t is firstly defined, then the two terms that are targeted separately, the first term in line overloading O_{veL} and the second term is related to bus voltage violations V_{ioB}, are included as follows:

$$F_{t\,=}\ 2 - \{\prod_{Line} Ove_L + \prod_{Line} Vio_B\}$$

$F_{t\,=}$ is a fitness function[1].

3. Algorithms Considered for Optimizing of FACTS Devices

3.1 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 $X_i \epsilon R^n$ and its movement by the velocity of the particle $X_i \epsilon R^n$, as shown in (1).

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

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:

$$v_i^{\rightarrow}(t) = v_i^{\rightarrow}(t-1) + \varphi_1 . rand_1 .(P_i^{\rightarrow} - x_i^{\rightarrow}(t-1)) +$$

$$\varphi_2 . rand_2 .\left(P_g^{\rightarrow} - x_i^{\rightarrow}(t-1)\right) \qquad 2$$

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].

P_i is the best position that the corresponding particle has found so far, P_g is the best position of the entire swarm [10,11]. The sequence of operation of PSO is depicted in Figure 1 below.

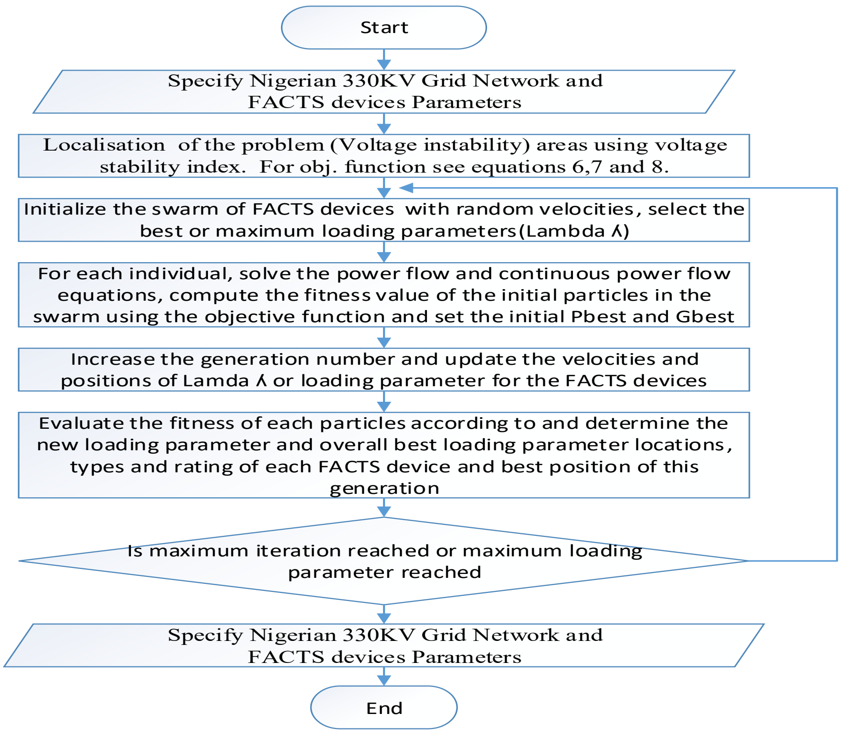

Figure 1: Proposed Particle Swarm Optimization Flowchart

3.2 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 [12,13]. The step lengths are generally distributed based on long likelihood distribution. A lévy flight is performed, if new solution (X^{t+1}) is to be generated and is given by;

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

Where; α= step size (usually α > 0)

⊕ = entry wise multiplications.

The sequence of operation is shown in figure 2 below.

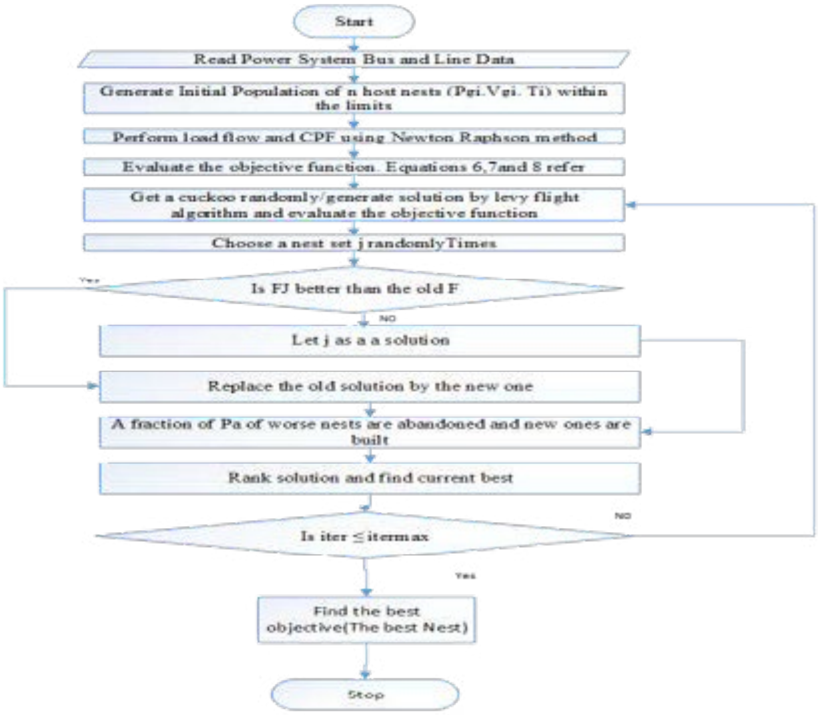

Figure 2: Proposed Cuckoo Search Optimization Flowchart

3.3 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 [14,15].

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

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

Where

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

The sequence of operation is shown in figure 3 below.

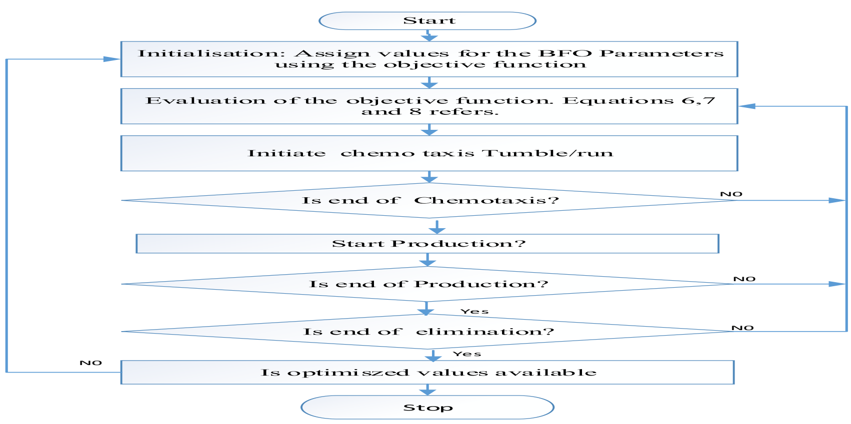

Figure 3: Proposed Bacterial Foraging Optimization Flowchart

3.4 Artificial Bee Colony

The colony of artificial bees comprises of three groups of bees: employed bees, onlookers and scouts. 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

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

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 [16].

The sequence of operation is shown in figure 4 below.

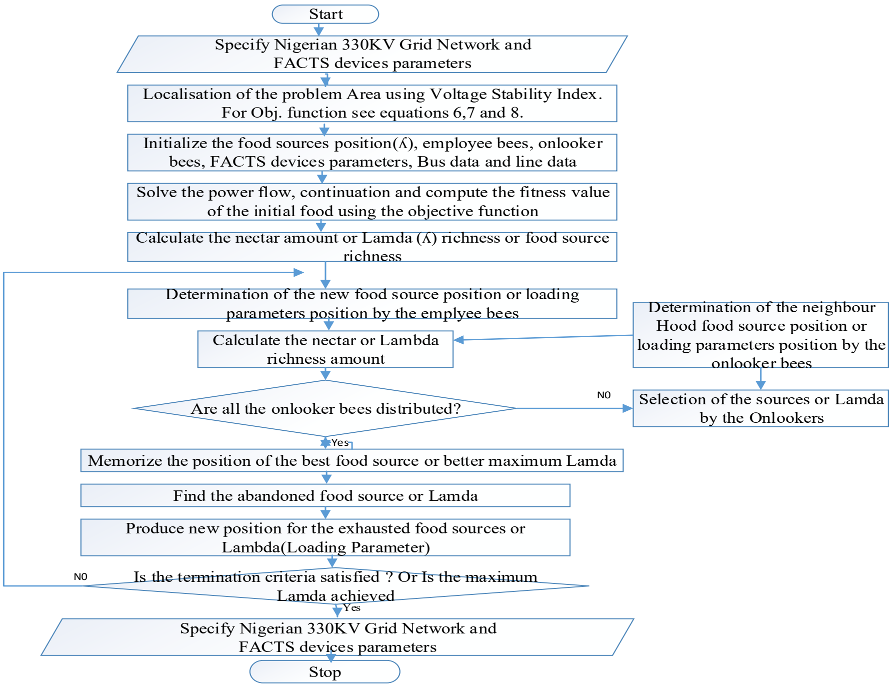

Figure 4: Proposed Artificial Bee Colony Optimization Flowchart

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	20	Number of	10	Number of	20	Max. Veocity	4
	Number of Chemotactic steps		Population		population			
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				

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

4. UPFC Model, Problem Formulation, Test System and Analysis Tools

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) [3].

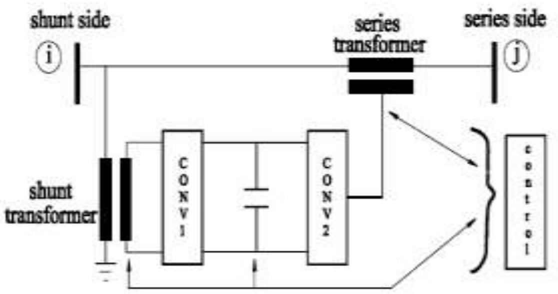

Figure 5: The UPFC device circuit arrangement [3]

The UPFC injection model is shown is figure 6 below.

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

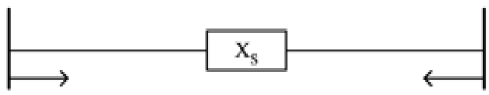

Figure 6: UPFC injection model. [3].

$P_{si} = r_{bs} V_i V_j \sin(\theta_{ij} + \gamma)$

$Q_{si} = r_{bs} V_i^2 \cos\gamma$

$P_{sj} = - r_{bs} V_i V_j \sin(\theta_{ij} + \gamma)$ 10

$Q_{sj} = - r_{bs} V_i V_j \cos((\theta_{ij} + \boldsymbol{\lambda})$

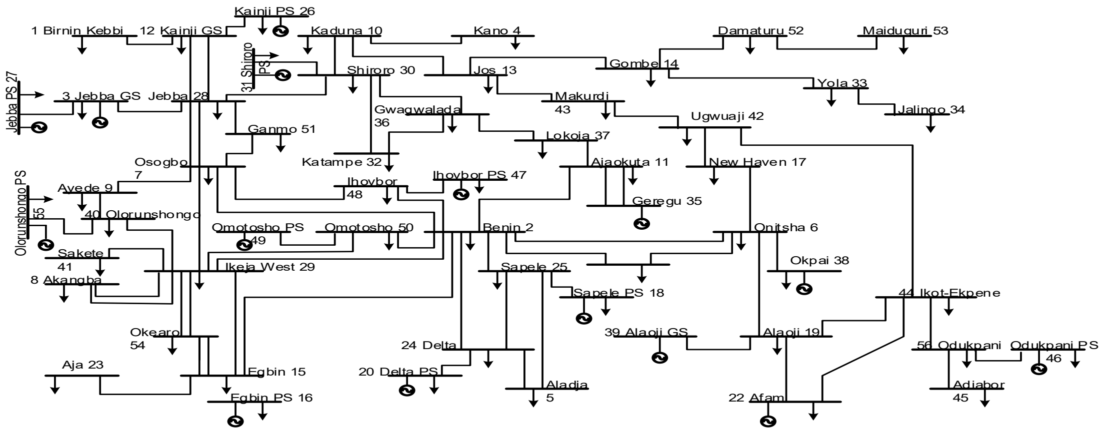

Figure 7: Single Line Diagram of 56-Bus Nigerian National Grid

Simulations were carried on Nigerian 56- bus practical test system. This system has 14 generators busbars, 42 load busbars and 67 lines. The system data is obtained from Transmission Company of Nigeria data bank. The aim of the simulations is to compute and compare the performance of the four different meta-heuristic techniques for 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.

5. Results and Discussions

Line stability index simulation was carried out to determine location for the placement of UPFC device before using optimization techniques viz:PSO, ABC, CS, BFO and their hybrids for voltage stability margin improvement. Table 3 below refers. Today, there is no venture in power business without the hope of return and there is no energy supplied if it is not gainful [17].

The analytical result obtained from the index indicated as shown from Table 3 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). UPFC device is sited on line 49.

BFO, PSO, Cuckoo and ABC optimization techniques are all very good approaches for solving voltage stability challenges but their hybrid versions perform better than the individual BFO or Cuckoo or ABC or PSO search techniques as shown in figures 9, 10, 11, 13 and 14 below.

The Parameters on table 2 above are used for the load parameter setting of the UPFC device on Nigerian 330KV Network to improve voltage stability margin. From the nose curve below, it is seen that BFO/CS (3.35) yielded the highest contribution to load margin improvement followed sequentially by ABC/PSO (3.32), ABC/BFO (3.30), and BFO/PSO (3.19). It can be seen that BFO/PSO has the least contribution to load margin improvement in power system when compared to the other techniques. This implies that BFO/CS outperforms all others in improving voltage stability of the power system network.

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

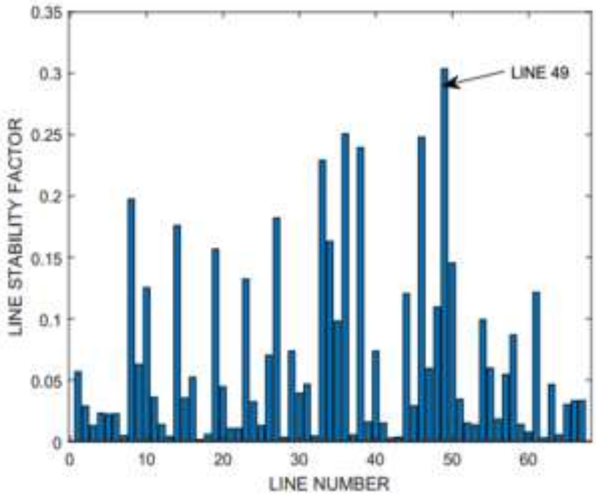

Figure 8: The bar chart of Line Stability Index Vs Line number for 56-bus Nigerian National Grid. Simulation for the load parameter setting of UPFC device using PSO/ABC, ABC/BFO, PSO/BFO AND CS/BFO hybrid techniques on Nigerian 330KV Network.

The developed UPFC model in figures 5 and 6 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 constant while varying the gamma (γ) of the UPFC between 0 to 2π on the 330KV 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 equation 13 above. All the simulations results are shown below:

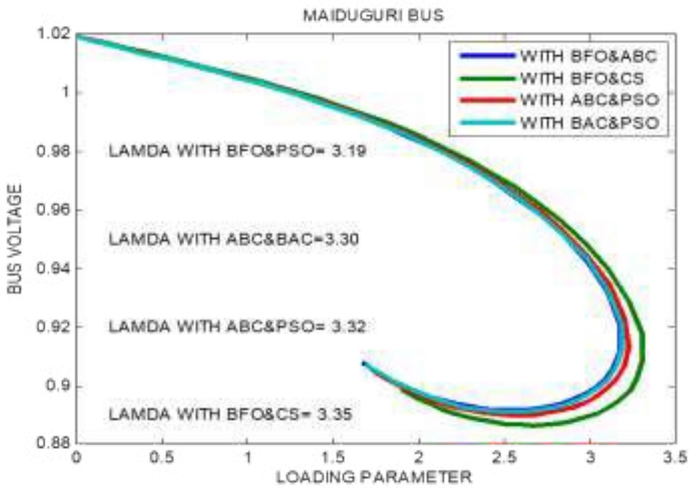

Figure 9: Performance of bus voltage versus loading parameter on Maiduguri

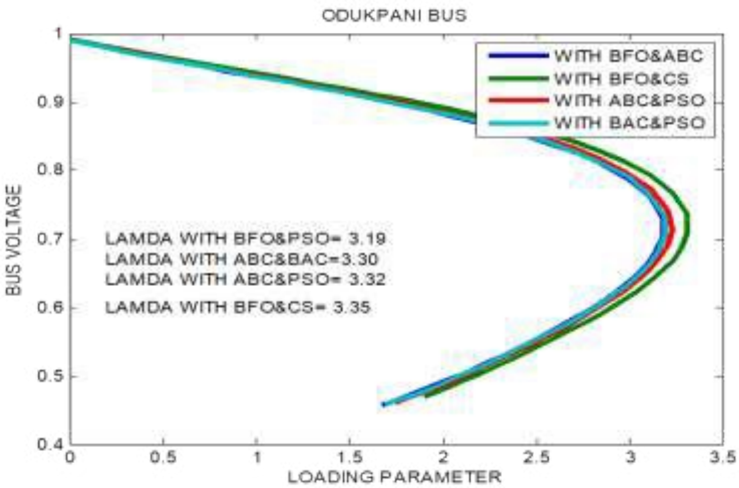

Figure 10: Performance of bus voltage versus loading parameter on Odukpani

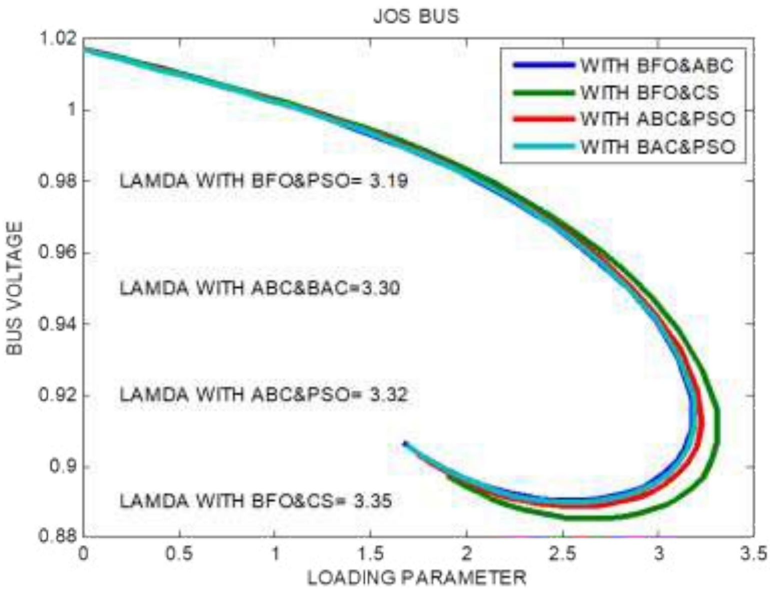

Figure 11: Performance of bus voltage versus loading parameter on Jos

Loadability Margin calculation for the selected Nigerian bus Network
Markurdi (Bus 43), Odukpani (Bus 56) and Maiduguri (Bus 53)

$$(\boldsymbol{LMI}) = \frac{(\lambda_{max}-\lambda_1)}{\lambda_1} \times \mathbf{100}\%$$

BFO/PSO has the least loading parameter yield, it is taken as the reference value ( ) to calculate voltage stability margin improvement.

<u>Improvement of ABC/BFO from BFO/PSO</u>

$$(\boldsymbol{LMI}) = \frac{(3.30-3.19)}{\mathbf{3.19}} \times \mathbf{100}\% = 3.44\%$$

ABC/BFO technique is better by 3.44 from BFO/PSO technique in improving voltage stability of margin of power system.
Improvement of PSO/ABC from BFO/PSO

$$(\boldsymbol{LMI}) = \frac{(3.32-3.19)}{\mathbf{3.19}} \times \mathbf{100}\% = \mathbf{4.07}\%$$

PSO/ABC technique is better by 4.07 from BFO/PSO technique in improving voltage stability of margin of power system.
Improvement of BFO/CS from BFO/PSO

$$(\boldsymbol{LMI}) = \frac{(3.35-3.19)}{\mathbf{3.19}} \times \mathbf{100}\% = \mathbf{5}\%$$

BFO/CS technique is better by 5% from BFO/PSO technique in improving voltage stability of margin of power system.

From the result obtained, it can be seen that the BFO/CS outperforms BFO/PSO, ABC/BFO, PSO/ABC and BFO/CS for voltage stability margin enhancement. For example, buses 43, 53 and 56 of Nigerian 330KV Network were tested. There is significant increase in Load Margin improvement for markurdi, Odukpani and Maiduguri buses respectively.

S/N	Algorithm/Techniques	UPFC gamma values from IEEE – 14 bus system	Nigerian Network UPFC gamma values from Power System
1	Individual PSO	1.17965	1.414970
2	Individual ABC	1.13854	1.226490
3	Individual BFO	1.10973	1.149760
4	Individual Cuckoo search	1.07903	1.119120
5	BFO/ABC Hybrid	1.04378	0.915503
6	PSO/ABC Hybrid	0.96546	0.884250
7	BFO/Cuckoo Search Hybrid	0. 74532	0.830913

Table 4: Gamma Values

5.2 Voltage Stability Improvement Contribution of UPFC to Nigerian 330KV Network

The real and reactive Power Flow on the UPFC line are related to gamma with the Equations below, it is gamma that determines the contribution of UPFC for voltage stability improvement. Gamma is the angle of the injected voltage which has magnitude between 0 and 2π.

The diagram below explains gamma further

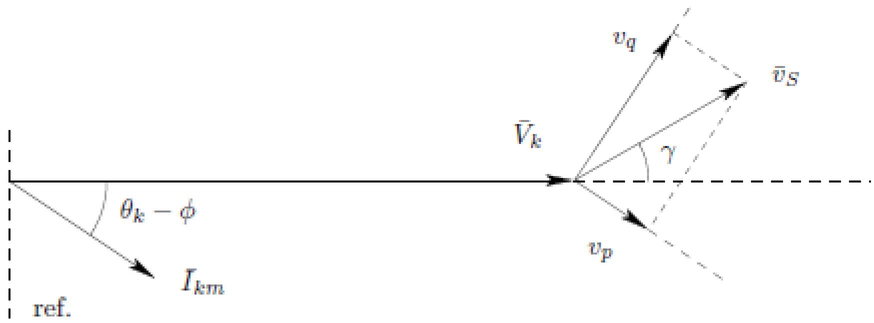

Figure 12: Gamma relative angle [21]

$$P_{km} = brV_k V_m \sin(\gamma + \theta_k - \theta_m) \text{ --(5.1)}$$

$$Q_{km} = brV_k^2 \cos\gamma - i_q V_K \text{ ---(5.2)}$$

$$P_{mk} = -brV_k V_m \sin(\gamma + \theta_k - \theta_m) \text{ --(5.3)}$$

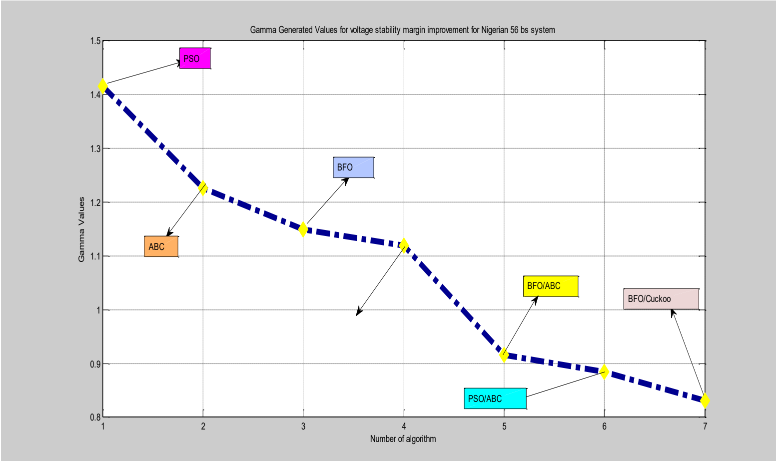

Figure 13: Graph For Generated Gamma Values on UPFC device for Nigerian 56 – bus system

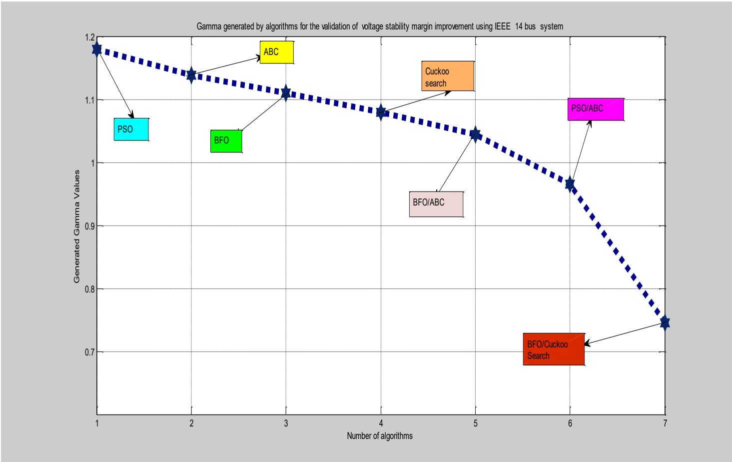

Figure 14: Graph For Generated Gamma Values on UPFC device for IEEE 14 bus

6. Contribution and Conclusion

Contribution of this work to knowledge is summarized as follows:

This paper analyzes the performance of BFO/ABC, BFO/CS, ABC/PSO and BFO/PSO on power system buses for voltage stability improvement. BFO/CS hybrid performs better than BFO/PSO, ABC/PSO, BFO/ABC techniques in improving voltage stability of power system. These techniques have also revealed that the smaller the gamma values, the better the loading parameter and of course the load margin and voltage stability improvement of power system as shown from analysis above. It is gamma that determines the contribution of UPFC for voltage stability improvement [18,19].

7. Conclusion

The techniques proposed in this paper were implemented in the MATLAB/Environment with the aid of power system tool box. The presented techniques aimed to find out the effect of BFO/ABC, BFO/CS, ABC/PSO and BFO/PSO techniques in the optimal placement of UPFC FACTS device to improve voltage stability of power system. The techniques used in this work were tested on the practical Nigerian 330KV – 56 bus networks. The above results have shown that BFO/CS strategy is a superior algorithm to all the other techniques used in this paper for improving voltage stability of power system. These results are very encouraging since voltage collapse phenomenon will be reduced to the barest minimum.

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