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OPTIMAL SITING OF UPFC FOR VOLTAGE STABILITY IMPROVEMENT USING CUCKOO SEARCH AND ARTIFICIAL BEE COLONY OPTIMIZATION ALGORITHMS

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ABSTRACT

The crisis of voltage collapse has been a recurring decimal in the global power network, this has been a source of concern for power system operators and consumers as it often led to system wide black out. This research work provided an efficient technique for optimal siting of UPFC on the IEEE 14-Bus network to improved voltage stability. Line/voltage stability indices were employed for the identification of the weakest lines and buses on the network. individual Artificial Bee Colony (ABC), Cuckoo Search (CS) and hybridize optimization algorithms was used to evaluate the optimal location of the UPFC device, the analysis tested on the IEEE 14-Bus network, and it was found the weakest line was line 9 and line was between bus 13 and bus 14, the stability index that was achieved was 0.15266. the hybrid optimization algorithms performed better than the individual algorithms by offering a better and higher loading parameter.

Keywords: Voltage, Stability, Optimization.

1. INTRODUCTION

The demand for the electricity in Nigeria is growing tremendously but the expansion of transmission line and generation facilities is restricted due to various environmental constraints and limited availability of resources, this causes the improper utilization of the transmission line which leads to voltage instability and its eventual collapse Voltage collapse is highly dangerous anytime they occur [1][2]. It could halt the economic activities of entire country coupled with the associated losses in monetary and nonmonetary perspective. The delivery of electrical energy to various consumers in Nigeria has been very unsatisfactory due to voltage instability [3]. In this era of electricity market deregulation and more so the recent eligible customer regime in Nigeria, there is always an increase in the number of unplanned power exchanges due to the competition among utilities and direct contracts concluded between generation companies and consumers. So, the problem of overloading takes place in some transmission lines [4]. Because many of the existing transmission lines could not handle the increasing power demand, voltage instability and voltage collapse has become a major concern [8].

This operational problems amongst others have motivated this research work to proffer a solution in ameliorating this monster on the Nigerian power system, thereby enhancing voltage stability, and improving the reliability of the network [9][10][16][20]. Flexible AC Transmission Systems (FACTS) provide technical solutions to address these operating challenges being presented today [14][25]. Devices, such as UPFC can be connected in series or shunt (or a combination of the two) to achieve voltage control and improvement [29][30][18] Performance of FACTS devices wholly depends on its optimal location and parameter setting on power system network. If not properly located and tuned in power system network, it may impact negatively to the network [11][12][23]. In view of foregoing, this research develops improved hybrid optimization techniques to tune FACTS device in the network and improve voltage stability.

2. METHODOLOGY

2.1 The IEEE 14-Bus Network

The IEEE 14-bus test system comprises of 5 generator buses (PV), 9 load buses (PQ) and 20 interconnected lines. One of the generator buses, bus 1 is selected as the slack bus. Figure 3.1 shows the single line diagram of the system. The PSAT model of the IEEE 14-Bus Network is as shown in the figure 2.1.

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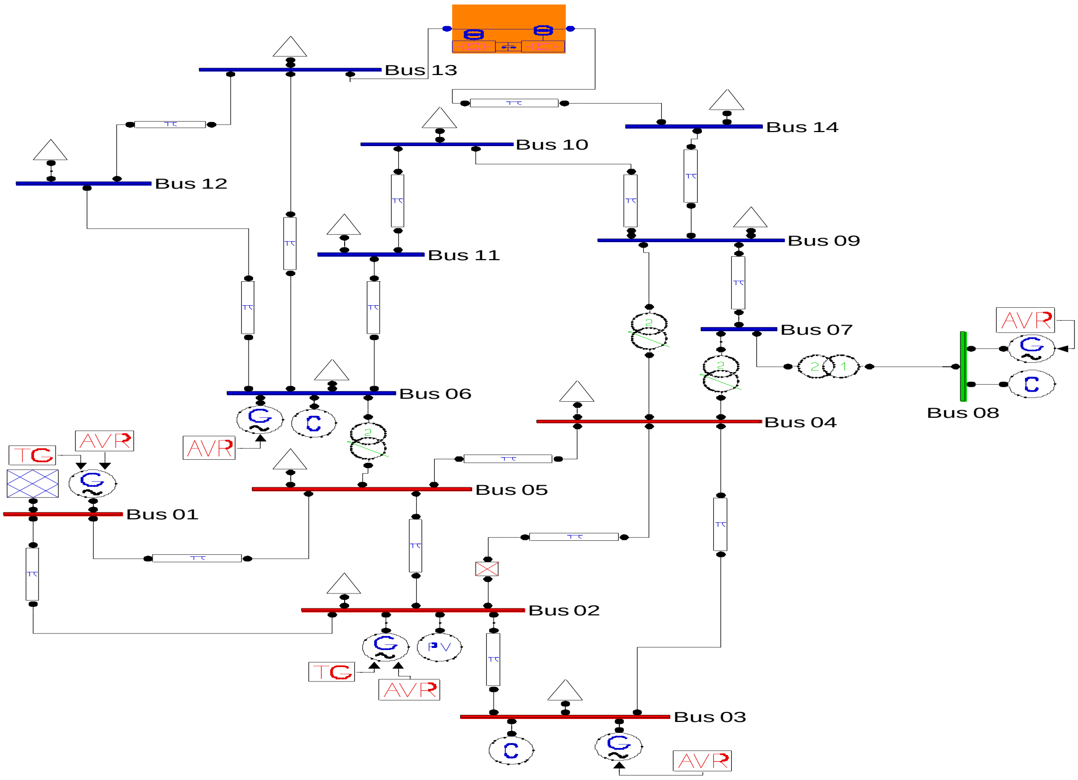

Figure 2.1: PSAT Model of the 14-bus IEEE System

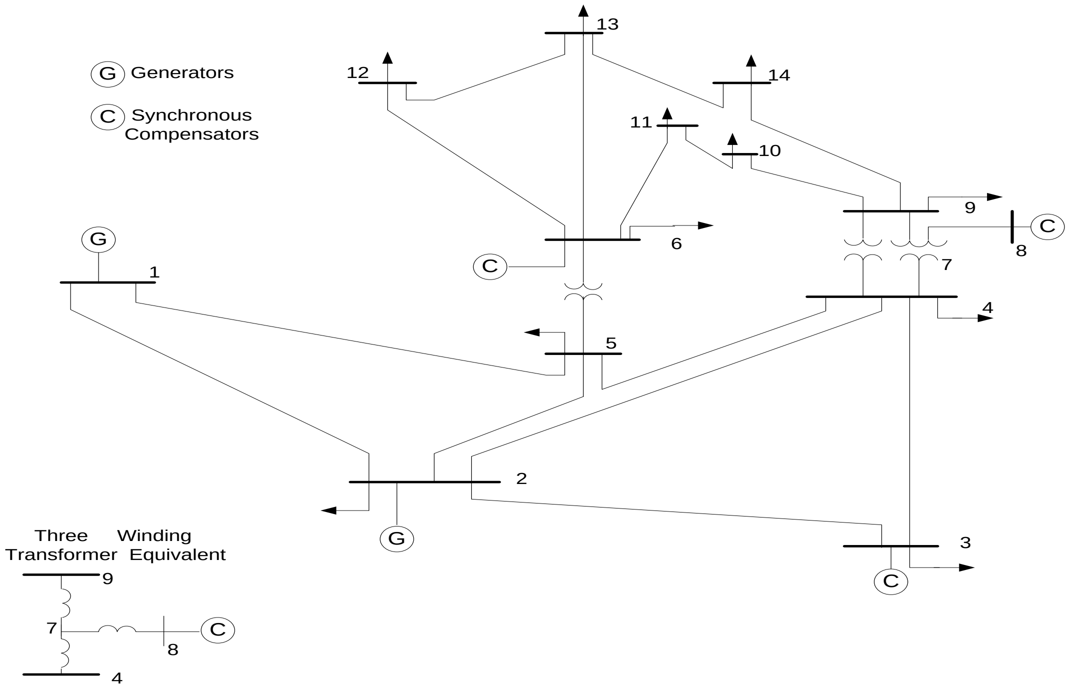

Figure 2.2: Single line diagram of the 14-bus IEEE System[20]

2.2 Determination of areas prone to voltage instability (Line Stability Index)

The line stability index is shown in Equation (2.5). Line stability index is used to retrieve voltage stability of the power system. It is a scalar magnitude that is implemented to observe the changes of the parameters in the system. Besides that, the index is also used to quantify the distance of the operating point with the point of voltage collapse.

2.3 Mathematical representations of the indices are as follows:

a. Line Stability Index (Lmn)

The line stability index is given as

$$L_{mn} = \frac{4Q_m X}{[V_k \sin(\theta-\delta)]2} \quad (2.5)$$

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.

b. Voltage Stability Index (L)

Voltage stability index L is used for monitoring the voltages of the buses which is derived based on load flow results. L index is given as

$$L_j = 1 - \sum_{i=1}^{i=g} F_{ji} \frac{V_i}{V_j} \quad (2.6)$$

Where g= no of generators

V_i is the i[th] bus voltage?

V_j is the j[th] 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.

c. Line Stability Factor (LQP)

$$LQP = 4\left[\left(\frac{X}{V_S^2}\right)\left(\frac{X}{V_S^2}P_S^2 + Q_R\right)\right] \quad (2.7)$$

d. Fast Voltage Stability Index (FVSI)

$$FVSI = \frac{4Z^2 Q_R}{V_S^2 X} \quad (2.8)$$

e. Voltage Collapse Proximity Indicators (VCPI)

$$VCPI\ (Power) = \frac{P_R}{P_{R(max)}} \text{ or } \frac{Q_R}{Q_{R(max)}} \quad (2.9)$$

$$VCPI\ (Loss) = \frac{P_{loss}}{P_{loss(max)}} \text{ or } \frac{Q_{loss}}{Q_{loss(max)}} \quad (2.10)$$

f. Line Collapse Proximity Indicator (VCPI)

$$LCPI = \frac{4Acos\alpha(P_R Bcos\beta + Q_R Bsin\beta}{(V_s\, cos\, \delta)2} \quad (2.11)$$

Where:

A= $(1 + Z^*Y/2) = A\angle\alpha$

B = Z ≡ $B\angle\beta$

C = $Y^*(1 + Z^*Y/4)$[11][17][23]

D = A.

3. RESULTS AND DISCUSSION

3.1 Discussion of Result on Line Stability Index for IEEE 14-Bus System

It is detected from Table 3.3 below that the most susceptible line with a line stability index of **0.1526**, which is line 9 is between bus 13 and bus 14 as also depicted in Figure 3.3. Therefore, the optimal location for placement of UPFC Devices will be in line 9 which is between bus 13 and bus 14.

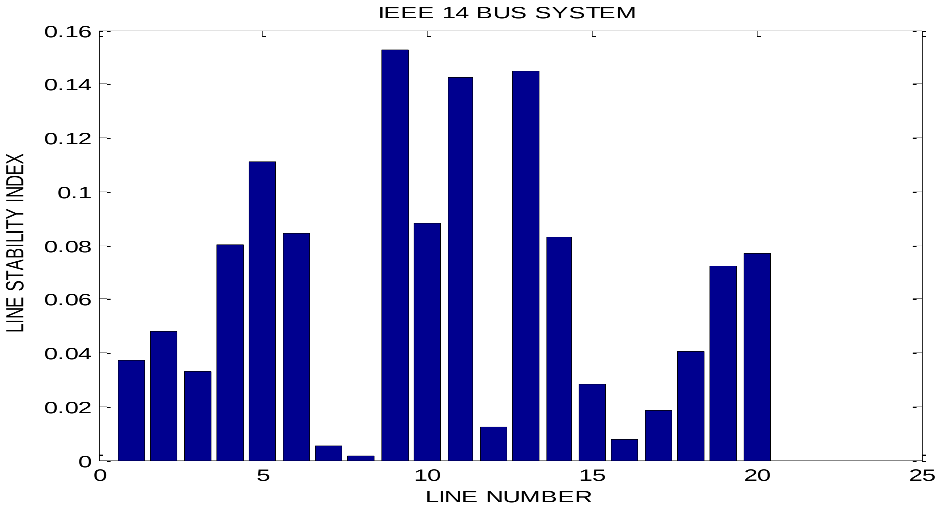

Figure 3.1: Line Stability Index for IEEE 14 bus system

Table 3.1: Line Stability Index for IEEE 14 Bus System

Line No.	From Bus	To Bus	Line Stability Index
1	5	2	0.03723
2	12	6	0.04800
3	13	12	0.03288
4	13	6	0.08023
5	11	6	0.11108
6	10	11	0.08427
7	10	9	0.00533
8	14	9	0.00178
9	13	14	0.15266
10	9	7	0.08821
11	2	1	0.14252
12	2	3	0.01248
13	4	3	0.14499
14	5	1	0.08308
15	4	5	0.02829
16	4	2	0.00762
17	6	5	0.01843
18	9	4	0.04032
19	7	4	0.07230
20	7	8	0.07712

Table 3.1: Algorithms and their Generated Gamma Values Using IEEE 14 – Bus Network.

S/N	Algorithm/Techniques	UPFC Gamma Values
1	Individual ABC	1.13854
2	Individual Cuckoo search	1.07903
3	ABC/Cuckoo Search Hybrid	0. 84532

3.2 Voltage Stability Margin of IEEE 14-Bus System

Figure 3.5. is the optimization process for ABC, Cuckoo search, and their hybrid of the results, it can be clearly seen that, the hybrid has the highest and best value of the values of these parameters are contained in Table 3.5. From these optimized parameters the optimized settings of UPFC were obtained. It is based on this setting that the nose curves below were obtained. These nose curves reveal the impact of UPFC on the voltage stability margin of the network. The nose curve for some selected buses is shown in Figures 3.5 to 3.8

Figure 3.3: Graph of Optimization Process for IEEE 14 bus system

Table 3.2: Loading Parameter for IEEE 14 bus system

Optimization Algorithm	Maximum Loading Parameter
CS	3.02
ABC	2.49
ABC and CS	3.73

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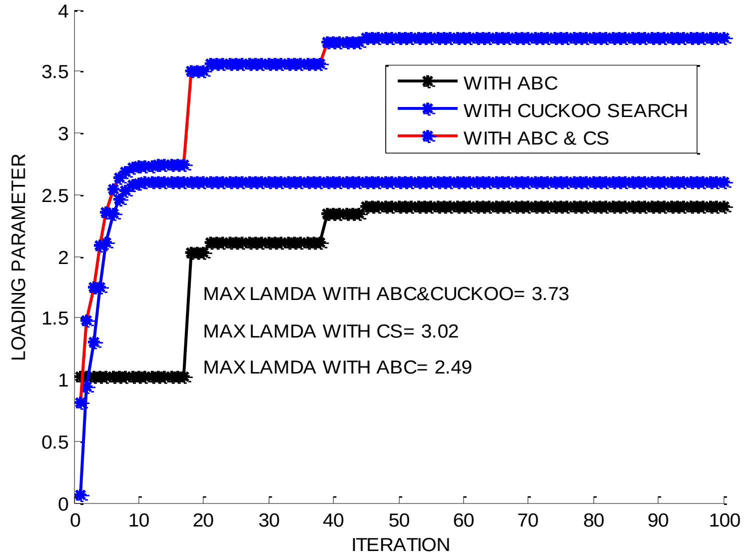

Figure 3.2: Line Stability Index for IEEE 14 bus system

Figure 3.2 contains the loading parameter obtained by employing cuckoo search, artificial bee colony and their hybrid with/without UPFC on bus 3 of the IEEE 14-bus network. The loading parameter values were obtained for various scenarios. These scenarios include without UPFC, with UPFC and ABC, with UPFC and CS, and with UPFC and their hybrid respectively. The values obtained for the various scenarios are 1.71, 2.49, 3.02 and 3.73 respectively. The hybridized optimization process provided a far better setting for the UPFC.

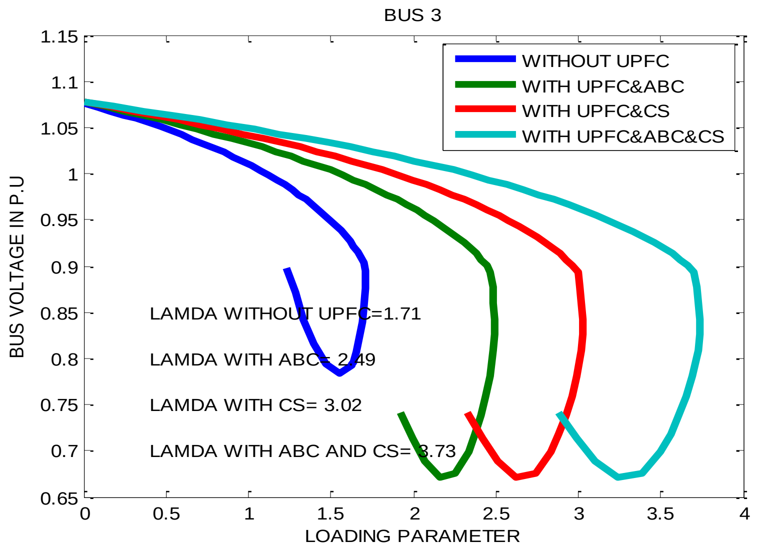

Figure 3.4: Nose Curve for Bus 3 of IEEE 14 bus system

Table 3.3: Loading Parameter for Bus 3 of IEEE 14 bus system

Cases	Loading Parameter
Without UPFC	1.71
With UPFC and ABC	2.49
With UPFC and CS	3.02
With UPFC, ABC and CS	3.73

Figure 3.7 is the nose curve for Bus 6. Table 3.7 contains the loading parameter obtained by employing cuckoo search, artificial bee colony and their hybrid with/without UPFC on bus 6 of the IEEE 14-bus network. The loading parameter values were obtained for various scenarios. These scenarios includes without UPFC, with UPFC and ABC, with UPFC and CS, and with UPFC and their hybrid respectively. The values obtained for the various scenarios are 1.71, 2.49, 3.02 and 3.73 respectively. It can be seen that the hybridized optimization process provided a far better setting for the UPFC.

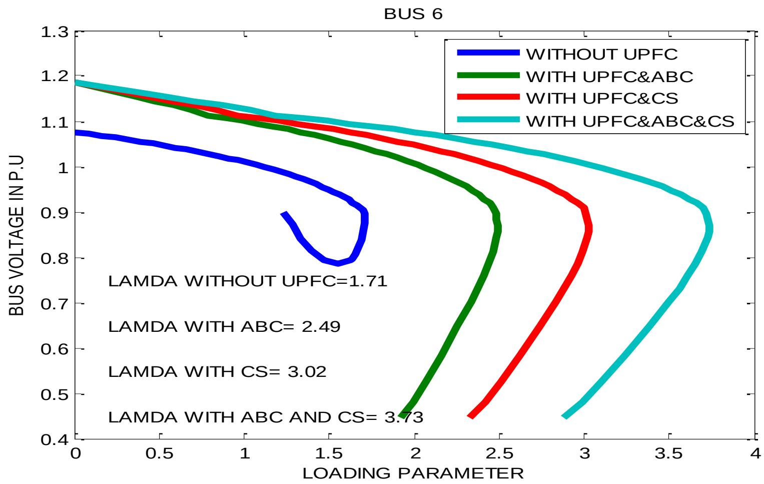

Figure 3.5 Nose curved for bus 6 of IEEE 14 bus system

Table 3.4 Loading Parameter for Bus 6 of IEEE 14 bus system

Cases	Loading Parameter
Without UPFC	1.71
With UPFC and ABC	2.49
With UPFC and CS	3.02
With UPFC, ABC and CS	3.73

Figure 3.8. is the nose curve for Bus 9. Table 3.8 contains the loading parameter obtained by employing cuckoo search, artificial bee colony and their hybrid with/without UPFC on bus 9 of the IEEE 14-bus network. The loading parameter values were obtained for various scenarios. These scenarios includes without UPFC, with UPFC and ABC, with UPFC and CS, and with UPFC and their hybrid respectively. The values obtained for the various scenarios are 1.71, 2.49, 3.02 and 3.73 respectively. The hybridized optimization process provided a far better setting for the UPFC.

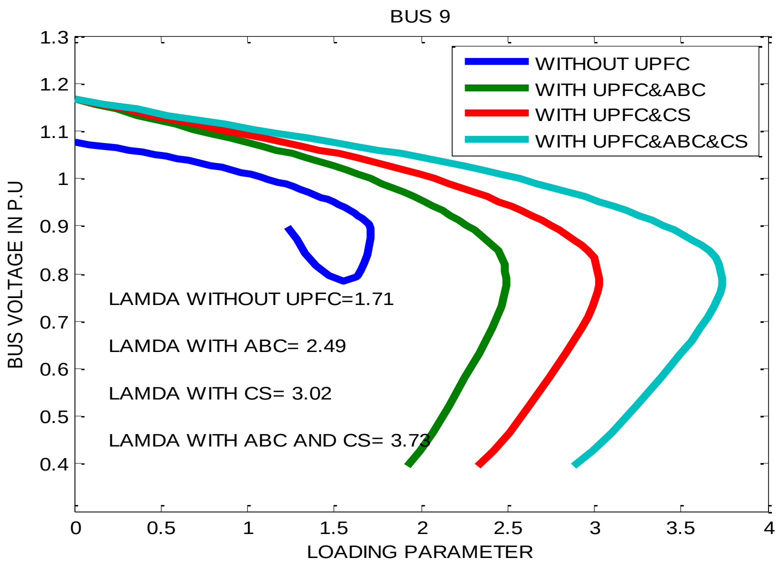

Figure 3.6 Nose curved for bus 9 of IEEE 14 bus system.

Table 3.5: Loading Parameter for Bus 9 of IEEE 14 bus system

Cases	Loading Parameter
Without UPFC	1.71
With UPFC and ABC	2.49
With UPFC and CS	3.02
With UPFC, ABC and CS	3.73

Figure 3.9. is the nose curve for Bus 11. Table 3.9 contains the loading parameter obtained by employing cuckoo search, artificial bee colony and their hybrid with/without UPFC on bus 11 of the IEEE 14-bus network. The loading parameter values were obtained for various scenarios. These scenarios include without UPFC, with UPFC and ABC, with UPFC and CS, and with UPFC and their hybrid respectively. The values obtained for the various scenarios are 1.71, 2.49, 3.02 and 3.73 respectively. The hybridized optimization process provided a far better setting for the UPFC.

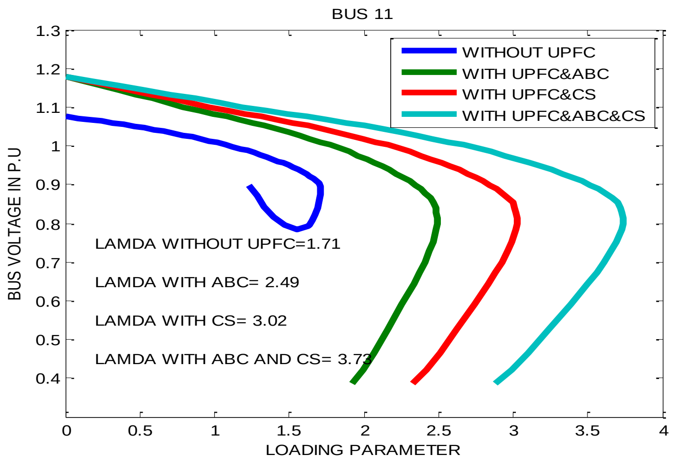

Figure 3.7: Nose curved for bus 11 of IEEE 14 bus system.

Table 3.6: Loading Parameter for Bus 11 of IEEE 14 bus system

Cases	Loading Parameter
Without UPFC	1.71
With UPFC and ABC	2.49
With UPFC and CS	3.02
With UPFC, ABC and CS	3.73

Figure 3.10. is the nose curve for Bus 12. Table 3.10 contains the loading parameter obtained by employing cuckoo search, artificial bee colony and their hybrid with/without UPFC on bus 12 of the IEEE 14-bus network. The loading parameter values were obtained for various scenarios. These scenarios include without UPFC, with UPFC and ABC, with UPFC and CS, and with UPFC and their hybrid respectively. The values obtained for the various scenarios are 1.71, 2.49, 3.02 and 3.73 respectively. The hybridized optimization process provided a far better setting for the UPFC.

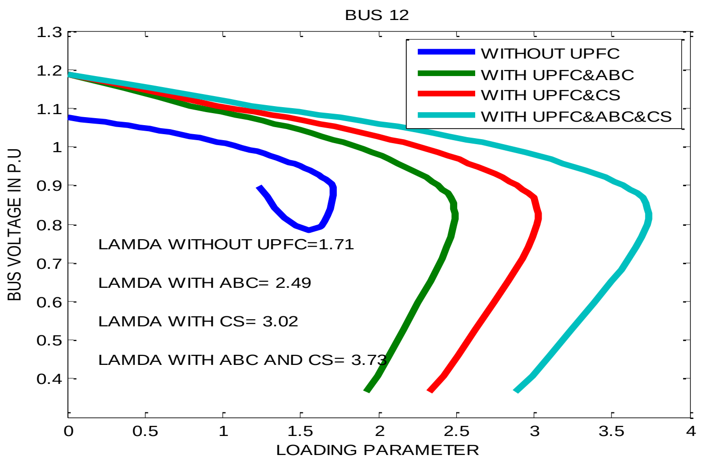

Figure 3.8: Nose curved for bus 12 of IEEE 14 bus system.

Table 3.7: Loading Parameter for Bus 12 of IEEE 14 bus system

Cases	Loading Parameter
Without UPFC	1.71
With UPFC and ABC	2.49
With UPFC and CS	3.02
With UPFC, ABC and CS	3.73

Figure 3.11. is the nose curve for Bus 13. Table 3.11 contains the loading parameter obtained by employing cuckoo search, artificial bee colony and their hybrid with/without UPFC on bus 13 of the IEEE 14-bus network. The loading parameter values were obtained for various scenarios. These scenarios include without UPFC, with UPFC and ABC, with UPFC and CS, and with UPFC and their hybrid respectively. The values obtained for the various scenarios are 1.71, 2.49, 3.02 and 3.73 respectively. The hybridized optimization process provided a far better setting for the UPFC.

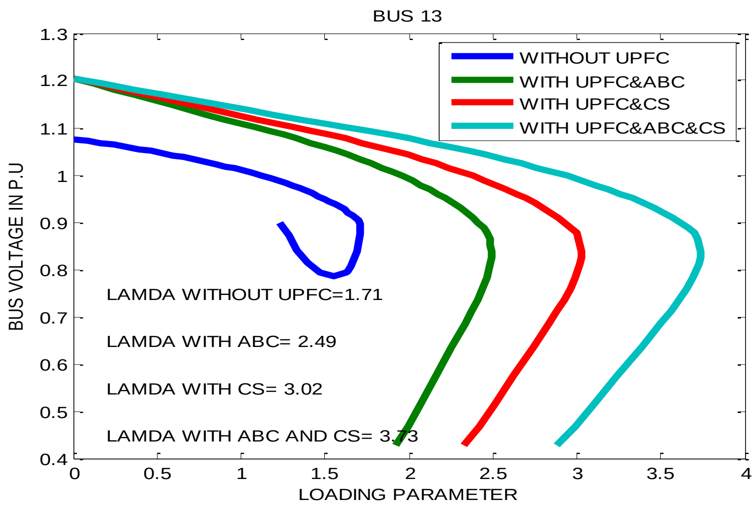

Figure 2.9: Nose curved for bus 13 of IEEE 14 bus system

Table 3.8: Loading Parameter for Bus 13 of IEEE 14 bus system

Cases	Loading Parameter
Without UPFC	1.71
With UPFC and ABC	2.49
With UPFC and CS	3.02
With UPFC, ABC and CS	3.73

4. CONCLUSION

Optimal voltage stability improvement is vital. This enables power systems around the world to operate optimal so that the electricity demands could be met. This work improved the stability of the system using IEEE 14 buses network. Artificial bee colony and cocoo search optimization algorithms were used to optimize the system, the results obtained showed that the hybridization of the two algorithms significantly improved the stability of the system.

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