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# Examining the Use of Interline Power Flow Controller for Congestion and Contingency Management on the Nigeria 330kv Transmission System

[1*]Akinropo, C., [2]Olarinoye G.A, [2] Okorie, P. U. and [3]Oricha J. Y.
[1*]Department Aircraft Engineering, Air Force Institute of Technology Kaduna, Nigeria
[2]Department of Electrical Engineering, Ahmadu Bello University Zaria, Nigeria
[3]Department of Electrical/Electronic Engineering, Federal University Oye, Oye-Ekiti,

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## Abstract

Nigeria, a country of over 200 million people, has witnessed high demand in power consumption in recent times. Consequently, power transmission lines have to transfer power at their maximum transmission limits. Stable and reliable operation of such transmission system can be achieved by monitoring the line stresses and predicting the effect of outages through contingency assessment. In this paper, a method of placement of interline power flow controller (IPFC) based on the probability of severity has been proposed. Composite Severity Index (CSI) of Fast Voltage Stability Index and Line Utilization Factor was used for the contingency ranking of lines for the placement of IPFC. IPFC is placed on the line with highest probability of severity during the event of different outages. Thereafter, cuckoo search algorithm was used to optimize the size of the IPFC. The method was applied to the Nigeria 330KV 31 bus system data. For this system, the overall CSI, active and reactive power losses were predicted to reduce by 2.22%, 15.35% and 28.11% respectively. The results show that optimal placement of IPFC effectively reduces line congestion and improves voltage stability. It also reduces the active and reactive power losses of the system and thereby reducing the risk of network collapse.

*Corresponding Author: Akinropo, **C.;** akinropocharles@gmail.com

## Introduction

The increase in the occurrence of blackoutin Nigeria is worrisome. Reliable operation of power transmission system in this nation under both normal and contingency situation is highly desirable. Hence contingency severity calculation becomes imperative to power system planning and reliability (Jun and Akihiko, 2006)

When disturbance occurs in power system, system stability is impacted and if preventive measures are not taken quickly there is a high risk of total system collapse (Karami *et al.*,2007).

A variety of solutions have been developed to minimise the effect of system disturbances and thus reduces the occurrences of system collapse. One of such solutions is the application of Flexible Alternate Current Transmission System (FACTS) devices in modern power systems. FACTS technology is regarded as one of emerging technologies for power system security improvement (Vassell, 1991).

IPFC is considered to be the most flexible, powerful, and versatile type of FACTs device. It employs at least two Voltage Source Converter (VSCs) with a common DC link which gives it the ability to compensate multi-transmission lines(Jayasankara *et al*., 2010). Proper positioning and tuning of the IPFC in the power system is a big concern in the industry as their effectiveness varies with position in a power system and it is the focus of this paper.The effectiveness of IPFC in controlling the power flow while maintaining the voltage profile in a 400kV power system network was investigated in Charan and Parimi (2018). In Rajagopalan *et al.*, (2018), IPFC was optimally located in order to minimise power losses on a 5 Bus power system using Bees Algorithm.

In this paper, placement and tuning of IPFC is proposed for protecting power transmission system against contingency. The line with the highest probability of severity is proposed to be the optimal location for IPFC placement. Cuckoo search algorithm is then used to tune the IPFC in order to minimize its size.Two different indices; Line Utilization Factor (LUF) and Fast Voltage Severity Index (FVSI) have been combined to develop a Composite Severity Index (CSI) to assess line overloads and bus voltage violations. LUF is used to measure line overloads in terms of both real and reactive power while FVSI has been employed for voltage contingency ranking. The CSI is used to obtain a precise estimate of overall stress on the line. The objective of this paper is to reduce active power lossand maximize security margin by optimal sizing and placement of IPFC on the network. The proposed method is implemented and tested on the Nigeria 31 bus transmission system.

**Model Equations**

The basic model of the IPFC consists of three buses i, j and k. Two transmission lines are connected with the bus i in common. The equivalent circuit of the IPFC with two converters is represented in Figure 1.

$$\boldsymbol{Vse_{in}} = Vse_{in}\langle\theta se_{in} \quad (1)$$

where n = j, k. $Vse_{in}$ and $\theta se_{in}$ are the magnitude and angle of $Vse_{in}$. $Zse_{in}$ is the series transformer impedance. $Pse_{in}$ is the active power exchange of each converter via the common DC link. $P_i$ and, $Q_i$ as given in Eqns. (2) and (3) are the sum of the active and reactive power flows leaving the bus i. The IPFC branch active and reactive power flows leaving bus .

$V_i$, $V_j$,$V_k$, are complex voltages at bus i, j, k respectively. Each of these voltages is characterized by a magnitude and phase angle. $Vse_{in}$ is the complex controllable series injected voltage source. $Vse_{in}$ is given by the following;

n are $P_{ni}$ and $Q_{ni}$ and the expressions are given in Eqns. (4) and (5). $I_{ji}$, $I_{ki}$ are the IPFC branch currents of branch j - i and k - i leaving bus j and k, respectively

$$P_i = V_i^2 g_{ii} - \sum_n V_i V_n[g_{in}cos(\theta_i - \theta_n) + b_{in}\sin(\theta_i - \theta_n)] - \sum_n V_i Vse_{in}[g_{in}cos(\theta_i - \theta se_{in}) + b_{in}\sin(\theta_i - \theta se_{in})] \quad (2)$$

$$Q_i = -V_i^2 b_{ii} - \sum_n V_i V_n[g_{in}sin(\theta_i - \theta_n) + b_{in}\cos(\theta_i - \theta_n)] - \sum_n V_i Vse_{in}[g_{in}sin(\theta_i - \theta se_{in}) + b_{in}\cos(\theta_i - \theta se_{in})] \quad (3)$$

$$P_{ni} = V_n^2 g_{nn} - V_i V_n(g_{in}cos\theta_{in} + b_{in}sin\theta_{in}) - V_n Vse_{in}(g_{in}\cos(\theta_i - \theta se_{in}) + b_{in}sin(\theta_i - \theta se_{in})) \quad (4)$$

$$Q_{ni} = -V_n^2 b_{in} - V_i V_n(g_{in}sin\theta_{in} - b_{in}cos\theta_{in}) - V_n Vse_{in}(g_{in}\sin(\theta_i - \theta se_{in}) + b_{in}cos(\theta_i - \theta se_{in})) \quad (5)$$

where n = j, k

$g_{in} + jb_{in} = Re(1/Zse_{in}) = yZse_{in}$

$g_{nn} + jb_{nn} = Re(1/Zse_{nn}) = yZse_{nn}$

$$g_{ii} = \sum_{n=j,k} g_{in} \; b_{ii} = \sum_{n=j,k} b_{in}$$

Assuming lossless converter, the active power supplied by one converter equals the active power demanded by the other, if there are no underlying storage systems.

$$Re(Vse_{ij}I_{ji}^* + Vse_{ik}I_{ki}^*) = 0 \quad (6)$$

where superscript * means complex conjugate.

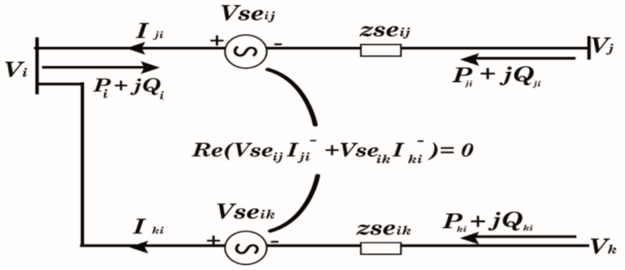

Figure 1: Equivalent circuit of IPFC

The following indices have been carefully selected to measure network performances.

**Line Utilization Factor (LUF)**

Line Utilization Factor LUF is given by

$$LUF_{ij} = \frac{MVA_{ij}}{MVA_{ij}^{max}} \quad (7)$$

Where; $LUF_{ij}$ is line utilization factor of the line connected to bus i and bus j, $MVA_{ij}^{max}$ is maximum MVA rating of the line between bus i and bus j, and $MVA_{ij}$ is actual MVA rating of the line between bus i and bus j.

The overall LUF of the system is given by:

$$OverallLUF = \sum_{\forall L} LUF \quad (8)$$

Where, L is the number of line in the system.

**Fast Voltage Stability Index**

Fast Voltage Stability Index (FVSI) is a line-based voltage stability indicator given by the following equation;

$$FVSI_{IJ} = \frac{4Z^2Q_j}{V_i^2X_{ij}} \quad (9)$$

Where; Z = line impedance

Symbols ‘i’ and ‘j’ represent the sending and receiving buses respectively.

$X_{ij}$ = line reactance

$Q_j$ = reactive power at the receiving end
$V_i$ = sending end voltage

The value of FVSI that is evaluated close to 1 indicates that the particular line is close to its instability point which may lead to voltage collapse in the entire system. To maintain a secure condition, the value of FVSI should be maintained well less than 1. The overall FVSI of the system is given by:

$$OverallFVSI = \sum_{\forall L} FVSI \quad (10)$$

## Composite Severity Index

The composite severity index is calculated as follows;

$$CSI_{\boldsymbol{ij}} = w_{\boldsymbol{1}} \times LUF_{ij} + w_{\boldsymbol{2}} \times FVSI_{ij} \quad (11)$$

$$w_{\boldsymbol{1}} = w_{\boldsymbol{2}} = 0.5$$

where, $w_{\boldsymbol{1}}$ and $w_{\boldsymbol{2}}$ are the weighting factors of both indices for line i-j.
The overall CSI of the system is given as:

$$OverallCSI = \sum_{\forall L} CSI \quad (12)$$

## Optimal Tuning of IPFC

To find the optimal size of IPFC, a multi objective function is formulated. The objective functions are; minimization of the active power loss, total voltage deviations, security margin and usage of minimum value of installed IPFC. Since there are four objective functions, weighing factors are used to reflect the relative importance of each one. The multi objective function is given as:

$$minF = min \sum_{i=1}^{4} w_i f_i \quad (13)$$

where $w_1$, $w_2$, $w_3$, $w_4$ are the weighing factors

$$w_1 + w_2 + w_3 + w_4 = 1 \quad (14)$$

$$w_1 = w_2 = w_3 = w_4 = 0.25 \quad (15)$$

The formulation for each objective functions is provided as follows:

## Minimization of the active power loss

$$minf_1(x) = min \sum_{i=j,k}^{lk} P_{loss} \quad (16)$$

$$P_{loss} = (|V_I|^2 G_{in} - |V_I||V_n|[G_{in}\cos\theta_{in} + B_{in}\sin\theta_{in}] - |V_I||V_{sin}|[G_{in}\cos\theta_{sin} + B_{in}\sin\theta_{sin}]) + (|V_I|^2 G_{in} - |V_I||V_n|[G_{in}\cos\theta_{ni} + B_{in}\sin\theta_{ni}] - |V_I||V_{sin}|[G_{ik}\cos\theta_{sin} + B_{ik}\sin\theta_{sin}]) \quad (17)$$

where: ik is the number of transmission lines,
$\boldsymbol{V_i} = V_i\langle\theta_i$ and $\boldsymbol{V_n} = V_n\langle\theta_n$ are voltages at the end buses i and n (n = j, k);
$V_{sin} = V_{sin}\langle\theta_{sin}$ is the series injected voltage source of $n^{th}$ line. $G_{in}$ and $B_{in}$ are the transfer conductance and susceptance between bus i and n respectively.

## Minimization of voltage deviation

The appropriate equation can be expressed as:

$$minf_2(x)(x) = \min(VD) = \min(\sum_{k=1}^{Nbus} \left|V^k - V_k^{ref}\right|^2 \quad (18)$$

where $V_k$ is the voltage magnitude at bus k.

## Minimization of security margin (SM)

The security rate of a system according to the critical state can be expressed as follows:

$$SM = \frac{\sum_{j\in J_L} S_j^{initail}}{\sum_{j\in J_L} S_j^{lim}} \quad (19)$$

where; $J_L$ = A set containing all load buses

SM has a value between zero and one for a system with stable operating condition. SM = 0 at the voltage stability limit. The objective function for SM can be rewritten as:

$$f_3(x,u,z) = 1 - SM = 1 - \frac{\sum_{j\in J_L} S_j^{initail}}{\sum_{j\in J_L} S_j^{lim}} \quad (20)$$

## Minimization of total capacity of installed IPFC

The minimum total capacity of the installed IPFC required for mitigating the overload on the transmission lines can be expressed as follows;

$$f_4(x) = \min(PQ_1^2 + PQ_2^2) \quad (21)$$

where PQ denotes capacity of each VSCof the IPFC.

$$\mathrm{PQ}_1^2 + \mathrm{PQ}_2^2 = (\mathrm{Vse}_{\mathrm{ij}}\left(\frac{\mathrm{V_i - Vse_{ij} - V_j}}{\mathrm{Z_{ij}}}\right))^2 + (\mathrm{Vse}_{\mathrm{ik}}\left(\frac{\mathrm{V_i - Vse_{ik} - V_k}}{\mathrm{Z_{ik}}}\right))^2 \quad (22)$$

The objective functions are subject to the following constraints;

## Equality constraints

$$P_{gi} + P_i - P_{di} = \sum_{j=1}^{n} V_i V_j Y_{ij} \cos\left(\theta_{ij} + \delta_j - \delta_i\right) \forall_i \quad (23)$$

$$Q_{gi} + Q_i - Q_{di} = \sum_{j=1}^{n} V_i V_j Y_{ij} \sin\left(\theta_{ij} + \delta_j - \delta_i\right) \forall_i \quad (24)$$

**Inequality constraints**

$$V_i^{min} \leq V_i \leq V_i^{max} \forall_i \in load\ bus \quad (25)$$

$$S_{ij}(V, \delta) \leq S_{ij}^{max} \forall_{ij} \quad (26)$$

**IPFC constraints**

$$Vse^{min} \leq Vse \leq Vse^{max} \quad (27)$$

$$\theta se^{min} \leq \theta se \leq \theta se^{max} \quad (28)$$

The algorithm as applied in this work is provided in Figure 2.

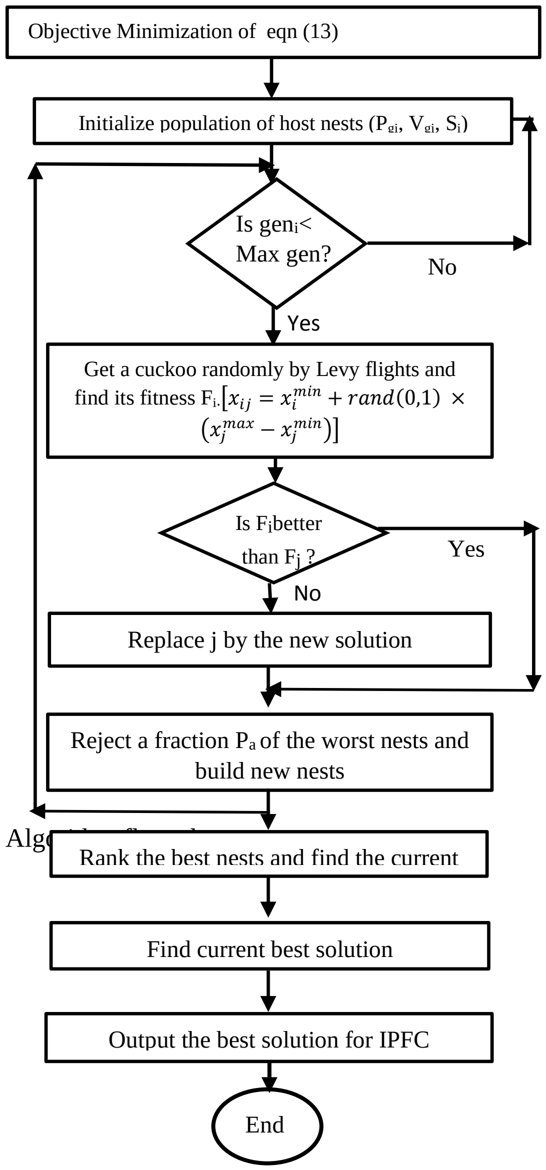

Figure 2: Cuckoo Search Alg

The parameters of the cuckoo search Algorithm is as shown in table 1

Table 1: Parameters of the CSA

| Initialization Parameters | Values Used |
|---|---|
| Number of cuckoo | 50 |
| Maximum number of generations | 400 |
| Minimum number of host egg for each cuckoo | 20 |
| Maximum number of host egg for each cuckoo | 40 |
| Motion coefficient | 9 |
| Number of cluster | 1 |
| Termination criteria | 1.exp-6 |

## Results and Discussion

The Nigeria 330KV 31 bus system has nine generator buses, 22 load buses and 36 transmission line as shown in Figure 3. The bus data and line data are shown in Tables2 and 3 respectively.The System base MVA is 100. An IPFC consisting of two converters has been used in the study and only load buses have been considered for IPFC placement.

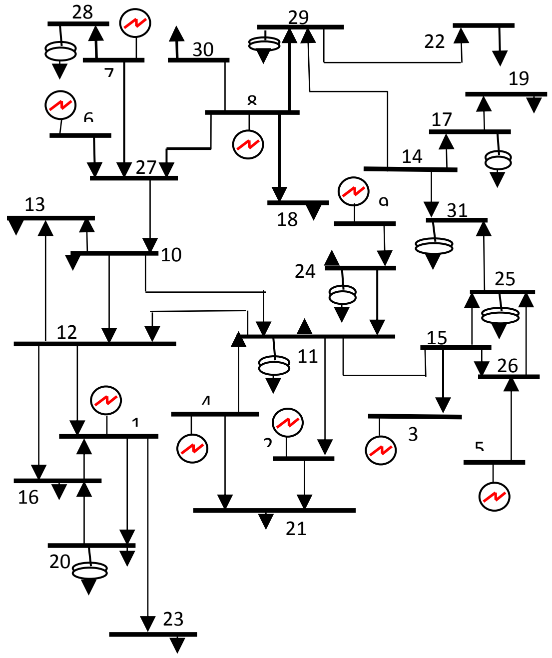

Figure 3: Nigeria 330 KV 31 Bus System

Table 2: Nigeria 330 KV 31 Bus System Bus Data

| Line No | From Bus | To Bus | R (p.u.) | X (p.u.) | 1/2BTr tap (p.u.) | |
|---|---|---|---|---|---|---|
| | 1 | 12 | 0.0022 | 0.0172 | 0.257 | 1 |
| | 7 | 28 | 0.0111 | 0.9420 | 1.178 | 1 |
| | 7 | 27 | 0.0022 | 0.0246 | 0.308 | 1 |
| | 8 | 29 | 0.0034 | 0.0292 | 0.364 | 1 |
| | 8 | 30 | 0.0019 | 0.0144 | 0.880 | 1 |
| | 8 | 18 | 0.0019 | 0.0154 | 0.880 | 1 |
| | 9 | 24 | 0.0022 | 0.0172 | 0.257 | 1 |
| | 10 | 27 | 0.0056 | 0.4770 | 0.597 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| 10 | 11 | 0.0089 | 0.0763 | 0.954 | 1 |
| 10 | 12 | 0.0049 | 0.0341 | 0.521 | 1 |
| 11 | 24 | 0.0070 | 0.0560 | 0.745 | 1 |
| 11 | 4 | 0.0018 | 0.0139 | 0.208 | 1 |
| 11 | 15 | 0.0049 | 0.0416 | 0.521 | 1 |
| 11 | 2 | 0.0022 | 0.0190 | 0.239 | 1 |
| 12 | 11 | 0.0101 | 0.0799 | 1.162 | 1 |
| 13 | 10 | 0.0041 | 0.0349 | 0.437 | 1 |
| 13 | 12 | 0.0049 | 0.0416 | 0.521 | 1 |
| 14 | 31 | 0.0029 | 0.0246 | 0.0 | 1 |
| 14 | 17 | 0.0095 | 0.0810 | 1.010 | 1 |
| 15 | 25 | 0.0034 | 0.0292 | 0.0355 | 1 |
| 15 | 26 | 0.0049 | 0.0419 | 0.5240 | 1 |
| 15 | 3 | 0.0090 | 0.0070 | 0.104 | 1 |
| 16 | 12 | 0.0006 | 0.0051 | 0.065 | 1 |
| 16 | 20 | 0.0006 | 0.0051 | 0.065 | 1 |
| 17 | 19 | 0.0021 | 0.0153 | 0.529 | 1 |
| 20 | 23 | 0.0022 | 0.0172 | 0.257 | 1 |
| 25 | 31 | 0.0019 | 0.0144 | 0.880 | 1 |
| 25 | 26 | 0.0019 | 0.0144 | 0.880 | 1 |
| 26 | 5 | 0.0090 | 0.0070 | 0.104 | 1 |
| 27 | 6 | 0.0030 | 0.0022 | 0.033 | 1 |
| 27 | 8 | 0.0087 | 0.0742 | 0.927 | 1 |
| 29 | 22 | 0.0082 | 0.0899 | 0.874 | 1 |
| 29 | 14 | 0.0070 | 0.0599 | 0.749 | 1 |

Table 3: Nigeria 330 KV 31 Bus System Line Data

| **B No** | **Bus Code** | $\lvert V \rvert$ | $\theta^{\circ}$ | **Load** | | **Generator** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **MW** | **MVAR** | **MW** | **MVAR** | **Qmin** | **Qmax** |
| 1 | 1 | 1.02 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 1.00 | 0 | 55 | 28.16 | 0 | 0 | 0 | 0 |
| 3 | 2 | 1.00 | 0 | 220 | 112.70 | 0 | 0 | 0 | 0 |
| 4 | 2 | 1.00 | 0 | 75 | 38.42 | 0 | 0 | 0 | 0 |
| 5 | 2 | 1.00 | 0 | 479 | 245.39 | 0 | 0 | 0 | 0 |
| 6 | 2 | 1.00 | 0 | 322 | 164.96 | 0 | 0 | 0 | 0 |
| 7 | 2 | 1.00 | 0 | 323 | 165.49 | 0 | 0 | 0 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 8 | 2 | 1.00 | 0 | 280 | 143.44 | 0 | 0 | 0 | 0 |
| 9 | 2 | 1.00 | 0 | 200 | 102.44 | 0 | 0 | 0 | 0 |
| 10 | 0 | 1.00 | 0 | 0 | 0 | 120.370 | 61.650 | 0 | 0 |
| 11 | 0 | 1.00 | 0 | 0 | 0 | 160.560 | 82.240 | 0 | 0 |
| 12 | 0 | 1.00 | 0 | 0 | 0 | 334.000 | 171.110 | 0 | 0 |
| 13 | 0 | 1.00 | 0 | 0 | 0 | 176.650 | 90.490 | 0 | 0 |
| 14 | 0 | 1.00 | 0 | 0 | 0 | 82.230 | 42.129 | 0 | 0 |
| 15 | 0 | 1.00 | 0 | 0 | 0 | 130.510 | 66.860 | 0 | 0 |
| 16 | 0 | 1.00 | 0 | 0 | 0 | 233.379 | 119.560 | 0 | 0 |
| 17 | 0 | 1.00 | 0 | 0 | 0 | 74.480 | 38.140 | 0 | 0 |
| 18 | 0 | 1.00 | 0 | 0 | 0 | 200 | 102.440 | 0 | 0 |
| 19 | 0 | 1.00 | 0 | 0 | 0 | 10 | 5.110 | 0 | 0 |
| 20 | 0 | 1.00 | 0 | 0 | 0 | 113.050 | 76.720 | 0 | 0 |
| 21 | 0 | 1.00 | 0 | 0 | 0 | 47.997 | 24.589 | 0 | 0 |
| 22 | 0 | 1.00 | 0 | 0 | 0 | 252.450 | 129.330 | 0 | 0 |
| 23 | 0 | 1.00 | 0 | 0 | 0 | 119.990 | 61.477 | 0 | 0 |
| 24 | 0 | 1.00 | 0 | 0 | 0 | 63.220 | 32.380 | 0 | 0 |
| 25 | 0 | 1.00 | 0 | 0 | 0 | 113.050 | 57.910 | 0 | 0 |
| 26 | 0 | 1.00 | 0 | 0 | 0 | 163.950 | 83.980 | 0 | 0 |
| 27 | 0 | 1.00 | 0 | 0 | 0 | 7.440 | 3.790 | 0 | 0 |
| 28 | 0 | 1.00 | 0 | 0 | 0 | 69.990 | 35.850 | 0 | 0 |
| 29 | 0 | 1.00 | 0 | 0 | 0 | 149.77 | 76.720 | 0 | 0 |
| 30 | 0 | 1.00 | 0 | 0 | 0 | 73.070 | 37.430 | 0 | 0 |
| 31 | 0 | 1.00 | 0 | 0 | 0 | 73.007 | 37.430 | 0 | 0 |

Contingency analysis was performed under 110% system loading. The severity index of all the lines corresponding to every outage was computed and it was discovered that the highest severity occurred when outage is on line 11 – 12. Hence, outages on line 11 – 12 was used as the contingency. Computation of CSI of all the lines was done for three scenarios. First scenario is that of the existing system without contingency also known as the base case. Second is the system after subjection to contingency and third is the system with contingency plus the application of optimally tuned IPFC. The CSI for these three scenarios is provided in Table 4 as well.

Table 4: CSI line values for the 31 Bus Test System with outages on Line 11 – 12

| **FB** | **TB** | **CSI before contingency** | **CSI after contingency** | **CSI with IPFC** |
|---|---|---|---|---|
| 1 | 12 | 0.0735 | 0.0635 | 0.0767 |
| 1 | 16 | 0.0608 | 0.0525 | 0.0634 |
| 1 | 20 | 0.0517 | 0.0447 | 0.0540 |
| 2 | 21 | 0.0121 | 0.2233 | 0.0126 |
| 4 | 21 | 0.0129 | 0.0111 | 0.0134 |
| 7 | 27 | 0.0948 | 0.0787 | 0.0990 |
| 8 | 2 | 0.0948 | 0.0977 | 0.0932 |
| 8 | 29 | 0.1989 | 0.1720 | 0.2077 |
| 8 | 30 | 0.0160 | 0.0138 | 0.0463 |
| 8 | 18 | 0.0444 | 0.0384 | 0.4136 |
| 9 | 24 | 0.0480 | 0.0415 | 0.0501 |
| 10 | 27 | 0.8145 | 1.0762 | 0.7547 |
| 10 | 11 | 0.0311 | 0.0268 | 0.0324 |
| 10 | 12 | 0.0182 | 0.0157 | 0.0191 |
| 11 | 24 | 0.1042 | 0.0901 | 0.1088 |
| 11 | 4 | 0.0052 | 0.0045 | 0.0054 |
| 11 | 15 | 0.0085 | 0.0073 | 0.0089 |
| 11 | 2 | 0.0145 | 0.0125 | 0.0151 |
| 13 | 10 | 0.0382 | 0.0330 | 0.0399 |
| 13 | 12 | 0.0578 | 0.0499 | 0.0603 |
| 14 | 31 | 0.0482 | 0.0417 | 0.0503 |
| 14 | 17 | 0.0652 | 0.0564 | 0.0680 |
| 15 | 25 | 0.0437 | 0.0378 | 0.0456 |
| 15 | 26 | 0.0092 | 0.0080 | 0.0096 |
| 15 | 3 | 0.0351 | 0.0304 | 0.0367 |
| 16 | 12 | 0.0127 | 0.0110 | 0.0132 |
| 16 | 20 | 0.0090 | 0.0078 | 0.0094 |
| 17 | 19 | 0.0012 | 0.0010 | 0.0012 |
| 23 | 1 | 0.0306 | 0.0264 | 0.0319 |
| 25 | 31 | 0.0456 | 0.0395 | 0.0376 |
| 25 | 26 | 0.0518 | 0.0448 | 0.0441 |
| 26 | 5 | 0.0770 | 0.0665 | 0.0503 |
| 27 | 6 | 0.0182 | 0.0152 | 0.0190 |
| 27 | 8 | 0.4869 | 0.4123 | 0.4083 |
| 29 | 22 | 0.4872 | 0.4123 | 0.5087 |
| 28 | 7 | 0.7735 | 0.7075 | 0.7770 |
| 29 | 14 | 0.2001 | 0.3200 | 0.2089 |

It can be observed from Table 4 that the line connected between the buses 10 - 27 has the highest CSI value of 1.0762 which is most vulnerable as compared to other lines. Hence the line 10 - 27 is chosen for the placement of the first converter of the IPFC. Further analysis was carried out on the two lines connected with the line 10- 27 through a common bus (i.e. lines 10 – 12 and 13 - 10). The CSI values of these lines for an outage on line 11 - 12 have been given in Table 5.

Table 5: CSI of Lines Connected to Line 10 - 27 for Contingency on Line 11 – 12

| From Bus | To Bus | CSI with contingency |
|---|---|---|
| 10 | 12 | 0.0157 |
| 13 | 10 | 0.0330 |

The performance metrics for the comparison are the active power losses, reactive power losses and voltage deviation plots.The graphs are shown in figures 4, 5 and 6 for active power loss, reactive power loss and voltage profile respectively.

Different performances of the system were calculated for the three scenarios mentioned. The results have been provided in Table 6. The performances taken into consideration are active power loss, reactive power loss, and overall CSI value.

Table 6: Network performance of the 330KV 31 bus system under three scenarios.

| **Parameter Description** | **Value in different system state** | | |
|---|---|---|---|
| | **Without contingency** | **With Contingency At 11-12** | **With Optimal placement of IPFC** |
| Active Power Loss (MW) | 46.5771 | 50.6334 | 42.8623 |
| Reactive Power Loss (MVAR) | 203.7499 | 242.6758 | 174.4678 |
| Capacity of installed IPFC (MVAR) | - | 5.2547e-4 | 5.0343e-4 |
| CSI of Line 7 - 9 | 0.8145 | 1.0762 | 0.7547 |
| Overall CSI | 4.1953 | 4.3918 | 4.2944 |

With the outage of line 11-12, it is observed that the active and reactive power losses of the system increased from 46.5771 MW to 50.6334 MW and 203.7499 MVAR to 242.6758 respectively as calculated from the algorithm. After placement and tuning of IPFC on the lines 10 - 27 and 10 – 12 using the CSA, the active and reactive power losses of the system reduced to 42.8623 MW and 174.4678 MVAR respectively as calculated from the optimization algorithm. The loss profiles with IPFC installed show considerable reduction in losses of the system as seen in Figures 4 and 5. The voltage profile of the system for the three scenarios is provided in Figure 6. It can be observed that the system voltage profile improves with the optimal placement of IPFC.

Placement of IPFC at the proposed location reduces the values of CSI and overall CSI to levels lower than the pre-contingency levels as shown in Table 5 and Figure 7. Reduction in CSI values mean that the lines concerned are now less vulnerable to congestion in the event of a contingency. The implication of these results is that optimal placement and tuning of IPFC reduces the congestion in the line considerably. It also mitigates active and reactive power losses in the system during a contingency

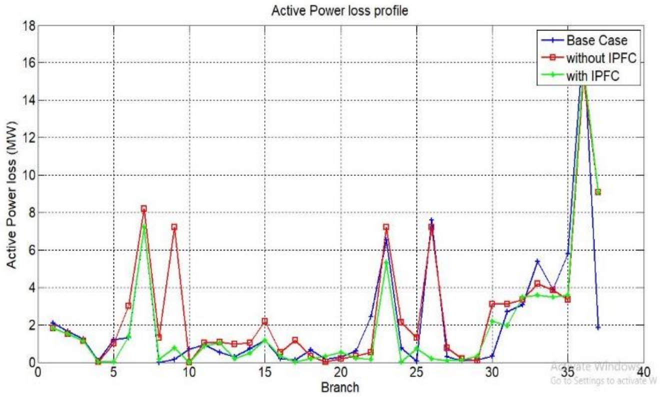

Figure 4: Active Power loss profile of the 330KV 31 bus system using CSI1 and CSA

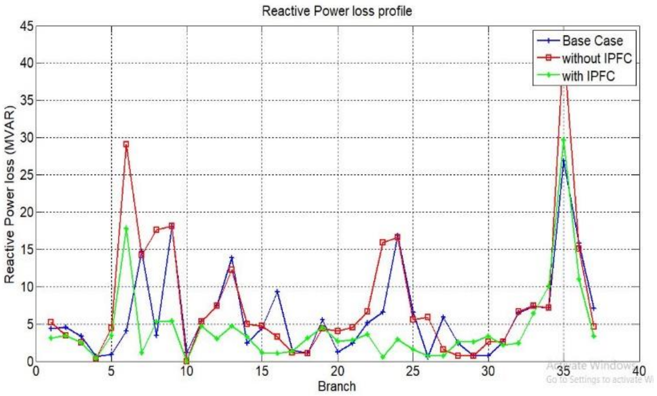

Figure 5: Reactive Power loss profile of the 330KV 31 bus system using CSI1 and CSA

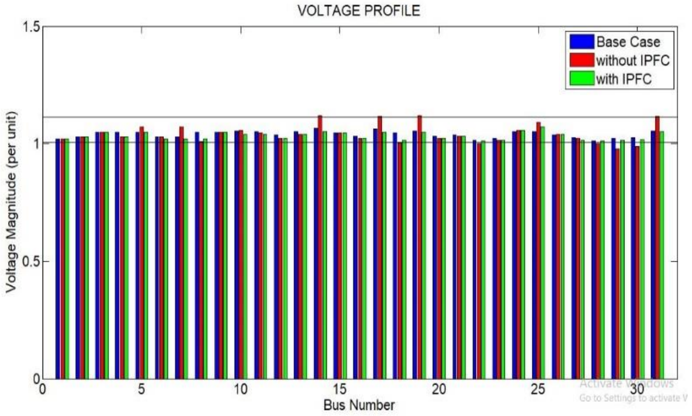

Figure 6: Voltage Profile of the 330KV 31 bus system using CSA

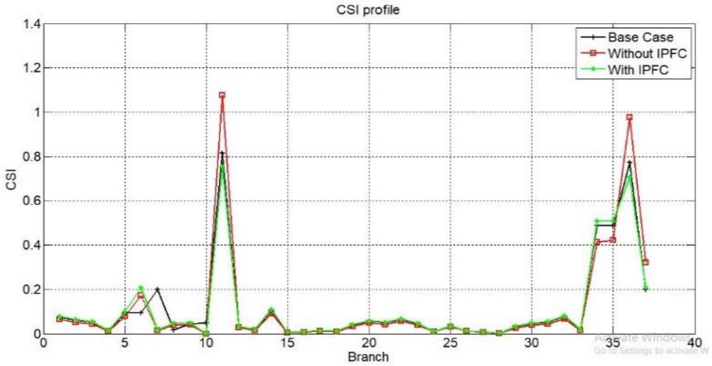

Figure 7: CSI Profile of 330KV 31 bus system using CSA optimization

**Conclusion**

Contingency severity assessment has been conducted in this paper. The paper provides yet another method by which transmission lines can be monitored before and during contingency with a view to informing any preventive course of action and thereby avert a system collapse. In addition, the paper has demonstrated the effectiveness of an optimally placed and tuned IPFC to reduce line congestion and severity of contingency on theNigeria 330 KV 31 bus transmission system.System parameters were studied for three different system conditions namely (1) without contingency (2) with contingency at line 11 – 12 and (3) with optimal placement and tuning of IPFC. Results have shown that parameters such as active power loss, reactive power loss and voltage deviation reduced by 15.35%, 28.11% and 0.35% respectively after placement and tuning of the IPFC. These results show that optimal placement of IPFC effectively reduces line congestion, improves voltage stability and reduces the active and reactive power loss of the system. It also reduces the voltage deviation and hence enhances the voltage profile of the system.

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