APPLICATION OF UNIFIED POWER FLOW CONTROLLER FOR ENHANCEMENT OF POWER SECURITY ON NIGERIAN 330KV NETWORK

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Abstract - *This paper presents the application of Unified Power Flow Controller (UPFC) for enhancement of power security on Nigeria's national grid by minimizing power loss in transmission lines. The UPFC is used because it is the most versatile among the Flexible Alternating Current Transmission System (FACTS) family. Voltage sensitivity index method is used to determine the most appropriate location for the UPFC and bat algorithm optimization technique is used for finding the optimal size of the UPFC. Simulation results obtained before and after connecting the UPFC show net active and reactive power losses reducing from 106.58MW and 703.75MVAr to 84.23MW and 597.50MVAr respectively. Bus voltage enhancement was archived on most of the load buses with maximum enhancement of 0.1 pu recorded on three buses.*

Keywords: **(UPFC, Power System Security, Voltage Sensitivity Index, Bat Algorithm)**

1. INTRODUCTION

Due to continuous expansion of the Nigerian national electrical power network as a result of continuous increase in power demand on it, the existing state of the network is best described as being over stretched. The demand on it compared with its operational capability means that the installed facilities are fully utilized. A power systems operated at this state are closer to their thermal and stability limits and they are constantly subjected to contingencies [1]. The factors that set the system security are voltage deviation, system overload and real power losses [2]. These factors have led to the continuous search for methods of reducing them so as to improve the power system performance in terms of its overall security. One of such methods is the use of Flexible Alternating Current Transmission Systems (FACTS) devices.

The evolution of the FACTS technology is given in [3]. Since then different kind of FACTS controllers have been recommended. FACTS controllers are based on voltage and current source converters and include devices such as Static Var Compensators(SVCs), Static Synchronous Compensators (STATCOMs), Thyristor Controlled Series Compensators (TCSCs), Static Synchronous Series Compensators (SSSCs) and Unified Power Flow Controllers (UPFCs). Among them, UPFC is the most versatile and efficient because it has the advantage of controlling the three transmission parameters, namely, voltage magnitude, line impedance and phase angle [4].

In the last decade, new algorithms have been developed with the use of FACTs devices especially for the optimal power flow incorporated with UPFC device placement. Some of them are sensitivity-based approach [5], evolutionary-programming-based load flow algorithm [6], genetic algorithm [7], particle swarm optimization [8], genetic algorithm [9] and artificial neural network ANN [10], a self-adaptive differential evolutionary (SADE) algorithm [11]. All these methods were adopted in searching for the optimal location or size of the UPFC in the network.

There has been some application of the UPFC to improve the performance of the Nigerian network. There are procedures of locating the UPFC [12-13], use of UPFC for transient enhancement [14], real and reactive power control [15], [23] and voltage stability enhancement [24]

In this paper, the real power loss function has been optimized using a bat algorithm optimization technique. Voltage sensitivity Index (VSI) method is used to identify the most appropriate location for the UPFC on the Nigerian 330kV integrated power network [15]. The performance of the network before and after installation of the controller are analyzed.

2. METHODOLOGY

This work is carried out in the following logical sequence:

1. Development and implementation of a power flow analysis based on Newton-Raphson for the study system in other to determine pre compensation (base case) bus voltages, power available on the buses and the power loss in each branch of the network.
2. Computation of voltage sensitivity indices (VSIs) for all the load buses of the study system to determine the weakest bus which is the optimal location for UPFC placement in the network.

3. Determination of optimal size of the UPFC using bat algorithm.
4. Evaluation of the benefit of this work on the Nigerian 31 bus transmission network.

2.1 Power Flow Analysis (PFA):

Power flow analysis, well documented in several literatures, is the method used to determine the steady state operational state of an interconnected power system using some known variables on its buses. The main objective of PFA is to obtain the system bus voltages in both magnitude and phase angle. Once this is done, it becomes possible to estimate the amount of power flow and losses in the system lines. Power flow is basically solving the complex and nonlinear power balance equations given in Equations (1) and (2).

$$P_i = \sum_{i=1}^{N} |V_i||V_j||Y_{ij}|\cos(\delta_i - \delta_j - \theta_{ij}), j = 1, \dots, N \qquad 1$$

$$Q_i = \sum_{i=1}^{N} |V_i||V_j||Y_{ij}|\sin(\delta_i - \delta_j - \theta_{ij}), j = 1, \dots, N \qquad 2$$

PFA is implemented in the following procedure:

Step 1: Form the nodal admittance matrix (Y_{ij}).

Step2: Initialization: Set one of the generator buses (N) as the slack bus with voltage magnitude $|V_N|=1$ and angle δ_N =0.0. For the load buses, real power P_{isch} and reactive power Q is being specified. Voltage magnitudes and phase angles are initialized with the slack bus values. For the generator buses, V_i and P_i are specified and the phase angles are set equal to the slack bus value. Initialize iteration counter k.

Step 3: Calculate the real power P_{ical} and reactive power Q_{ical} using equations (1) and (2) respectively.

Step 4: Form the Jacobian Matrix J.

Step 5: Calculate the power differences ΔP_i and ΔQ_i for all the load buses using equations (3) and (4).

$$\Delta P_i = P_{isch} - P_{ical}^{k} \qquad 3$$
$$\Delta Q_i = Q_{isch} - Q_{ical}^{k} \qquad 4$$

Step 6: Choose the tolerance values.

Step 7: Stop the iteration if all ΔP_i and ΔQi are within the tolerance values.

Step 8: Update the values of V_i and δ_i using Equations (5) and (6) respectively.

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right| \qquad 5$$

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \qquad 6$$

Step 9: Repeat from step 3 until all ΔP_i and ΔQi are within the tolerance values.

2.2 Computation of Voltage Sensitivity Index(VSI)

A bus that cannot withstand its load due to inadequate reactive power support is termed a weak bus. The weakest bus is thus the most appropriate location for a compensator. One effective way of identifying weakest bus in a power system is to calculate one of several metrics of stability called stability indices. Many of these matrices have been developed by different researchers and made available in literature such as [18-20]. Among such indices are, Fast Voltage Stability Index (FVSI), Line Stability Index (Lmn), Voltage Collapse Prediction Index (VCPI) and Reactive Power Voltage Stability Index (RPVSI). Others are Power Transfer Stability Index (PTSI), Line Voltage Stability Index (LVSI), Equivalent Node Voltage Collapse Index (ENVCI) and many more.

The bus voltage of power system is more affected by reactive power than active power except in heavily loaded power system where the effect of active power on bus voltages can be noticeable [19]. Therefore, it is adequate to investigate bus voltage stability level by considering the variations of the bus voltage with the reactive power as (7).

$$\mathrm{VSI} = \frac{\partial V_i}{\partial Q_j} \qquad 7$$

The VSI in (7) is the Reactive Power Voltage Sensitivity Index (RPVSI). The computation of the RPVSI is by considering the linearized form of the nonlinear power balance equations. The linearized form is given in equation (8)

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_1 & J_2\\ J_3 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \qquad 8$$

The reactive power is less sensitive to changes in phase angle and mainly dependent on changes in voltage magnitude. Similarly, the real power changes is less sensitive to the change in phase angle. So, it is quite accurate to set J_2 and J_3 in equation (8) to zero resulting in equation (9)

$$\frac{\Delta|V|}{\Delta Q} = J_{4ij}^{-1} \qquad 9$$

The RPVSI are computed as in equation (10).

$$RPVS_i = diag\{J_{4ij}^{-1}\} \qquad 10$$

A positive RPVSI is an indication of stable operation, the smaller the sensitivity index, the more stable the bus is, while the higher the sensitivity index, the weaker the bus.

2.3 Bat Algorithm

BAT Algorithm is an optimization algorithm based on the echolocation behavior of bats. The capability of echolocation of bats is appealing as these bats can find their prey and discriminate between different types of insects even when they are in a complete darkness [21]. The advanced capability of echolocation of bats has been used to solve different optimization problems. Echolocation of bats works as a type of sonar in bats, where the bats emits a loud and short pulse of sound, wait as it hits into an object, the echo returns back to their ears. Thus, bats can compute how far they are from an object. In addition, this amazing orientation mechanism makes bats being able to distinguish the difference between an obstacle and a prey, allowing them to hunt even in a complete darkness.

Bats algorithm uses frequency tuning, it is in fact the first algorithm of its kind in the context of optimization and computational intelligence. Each bat is encoded with a velocity v_i^t and a location x_i^t at iteration t, in a d-dimensional search or solution space. The location can be considered as a solution vector to a problem of interest. Among the n bats in the population, the current best solution $x*$ found so far can be archived during the iterative search process.

The Bat algorithm was developed with the following characteristics:

1. All bats use echolocation to sense distance, and also know the difference between food/prey and background barriers in some magical way;
2. Bats fly randomly with velocity (v_x) at position (x_i) with a frequency (f) or wavelength (λ) and loudness (A_0) to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission $r \in [0,1]$, depending on the proximity of their target;
3. Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive) A_0 to a minimum constant value A_{min}.

In this study, Bat Algorithm was used based on the following advantages especially over other methods. This includes:

1. Frequency Tuning: the BA uses echolocation and frequency tuning to solve problems. Though echolocation is not directly used to mimic the true function in reality, frequency variation is used, hence these made it to distinguish itself from the PSO, SA AND HS and other swam intelligent based algorithm.
2. Automatic Zooming: BA has a unique edge over other metaheuristic algorithm due to its capability of automatically zooming into a region where promising solutions have been found, thus guarantying a quick convergence rate at early stages compared to other algorithm.
3. Parameter control: many metaheuristic algorithms used fixed parameter by using some pre-tuned algorithm dependent parameter. Here, BA uses parameter control which can vary the values of the parameters (A and r) as the iteration proceed. This provides an automatic switch from exploration to exploitation when the optimal solution is approaching.

According to [21], the mathematical equations for updating the locations x_i^t and velocities v_i^t can be written as:

$$fi = f_{min} + (f_{max} - f_{min}) \beta \tag{11}$$

$$V_i^t = V_i^{t-1} + (x_i^t - x_*) f_i \tag{12}$$

$$X_i^t = X_i^{t-1} + v_i^t \tag{13}$$

where $\beta \in [0,1]$ is a random vector drawn from a uniform distribution.

Here x_* is the current global best location (solution) after comparing all the solutions among all the n bats. A new solution for each bat is generated locally using random walk given by:

$$x_{new} = x_{old} + \varepsilon A^t \tag{14}$$

In addition, the loudness and pulse emission rates can be varied during the iterations. The following equations for varying the loudness and pulse emission rates is giving by

$$A_i^{t+1} = \alpha A_i^i \tag{15}$$

$$r_i^{t+1} = r_i^0 \, [1 - \exp(-\gamma t) \tag{16}$$

where $0 < \alpha < 1$ and $\gamma > 0$ are constants.
For any $0 < \alpha < 1$ and $y > 0$, we have:
$A_i^t \to 0$. $r_i^t \to r_i^0$ as $t \to \infty$The initial loudness A_0 can typically be (1, 2), while the initial emission rate r_i^0 can be (0, 1).

2.4 Objective Function

In this work, the aim is to minimize the real power losses in order to obtain maximum power transfer capability. Mathematically, the objective function can be written as [22],

$$f = \min(P_{loss}) \tag{17}$$

Where $P_{loss} = \sum_{i=1}^{Ntl} G_{ij} \, [V_i^2 + V_j^2 - 2 V_i V_j \cos(\delta_i - \delta_j)$ 18

G_{ij} is the conductance of line ij, V_i and V_j are the magnitudes of sending end and receiving end voltages of the line. δ_i and δ_j are the phase angles of the end voltages. Ntl is the number of transmission lines.

The equality constraints:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{Nb} V_j \left(G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j)\right) = 0 \tag{19}$$

$$Q_{Gi} - Q_{Ci} - Q_{Di} - V_i \sum_{j=1}^{Nb} V_j \left(G_{ij} \sin(\delta_i - \delta_j) - B_{ij} \cos(\delta_i - \delta_j)\right) = 0 \tag{20}$$

P_{Gi} is the real power generation at bus i, P_{Di} is the power demand at bus i, Nb is the number of PQ nodes in the system. Q_{Gi} is the reactive power generation at bus i, Q_{Di} is the reactive power demand at bus i, Q_{Ci} is the reactive power from compensation nodes. The inequality constraints are:

Voltage limits for generator buses:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max} \qquad 21$$

Where V_{Gi}^{min} is the minimum voltage at the generator bus, V_{Gi} is the actual voltage at the generator bus and V_{Gi}^{max} is the maximum voltage at the generator bus.

Real power generation limits:

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \qquad 22$$

Where P_{Gi}^{min} is the minimum real power at the generator bus, P_{Gi} is the actual real power at the generator bus and P_{Gi}^{max} is the maximum real power at the generator bus.

Reactive power generation limits:

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \qquad 23$$

Where Q_{Gi}^{min} is the minimum reactive power at the generator bus, Q_{Gi} is the actual reactive power at the generator bus and Q_{Gi}^{max} is the maximum reactive power at the generator bus.

UPFC limits:

$$V_{vr}^{min} \leq V_{vr} \leq V_{vr}^{max} \qquad 24$$

Where V_{vr}^{min} is the minimum shunt converter voltage magnitude (p.u), V_{vr} is the actual shunt converter voltage (p.u) and V_{vr}^{max} is the maximum shunt converter voltage magnitude (p,u).

$$V_{cr}^{min} \leq V_{cr} \leq V_{cr}^{max} \qquad 25$$

Where V_{cr}^{min} is the series converter voltage magnitude (p.u), V_{cr} is the actual series converter voltage magnitude (p.u) and V_{cr}^{max} is the maximum series converter voltage magnitude (p.u)

2.5 Input Parameters of the Bat Algorithm

The table below shows the input data for the bat algorithm:

TABLE I
INPUT PARAMETERS OF BATALGORITHM

S/N	Parameters	Quantity
1	Number of iterations	50
2	Number of population	20
3	Pulse rate	0.9
4	Loudness	0.9

2.6 Study System and Data Presentation

The transmission line data indicates the impedance per unit length on each line segment while the bus data includes information such as real power, reactive power, voltage magnitude and phase angle on each bus. The network has 31 buses of which nine (9) among these buses are generating stations i.e. generator bus, while the rest are load buses. One of the power station (Egbin power station) was chosen as the slack bus based on its location in the network and having the largest generating capacity [23]. This along with the one-line diagram is seen on the appendix of this paper.

3. RESULT

The simulated result and analysis of this work is seen below

3.1 Optimal Location of the UPFC

The computed RPVSI for the Nigerian 330kV network are given in Table II.

TABLE II:
VSI RESULT FOR LOAD BUSES

S/NO	Load Bus Number	Voltage Sensitivity Index (VSI)	Bus Weakness Ranking
1	10	0.0253	9
2	11	0.0061	19
3	12	0.0073	17
4	13	0.0330	7
5	14	0.0601	4
6	15	0.0107	15
7	16	0.0062	18
8	17	0.2631	2
9	18	0.0150	12
10	**19**	**0.2878**	**1**
11	20	0.0074	16
12	21	0.0060	20
13	22	0.1514	3
14	23	0.0251	10
15	24	0.0141	14
16	25	0.0207	11
17	26	0.0041	21
18	27	0.0470	5
19	28	0.0032	22
20	29	0.0310	8
21	30	0.0150	13
22	31	0.0364	6

From Table II, the bus with the highest RPVSI value is bus 19, which is an indication of being the weakest bus and therefore the best location for the UPFC placement.

3.2 UPFC Size

The UPFC sizing was obtained using the bat algorithm and the optimal size of the UPFC was found to be 182.0438MVAr.

3.3 Validation of the technique

Power flow analysis using Newton Raphson method was re-run for the system with the UPFC sized and located and the following results were obtained.

The variation of line losses before and after installation of UPFC are given in Table III.

TABLE III
SUMMARY OF LINE LOSSES BOTH BEFORE AND AFTER UPFC PLACEMENT

S/N	Branch		Real Power Loss			Reactive Power Loss		
	From Bus	To Bus	MW Before UPFC	MW After UPFC	Diff. in MW	MVar Before UPFC	MVar After UPFC	Diff. in MVar
1	1	12	2.0974	1.9309	0.1665	16.3979	15.0963	1.3016
2	1	16	1.6586	1.5595	0.4991	12.5706	11.8194	0.7509
3	1	20	1.2386	1.1741	0.0645	9.3871	8.8982	0.4889
4	2	21	0.0843	0.0083	0.0760	0.6746	0.0663	0.6083
5	4	21	0.1084	0.0119	0.0965	0.8958	0.0984	0.7974
6	7	28	1.2143	1.2143	0.0000	103.0546	103.0546	0
7	7	27	1.3159	1.3167	-0.0008	14.7137	14.7233	-0.0096
8	8	29	7.2287	6.4932	0.7355	62.0818	55.7652	6.3166
9	8	30	0.1538	0.1521	0.0017	1.1659	1.1529	0.0130
10	8	18	0.6965	0.7259	-0.0294	5.2785	5.5018	-0.2233
11	9	24	0.9491	0.9069	0.00422	7.4200	7.0903	0.3297
12	10	27	0.5152	0.5640	-0.0488	43.8833	48.0400	-4.1567
13	10	11	0.2804	0.3882	-0.1078	2.4037	3.3285	-0.9248
14	10	12	0.7169	0.6062	0.1107	4.9888	4.2189	0.7699
15	11	24	0.1604	1.1536	-0.9932	9.2829	9.2286	0.0543
16	11	4	0.1888	0.5546	-0.3658	1.4577	4.2825	-2.8248
17	11	15	0.1268	0.1717	-0.0449	1.0768	1.4573	-0.3805
18	11	2	0.6474	0.3423	0.3051	5.5911	2.9566	2.6345
19	12	11	0.1594	0.1824	-0.0227	1.2611	1.4430	-0.1819
20	13	10	0.2874	0.2984	-0.0110	2.4465	2.5399	-0.0934
21	13	12	0.6069	0.5581	0.0488	5.1523	4.7385	0.4138
22	14	31	2.4236	0.6200	1.8036	20.5585	5.2596	15.2989
23	14	17	6.5538	0.5958	5.9580	55.8795	5.0796	50.7999
24	15	25	0.7644	0.2689	0.4955	6.5652	2.3093	4.2559
25	15	26	0.0646	0.1025	-0.0379	0.5528	0.8769	-0.3241
26	15	3	7.6060	5.1673	2.4387	5.9158	4.0190	1.8968
27	16	12	0.2841	0.2412	0.0429	2.4153	2.0501	0.3652
28	16	20	0.0818	0.0740	0.0078	0.6955	0.6288	0.0667
29	17	19	0.1042	0.3014	-0.1972	0.7594	2.1957	-1.4363
30	20	23	0.3287	0.3292	-0.0005	2.5700	2.5738	-0.0038
31	25	31	2.7085	1.0536	1.6549	20.5277	7.9849	12.5428
32	25	26	3.0825	1.8597	1.2228	23.3618	14.0943	9.2675
33	26	5	32.3898	25.3584	7.0313	25.1921	19.7232	5.4689
34	27	6	3.8950	3.6353	0.2597	2.8563	2.6659	0.1904
35	27	8	17.8066	17.5264	0.2802	151.8679	149.4777	2.3902
36	29	22	5.2090	6.2416	-1.0326	57.1080	68.4288	-11.3208
37	29	14	1.8393	0.5416	1.2977	15.7395	4.6344	11.1051
	TOTAL		**106.5771**	**84.2301**	**22.3470**	**703.7499**	**597.5021**	**106.2478**

Graphical presentation of the real power before UPFC placement (base case) and after UPFC placement is given in Fig 1.

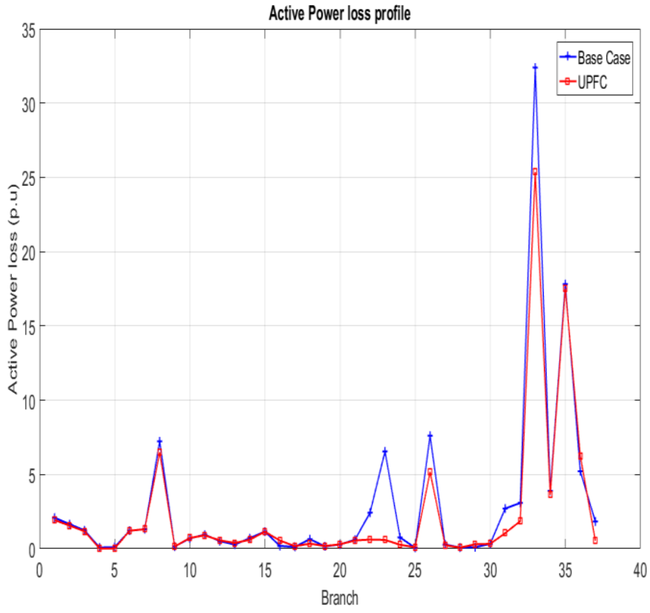

Chart-1: Variation of real Power Loss Profile

Graphical presentation of the reactive power before UPFC placement (base case) and after UPFC placement is given in Fig 2

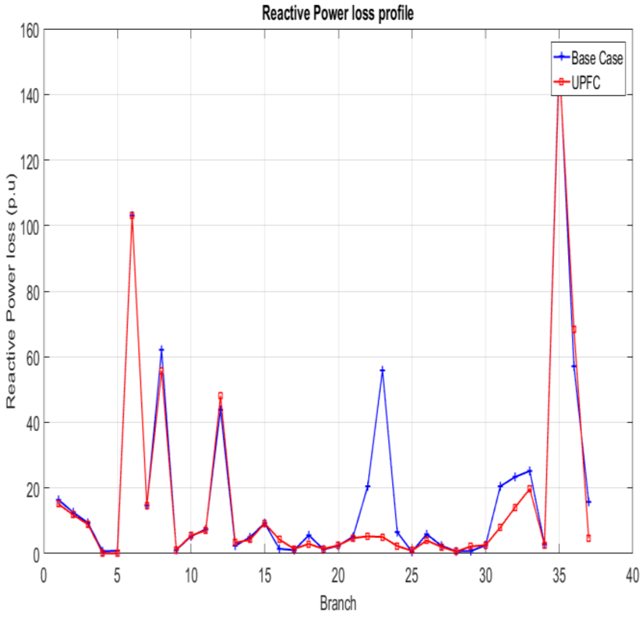

Chart -2: Variation of Reactive Power Loss Profile

The voltage magnitude on the buses of the 31 Bus network before and after placement of the UPFC are given in Table IV and graphically in Fig. 3.

TABLE IV
VOLTAGE PROFILE IMPROVEMENT

Bus No.	V(pu) Before UPFC	V(pu) After UPFC	V(pu) Improvement
1	1.0200	1.0200	0
2	1.0300	1.0300	0
3	1.0500	1.0500	0
4	1.0500	1.0500	0
5	1.0500	1.0500	0
6	1.0300	1.0300	0
7	1.0300	1.0300	0
8	1.0500	1.0500	0
9	1.0500	1.0500	0
10	1.0737	1.0748	0.0011
11	1.0616	1.0617	0.0001
12	1.0372	1.0374	0.0002
13	1.0557	1.0564	0.0007
14	1.1848	1.2848	0.1
15	1.0458	1.0458	0
16	1.0306	1.0308	0.0002
17	1.3836	1.4836	0.1
18	1.0451	1.0451	0
19	1.3942	1.4942	0.1
20	1.0303	1.0304	0.0001
21	1.0371	1.0371	0
22	1.0138	1.0143	0.0005
23	1.0217	1.0218	0.0001
24	1.0606	1.0606	0
25	1.0809	1.0875	0.0066
26	1.0384	1.0398	0.0014
27	1.0246	1.0246	0
28	0.7020	0.7020	0
29	1.0918	1.1823	0.0905
30	1.0569	1.0569	0
31	1.1237	1.1343	0.0106

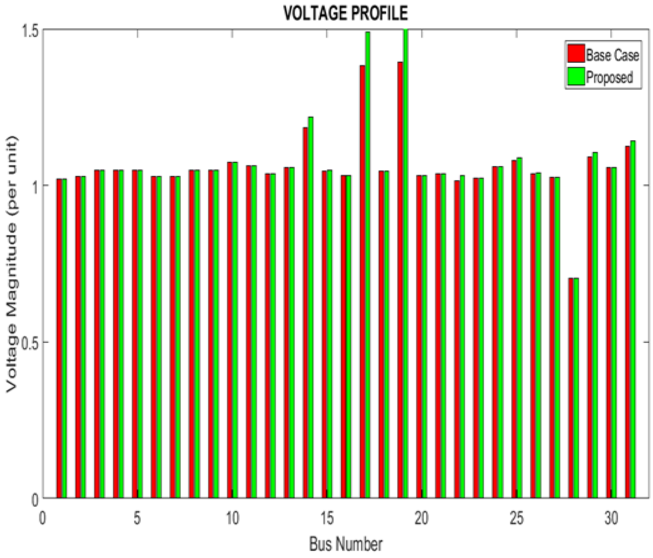

Chart -3: Variation of bust voltage magnitude

4. CONCLUSION

Voltage sensitivity index method has been used to identify the weakest bus which is the most appropriate location for a compensator on the Nigerian 330kV, 31 bus network. Bat algorithm optimization technique has been applied to determine the optimal size of the UPFC compensator. Simulation of the Nigerian 31 bus network with the UPFC was carried out. Results obtained shows that the weakest bus is bus 19, having the highest index as 0.2878. Optimal UPFC size was found to be 182.0438MVAr. The results also indicate a significant reduction of real power loss from 106.5771MW for the base case (without UPFC) to 84.23MW with UPFC. The reactive power loss also reduced from 703.7499MVAr for the base case to 597.5021MVAr with UPFC. Voltage magnitudes on the buses of the network also improved on most of the buses.

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APENDICES

1, BUS DATA OF THE NIGERIAN 330KV TRANSMISION NETWORK

BUS No.	Bus Name	Generation		Load		V (volts)	Angle (Degree)	Remark
		P(MW)	Q(MVar)	P(MW)	Q(MVar)			
1.	Egbin GS	-	-	0,0000	0.0000	1.02	0.0000	Slack
2.	Delta PS	55.000	28.160	-	-	1.0000	0.0000	PV Bus
3.	Okpai GS	220.000	112.700	-	-	1.0000	0.0000	PV Bus
4.	Sapele PS	75.000	38.420	-	-	1.0000	0.0000	PV Bus
5.	Afam GS	479.000	245.390	-	-	1.0000	0.0000	PV Bus
6.	Jebba GS	322.000	164.960	-	-	1.0000	0.0000	PV Bus
7.	Kainji GS	323.000	165.490	-	-	1.0000	0.0000	PV Bus
8.	Shiroro GS	280.000	143.440	-	-	1.0000	0.0000	PV Bus
9.	Geregu	200.000	102.440	-	-	1.0000	0.0000	PV Bus
10.	Oshogbo	-	-	120.370	61.650	1.0000	0.0000	Load Bus
11.	Benin	-	-	160.560	82.240	1.0000	0.0000	Load Bus
12.	Ikj-West	-	-	334.000	171.110	1.0000	0.0000	Load Bus
13.	Ayede	-	-	176.650	90.490	1.0000	0.0000	Load Bus
14.	Jos	-	-	82.230	42.129	1.0000	0.0000	Load Bus
15.	Onitsha	-	-	130.510	66.860	1.0000	0.0000	Load Bus
16.	Akamgba	-	-	233.379	119.560	1.0000	0.0000	Load Bus
17.	Gombe	-	-	74.480	38.140	1.0000	0.0000	Load Bus
18.	Abuja(ka tamkpe)	-	-	200.000	102.440	1.0000	0.0000	Load Bus
19.	Maiduguri	-	-	10.000	5.110	1.0000	0.0000	Load Bus
20.	Egbin TS	-	-	0.000	0.000	1.0000	0.0000	Load Bus
21.	Aladja	-	-	47.997	24.589	1.0000	0.0000	Load Bus
22.	Kano	-	-	252.450	129.330	1.0000	0.0000	Load Bus
23.	Aja	-	-	119.990	61.477	1.0000	0.0000	Load Bus
24.	Ajaokuta	-	-	63.220	32.380	1.0000	0.0000	Load Bus
25.	N.Heaven	-	-	113.050	57.910	1.0000	0.0000	Load Bus
26.	Alaoji	-	-	163.950	83.980	1.0000	0.0000	Load Bus
27.	Jebba TS	-	-	7.440	3.790	1.0000	0.0000	Load Bus
28.	B.Kebbi	-	-	69.990	35.850	1.0000	0.0000	Load Bus
29.	Kaduna	-	-	149.77	76.720	1.0000	0.0000	Load Bus
30.	ShiroroTS	-	-	73.070	37.430	1.0000	0.0000	Load Bus

2. Line Data of the Nigerian 330KV Network

Branch	From Bus	To Bus	Length(km)	R pu	Xpu	B/2 pu
1	Egbin (1)	IK West(12)	62	0.0022	0.0172	0.257
2	Egbin(1)	Akamgba(16)	86	0.0019	0.0144	0.880
3	EgbinGS(1)	Egbin TS(20)	5	0.0019	0.0144	0.880
4	DeltaPS(2)	Aladja(21)	32	0.0011	0.0088	0.171
5	Sapele(4)	Aladja(21)	63	0.0023	0.0190	0.239
6	KainjiGS(7)	B.Kebbi(28)	310	0.0111	0.9420	1.178
7	KainjiGS(7)	JebbaTS(27)	81	0.0022	0.0246	0.308
8	ShiroroGS(8)	Kaduna(29)	96	0.0034	0.0292	0.364
9	ShiroroGS(8)	ShiroroTS(30)	8	0.0019	0.0144	0.880
10	ShiroroGS(8)	Abuja(18)	144	0.0019	0.0144	0.880
11	Geregu(9)	Ajaokuta(24)	5	0.0022	0.0172	0.257
12	Oshogbo(10)	JebbaTS(27)	157	0.0056	0.4770	0.597
13	Oshogbo(10)	Benin(11)	251	0.0089	0.0763	0.954
14	Oshogbo(10)	IK-West(12)	252	0.0049	0.0341	0.521
15	Benin(11)	Ajaokuta(24)	195	0.0070	0.0560	0.745
16	Benin(11)	SapelePS(4)	50	0.0018	0.0139	0.208
17	Benin(11)	Onitsha(15)	137	0.0049	0.0416	0.521
18	Benin(11)	DeltaPS(2)	107	0.0022	0.0190	0.239
19	IK-West(12)	Benin(11)	280	0.0101	0.0799	1.162
20	Ayede(13)	Oshogbo(10)	115	0.0041	0.0349	0.437
21	Ayede(13)	IK-West(12)	137	0.0049	0.0416	0.521
22	Jos(14)	Makurdi(31)	275	0.0029	0.0246	0.0
23	Jos(14)	Gombe(17)	264	0.0095	0.0810	1.010
24	Onitsha(15)	Alaoji(25)	138	0.0034	0.0292	0.0355
25	Onitsha(15)	N.Heaven(26)	96	0.0049	0.0419	0.5240
26	Onitsha(15)	Okpai(3)	80	0.0090	0.0070	0.104
27	Akamgba(16)	IK-West(12)	18	0.0006	0.0051	0.065
28	Akamgba(16)	EgbinGS(20)	86	0.0006	0.0051	0.065
29	Gombe(17)	Maiduguri(19)	284	0.0021	0.0153	0.529
30	EgbinTS(20)	Aja(23)	27.5	0.0022	0.0172	0.257
31	N.Heaven(25)	Makurdi(31)	195	0.0019	0.0144	0.880
32	N.Heaven(25)	Alaoji(26)	138	0.0019	0.0144	0.880
33	Alaoji(26)	Afam(5)	25	0.0090	0.0070	0.104
34	JebbaTS(27)	JebbaGS(6)	8	0.0030	0.0022	0.033
35	JebbaTS(27)	ShiroroGS(8)	244	0.0087	0.0742	0.927
36	Kaduna(29)	Kano(22)	230	0.0082	0.0899	0.874
37	Kaduna(29)	Jos(14)	196	0.0070	0.0599	0.748

3. One Line Diagram of Nigerian330KV Network