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Research Article

Genetic Algorithm Based Optimal Placement of Tcsc and Upfc in the Nigeria 330KV Integrated Transmission Line Network at Different Reactive Power Loadings

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Abstract

The Nigeria 330KV integrated power network consisting of 52 buses, 64 transmission lines and sixteen generating stations was studied. The network was subjected to different reactive power loadings ranging from 25%, 50%, 75%, 100%, 125% and 150% respectively with and without UPFC and TCSC FACTS devices using Newton-Raphson power flow algorithm and Genetic Algorithm (GA) for optimally locating these devices on the network. The heavily loaded active power lines were identified. The heavily loaded active power lines are thirteen (13). These include: Katampe-Shiroro, Akangba-Ikejawest, Aiyede-Oshogbo, Alaoji-Onitsha, Egbin-ikejawest, Jebba-Oshogbo, Jebba-Shiroro, Jos-Makurdi, Kaduna-Shiroro, Kaduna-Kano, Ajaokuta-Benin, Benin-Ikejawest, and Benin-Onitsha. The ten(10) heavily loaded reactive power lines include: B-Kebbi-Kainji, Benin-Oshogbo, Benin-Egbin, Benin-Sapele, Damaturu-Gombe, Damaturu-Maiduguri, Gombe-Yola, Jalingo-Yola, Ikeja West-Oshogbo and Jos-New Haven. Weak buses were New-Haven(0.9201pu),Damaturu (0.9283pu), Gombe (0.9405pu), Maiduguri(0.9425pu), Makurdi (0.9260pu), Jalingo (0.9354pu),Erunkan(0.9314pu) and Jos (0.9461pu).Ten(10) heavily loaded reactive power lines include:B-Kebbi-Kainji, Benin-Oshogbo, Benin-Egbin, Benin-Sapele, Damaturu-Gombe, Damaturu-Maiduguri, Gombe-Yola, Jalingo-Yola, Ikeja West-Oshogbo and Jos-New Haven. Using GA for optimal location of these devices, eight (8) of the thirteen (13) lines were installed with UPFC. These are Akangba-Ikejawest, Alaoji-Onitsha, Jebba-Oshogbo, Jos-Makurdi, Kaduna-Kano, Ajaokuta-Benin, Benin-Ikeja west, and Benin-Onitsha . Also of the eight (8) weak buses six (6) had UPFC and the improved bus voltage values are Damaturu (0.9983pu), Gombe (0.9751 pu), Maiduguri (0.9815 pu), Makurdi (0.9804 pu), Jalingo (0.9541 pu) and Jos (0.9646 pu). Six (6) TCSC devices were incorporated on the ten (10) heavily loaded lines, which include Ikeja West-Oshogbo, Damaturu-Maiduguri, Gombe-Yola, Jos-New Haven, Benin-Oshogbo and B-Kebbi-Kainji. Comparison was made between the power losses with and without FACTS devices at the various percentage loadings. Real and active power losses.

Keywords: Antenna array, particle swarm optimization, phased array.

1. Introduction

Flexible Alternating Current Transmission Systems (FACTS) Devices use power electronic technology for effective control of electrical quantities, such as active and reactive power, phase angles and bus voltages, line impedances and terminal voltages, for the overall improvement of power quality in the network. The use of these devices allows for effective utilization of power system network at the generation, transmission and distribution stations and ensures power systems stability even when the network is subjected to excess active and reactive loadings(1). Assessment of the impact of FACTS Devices on power system network were studied in (2, 3, 4 and 5), to increase power transfer over transmission lines. The optimal location and placement of these devices in power system network using genetic algorithm for optimization and increased system loadings were studied in (6, 7, 8, 9 and 13).

The aim of this work is to optimally locate FACTS (Unified Power Flow Controllers (UPFC) and the Thyristor Controlled Series Controllers (TCSC) devices in the Nigeria

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330KV integrated power network for power transfer increase and loss minimization, when subjected to different active and reactive power loadings.

Currently, the control and regulation of line flows (active and reactive power), line impedance, bus voltages and phase angles in the Nigeria power network when subjected to different percentage levels of power loadings (active and reactive) is done by controlling/regulating the reactive power from the generators, addition/removal of series and shunt reactors and controlling the positions of the tap changing transformers. With the existing control mechanism, the total active and reactive power loss is 92.633MW+85.9432MVar, of which 39% of the total reactive power losses is from the generating stations (1).Thus, FACTS devices is used for the control and regulation of these parameters. This work uses UPFC to improve the weak buses, phase angles and relief the heavily loaded active power lines, while the TCSC is used to relief the heavily loaded reactive power lines and to alter their line impedances. Genetic algorithm (GA) based technique is used for optimal placement of these devices.

2. Fact Device Models for the Study

Different algorithms for the various FACT devices used for the study are TCSC and UPFC. These were formulated using the relevant equations and incorporated in the Newton Raphson (N-R) method for the power flow study and also an evolutionary algorithm (Genetic algorithm) for optimal placement was employed. N-R based Power flow is carried out at different percentage line loadings (25%,50%,75%,100%,125% and 150%) of active and reactive power, to determine the steady – state operating conditions of 330KV integrated power network, flow of active and reactive power, voltage magnitudes and phase angles in all buses without the FACTS devices. Then a proposed model, where these devices are incorporated optimally was also carried out. Comparisons were made with and without FACTS devices on the integrated power network in terms of transmission line losses, bus voltages and loading capacities.

2.1. TCSC

It is used to control effectively the 330KV transmission line parameters by connecting a variable reactance in series with the transmission line. This increases the transmission line capability which in turn reduces the transmission lines net impedance. The TCSC perform the function of a variable reactance compensator, either in the capacitive or inductive mode by either adding/removing an inductive or capacitive component to the main transmission line reactance. Operating in the inductive region increase the length of the line thereby reducing the lines ability to transfer power. In the capacitive mode, the line length is shortened, thus increasing power transfer margins. Adjusting the phase angle difference across a series connected impedance also control the active power flow.

2.1.1. Power Flow Model of TCSC

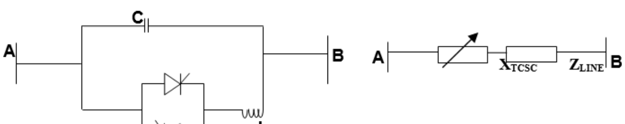

Fig. 1a,b. Basic Element of Tcsc, and the Equivalent Circuit

This is expressed mathematically as:

$$X_{reactance} = X_{Line} + X_{TCSC} \quad (1)$$

where:

$$X_{TCSC} = r_{TCSC} * X_{Line} \quad (2)$$

r_{TCSC} is the degree of compensation as provided by the TCSC. Its working range is between -0.7xl_{ine} to 0.2x_{line} (14, 15). its range of values depends on the reactance of the line where it is placed.

2.2. UPFC.

It allows the simultaneous control of active and reactive power flow and voltage magnitude at the series- shunt compensator terminals. The active power control takes place between the series converter and the AC system, while the shunt converter generates or absorbs reactive power so as to provide voltage magnitude at the point of connection of the device and the AC system.

2.2.1. Power Flow Model of UPFC.

It controls the power flow in the transmission systems by controlling the impedance, phase angles and voltage magnitude. The basic structure of UPFC consist of two voltage source converters (V_{SC1} and V_{SC2}): one connected in parallel and the other in series to the line with these two converters. UPFC supplies both reactive and active power through the converters. Figure 2 shows the basic element of a UPFC.

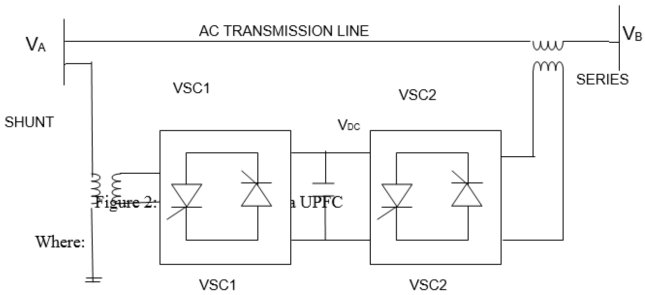

Fig. 2. Basic Element of a UPFC

where:

V_{SC1} and V_{SC2}=Shunt and series connected controllers through shunt and series transformers.
V_{DC}=phase voltage angle
V_A and V_B = Bus voltages at node A and B, n is total number of nodes.

It is used to control line impedance, terminal voltages and phase voltages and the power flow through the transmission line A-B is given as

$$P_A = \frac{V_A V_B}{XAB|} (cos\ (\delta_A - \delta_B)) \quad (3)$$

V_A , V_B are bus voltages. X_{AB}, $\delta_A and \delta_B$ are transmission line impedance and phase voltages between buses A and B P_A ,P_B, Q_A and Q_B are the active and reactive power at node A and B respectively.

$$P_A - P_B = \sum_{B=A}^{n} \|V_A V_B\| (G_{AB}(cos\ (\delta_{AB})) + B_{AB}\ (cos\ (\delta_{AB})) \quad (4)$$

$$Q_A - Q_B = \sum_{B=A}^{n} \|V_A V_B\| (G_{AB}(\sin\ (\delta_{AB})) + B_{AB}\ (cos\ (\delta_{AB})) \quad (5)$$

$$P_A - P_B = \sum_{B=A}^{n} \|V_A V_B\| (G_{AB}(cos\ (\delta_{AB})) + B_{AB}\ (sin\ (\delta_{AB}))\ + \Delta P \quad (6)$$

$$Q_A - Q_B = \sum_{B=A}^{n} \|V_A V_B\| (G_{AB}(\sin\ (\delta_{AB})) + B_{AB}\ (cos\ (\delta_{AB})) + \Delta Q \quad (7)$$

On incorporation of UPFC at bus B gives

$$P_{UPFC} - P_B = \sum_{B=A}^{n} \|V_{UPFC} V_B\| (G_{(UPFC)(B)}(cos\ (\delta_{AB})) + B_{AB}\ (cos\ (\delta_{AB})) \quad (8)$$

$$Q_A - Q_B = \sum_{B=A}^{n} \|V_A V_B\| (G_{AB}(\sin\ (\delta_{AB})) + B_{AB}\ (cos\ (\delta_{AB})) \quad (9)$$

3. Nigeria 330KV Integrated Power System

Nigeria is gradually becoming industrialized and requires large amount of power to meet the high demand of consumers, thus making the network more congested. In an attempt to solve this, the Federal Government embarked on improving the power industry by building more generating stations, transmission and distribution stations/lines. Prior to the 330KV integrated power system, the existing network consist of nine (9) generating stations, twenty eight (28) buses and thirty two (32) transmission lines. The integrated power network under study consists of fifty two (52) buses, sixty four (64) transmission lines and sixteen (16) generating stations. One line diagram of the network is shown in appendix A.

With the existing power generating stations, National Integrated Power Producers (NIPP) and the Independent Power Producers (IPP), the present installed capacity is 8,692.25MW, with average available capacity and availability factor of 4,850.77MW and 0.597 respectively. Summary of this is shown in Table 1.0. While table 2.0 shows the bus voltages and numbers used for the study.

Table 1. The availability factor, average availability and installed capacity of present generating stations

S/N	Power Station	Availability Factor	Average Availability (MW)	Installed Capacity(MW)
1	KAINJI	0.586	445.45	760
2	JEBBA HYDRO	0.792	457.99	578.40
3	SHIRORO	0.674	404.56	600.00
4	EGBIN STEAM	0.743	980.89	1320.00
5	TRANS-AMADI	0.256	25.60	100
6	A.E.S	0.783	236.44	302.00
7	SAPELE	0.195	199.07	1020.00
8	OKPAI GAS	0.929	446.25	480.00
9	AFAM (I-V)	0.068	63.52	931.60
10	AFAM VI	0.649	322.82	497.25
11	DELTA GAS	0.289	255.33	882.00
12	GEREGU GAS	0.725	300.00	414.00
13	OMOKU GAS	0.961	96.05	100.00
14	OMOTOSHO	0.890	298.15	335.00
15	IBOM	0.078	2.90	37.00
16	OLORUNSHOGO PHASE 1 AND 2	0.943	315.75	335.00
		0.597	4,850.77MW	8,692.25MW

Where

$$\text{availability factor} = \frac{\text{Average Availability (MW)}}{\text{Installed Capacity(MW)}} \quad (10)$$

$$\text{Average availability factor} = \frac{\text{Availability Factor}}{\text{No of Generating Stations}} \quad (11)$$

Table 2. Bus Voltages in the Integrated Power System

S/NO	BUSES	S/NO	BUSES	S/NO	BUSES
1	Shiroro	21	New Haven South	41	Yola
2	Afam	22	Makurdi	42	Gwagwalada
3	Ikot-Ekpene	23	B-kebbi	43	Sakete
4	Port-Harcourt	24	Kainji	44	Ikot-Abasi
5	Aiyede	25	Oshogbo	45	Jalingo
6	Ikeja west	26	Onitsha	46	Kaduna
7	Papalanto	27	Benin North	47	Jebba GS
8	Aja	28	Omotosho	48	Kano
9	Egbin PS	29	Eyaen	49	Katampe
10	Ajaokuta	30	Calabar	50	Okpai
11	Benin	31	Alagbon	51	Jebba
12	Geregu	32	Damaturu	52	AES
13	Lokoja	33	Gombe		
14	Akangba	34	Maiduguri		
15	Sapele	35	Egbema		
16	Aladja	36	Omoku		
17	Delta PS	37	Owerri		
18	Alaoji	38	Erunkan		
19	Aliade	39	Ganmo		
20	New Haven	40	Jos		

Even the Nigeria 330KV integrated power system is still characterised with high power congestion (1). However, incorporation of FACTS controllers in their appropriate location in the network will be investigated. The heavily loaded lines with high active power flow and weak bus voltages magnitudes and phase angles will be controlled by UPFC. Heavily loaded lines with high reactive power flow are controlled by the TCSC.

4. Genetic Algorithms (GA)

It is one of the evolutionary Algorithms search technique based on mechanism of natural selection and genetics. It searches several possible solutions simultaneously and do not require prior knowledge or special properties of the objective function (16, 17). GA starts with initial random generation of population of binary string, calculates fitness values from the initial population, after which the selection, cross over and mutation are done until the best population is obtained. The flow chart for the GA optimization is shown in appendix B.

4.1. Initial Population/Selection

It is obtained from the parameters below

N_1: Number of FACT devices to be located

N_2: Type of FACT devices

N_3: The possible location of FACT devices

N_4: Number of individuals of the population. (11)

It generates and selects the initial population of the binary strings from all po ssible locations. If there is need for FACTS devices to be located, then from the binary string a first value of one will be selected. If it is not necessary for the device to be located, the next value of zero will be selected. Initial population is generated on the basis of population size and string length. The type of FACT devices are also selected after its location is established.

4.2. Encoding and Initialization of the Device

For TCSC

The initialization of TCSC reactance values ranging between $-0.7X_L$ - $0.2X_L$ is randomly generated. Random numbers sets consisting of 0's and 1's are generated. For transmission lines having the TCSC, a value of 1 is given for a device that will exist on the line and a value of 0 is given a line that it will not exist. To obtain the rating of the TCSC, the values generated between $(-0.7X_L) - (+0.2X_L)$ is multiplied with the generated random numbers.

For UPFC

A set of random numbers is generated. If there is a UPFC device necessary for the transmission line, a 1 is generated, and a 0 means there is no device necessary.

4.3. Fitness Computation of Each Device

Fitness computation evaluates each individual population and then compares different solutions. This applies to the two FACTS devices.

Reproduction

Though various methods are used in selecting the fittest individual in the reproduction process. These include: Rank, Tournament, Boltzmann and Roulette-Wheel selection. In this work, the Roulette-wheel selection is utilized. Random numbers are generated in the interval whose segment spans this selection.

Cross Over

Cross over produces new strings by the exchange of information among the strings of mating pools. Probability of cross over rate varies from 0 to 1 and range from (0.7)-(+1) for population within the range of 50-300. (1)

Mutation

Mutation introduces some sort of artificial diversification in the population to avoid premature convergence to local optimum (11, 16).

Table 3. showed the various parameters used for the study using GA for optimal location of UPFC and TCSC devices.

Table 3. Parameters Used For the Genetic Algorithm for All the Various FACTS Devices

Parameter	Value/Type
Maximum Generations	200
Population Size	50
Type Of Cross Over	Arithmetic
Type Of Mutation	Non-Uniform
Termination Method	Maximum Generation
Reproduction/Selection Method	Roulette Wheel

5. Results

The Nigeria 330KV integrated network consisting of 52 buses, 64 transmission lines and sixteen (16) generating stations, were subjected to different levels of reactive loadings ranging from 25%,50%,75%,100%,125% and 150% without and with FACTS (STATCOM,UPFC and TCSC) devices respectively. GA based optimization technique was used to optimally place UPFC and TCSC on the transmission lines.

5.1. Without Facts Devices in the Nigeria 330kv Integrated Network

A power flow study was carried out using N-R algorithm, at different percentage of reactive loadings, to obtain the active and reactive power flows on the lines, phase angles and bus voltages. Table 4.0a showed the result obtained at different active and reactive power loadings. Table 4.0b showed the bus voltages and phase angles of the weak buses.

5.2. With Facts Devices in the Nigeria 330kv Integrated Power Network

The next step involved incorporating FACTS devices (UPFC and TCSC) into the N-R algorithm to obtain the values of active and reactive power flows at different loadings of 25%, 50%, 75%, 100% 125% and 150%,using GA for optimal placement of FACTS devices in the network. UPFC regulates both bus voltage magnitudes and phase angles while TCSC modifies the transmission line reactance to allow for regulation of reactive power flow either in the capacitive or inductive mode. The heavily loaded active power lines are thirteen (13). These include: Katampe-Shiroro(49-1), Akangba-Ikejawest(14-6), Aiyede-Oshogbo(5-25), Alaoji-Onitsha(18-26), Egbin-ikeja West(9-6), Jebba-Oshogbo(51-25), Jebba-Shiroro(51-1), Jos-Makurdi,(40-22), Kaduna-Shiroro(46-1), Kaduna-Kano(46-48), Ajaokuta-Benin(10-11), Benin-Ikeja West(11-6), and Benin-Onitsha(11-26). However, using GA for optimal location of these devices, eight (8) of the thirteen (13) lines were installed with UPFC. These include: Akangba-Ikejawest (14-6), Alaoji-Onitsha(18-26), Jebba-Oshogbo(51-25), Jos-Makurdi (40-22), Kaduna-Kano (46-48), Ajaokuta-Benin (10-11), Benin-Ikeja west (11-6),and Benin-Onitsha (11-26). Also of the eight weak buses in the network as shown in table 4.0b, six (6) had UPFC. These include Damaturu (32), Gombe (33), Maiduguri (34), Makurdi (22), Jalingo (45) and Jos (40). The ten(10) heavily loaded reactive power lines include: B-Kebbi-Kainji(23-24), Benin-Oshogbo(11-25), Benin-Egbin(11-9), Benin-Sapele(11-15), Damaturu-Gombe(32-33), Damaturu-Maiduguri(32-34), Gombe-Yola(33-41), Jalingo-Yola(45-41), Ikeja West-Oshogbo(6-25) and Jos-New Haven(40-22).GA optimally located six(6) TCSC devices on the ten(10) heavily loaded lines. These include Ikeja West-Oshogbo(6-25), Damaturu-Maiduguri(32-34), Gombe-Yola(33-41), Jos-New Haven(40-22), Benin-Oshogbo(11-25) and B-Kebbi-Kainji(23-24).The required number of UPFC is fourteen (14) and TCSC is six (6).Hence the total FACTS device become twenty (20) as specified by GA. This implies that the parameters that will make up the population size for the GA is minimum of forty (40). Each UPFC controls two parameters (bus voltages and phase angles) while the TCSC modifies the transmission line reactance. Table 5.0a showed the result obtained at different active and reactive power loadings while Table 5.0b showed the bus voltages and phase angles.

Table 4.A. Active and Reactive Power Flows at Different Loadings without Facts Devices

CONNECTED BUS		Active and Reactive power Flow for 25% Loading in Per Unit (PU)		Active and Reactive Power Flow for 50% Loading in Per Unit (PU)		Active and Reactive Power Flow for 75% Loading in Per Unit (PU)		Active and Reactive power Flow for 100% Loading in Per Unit (PU)		Active and Reactive Power Flow for 125% Loading in Per Unit (PU)		Active and Reactive Power Flow for 150% Loading in Per Unit (PU)	
From	**To**	**P**	**Q**	**P**	**Q**	**P**	**Q**	**P**	**Q**	**P**	**Q**	**P**	**Q**
49	1	0.1775	0.0727	0.1771	0.0723	0.1776	0.0718	0.1772	0.0712	0.1769	0.0706	0.1767	0.0702
14	6	0.0199	0.0120	0.0195	0.0118	0.0120	0.0113	0.0190	0.0110	0.0191	0.0117	0.0199	0.0112
2	18	0.0556	0.0383	0.0551	0.0379	0.0550	0.0372	0.0548	0.0368	0.0550	0.0364	0.0549	0.0361
2	3	-0.0038	0.0017	-0.0034	0.0015	-0.0041	0.0012	-0.0039	0.0010	-0.0041	0.0008	-0.0039	0.0077
2	4	0.0063	0.0023	0.0059	0.0020	0.0059	0.0016	0.0061	0.0013	0.0056	0.0010	0.0058	0.0009
16	17	-0.0512	0.0566	-0.0509	0.0569	-0.0514	0.0562	-0.0511	0.0559	-0.0509	0.0550	-0.0511	0.0546
5	25	0.1621	0.2790	0.1617	0.3000	0.1622	0.2600	0.1619	0.2880	0.1622	0.2872	0.1619	0.2590
5	6	0.0186	0.0119	0.0182	0.0123	0.0184	0.0119	0.0180	0.0116	0.0182	0.0111	0.0180	0.0108
5	7	0.0283	0.0182	0.0279	0.0186	0.0273	0.0182	0.0270	0.0179	0.0272	0.0173	0.0269	0.0169
8	9	0.0999	0.0619	0.0996	0.0623	0.0998	0.0619	0.0995	0.0616	0.0997	0.0612	0.0995	0.0608
8	31	0.0187	0.0119	0.0184	0.0121	0.0192	0.0119	0.0189	0.0116	0.0192	0.0113	0.0195	0.0109
10	11	0.2150	0.0134	0.2114	0.0136	0.2180	0.0132	0.2158	0.0129	0.2178	0.0124	0.2192	0.0120
10	12	0.0239	0.0166	0.0236	0.0162	0.0241	0.0158	0.0239	0.0154	0.0241	0.0150	0.0239	0.0148
10	13	0.0289	0.0180	0.0286	0.0184	0.0291	0.0180	0.0289	0.0177	0.0286	0.0172	0.0288	0.0169
16	15	0.1315	0.0163	0.1311	0.0161	0.1317	0.0157	0.1319	0.0154	0.1317	0.0151	0.1317	0.0148
18	26	0.2461	0.1781	0.2458	0.1778	0.2463	0.1772	0.2460	0.1769	0.2462	0.1765	0.2458	0.1761
18	3	0.0457	0.0294	0.0454	0.0291	0.0462	0.0289	0.0459	0.0285	0.0459	0.0281	0.0457	0.0278
18	37	0.0155	0.0116	0.0152	0.0114	0.0152	0.0110	0.0149	0.0108	0.0147	0.0103	0.0145	0.0101
19	21	-0.0026	0.0050	-0.0023	0.0047	-0.0031	0.0042	-0.0029	0.0039	-0.0031	0.0034	-0.0033	0.0030
19	22	0.0031	-0.0024	0.0026	-0.0020	0.0032	-0.0018	0.0033	-0.0014	0.0030	-0.0011	0.0028	-0.0008
23	24	0.0885	0.0543	0.0882	0.0540	0.0887	0.0538	0.0884	0.0533	0.0889	0.0529	0.0887	0.0524
11	6	0.1592	-0.0114	0.1565	-0.0110	0.1620	-0.0108	0.1601	-0.0105	0.1587	-0.0101	0.1562	-0.0980
11	15	0.0257	0.0595	0.0253	0.0591	0.0259	0.0588	0.0260	0.0584	0.0258	0.0581	0.0256	0.0577
11	17	0.0611	-0.0549	0.0608	-0.0546	0.0615	-0.0541	0.0613	-0.0539	0.0610	-0.0533	0.0608	-0.0530
11	25	0.0108	0.0843	0.0105	0.0840	0.0110	0.0836	0.0108	0.0833	0.0111	0.0828	0.0108	0.0823
11	26	0.2510	-0.0194	0.2490	-0.0190	0.2513	-0.0187	0.2519	-0.0184	0.2521	-0.0181	0.2523	-0.0178
11	27	0.0393	0.0294	0.0390	0.0290	0.0398	0.0286	0.0401	0.0283	0.0402	0.0279	0.0398	0.0274
11	9	0.0921	0.0779	0.0918	0.0774	0.0924	0.0771	0.0921	0.0768	0.0923	0.0762	0.0920	0.0759
11	28	0.0476	-0.0343	0.0473	-0.0341	0.0479	-0.0348	0.0477	-0.0344	0.0475	-0.0341	0.0472	-0.0338
27	29	-0.0308	0.0192	-0.0305	0.0197	-0.0311	0.0194	-0.0308	0.0192	-0.0310	0.0188	-0.0307	0.0184
30	3	0.0283	0.0182	0.0284	0.0179	0.0289	0.0174	0.0285	0.0172	0.0283	0.0169	0.0279	0.0164
32	33	0.0367	-0.0940	0.0364	-0.0938	0.0369	-0.0935	0.0365	-0.0937	0.0367	-0.0939	0.0367	-0.0942
32	34	0.0485	-0.0843	0.0482	-0.0846	0.0490	-0.0841	0.0487	-0.0844	0.0489	-0.0846	0.0486	-0.0841
35	37	-0.0181	0.0132	-0.0179	0.0136	-0.0182	0.0132	-0.0179	0.0130	-0.0181	0.0124	-0.0181	0.0121
35	36	-0.0112	0.0088	-0.0109	0.0092	-0.0114	0.0089	-0.0112	0.0087	-0.0110	0.0084	-0.0108	0.0081
9	6	0.2148	0.1549	0.2145	0.1544	0.2150	0.1540	0.2149	0.1538	0.2151	0.1533	0.2153	0.1530
9	38	-0.2605	0.0159	-0.2602	0.0161	-0.2609	0.0165	-0.2605	0.0163	-0.2602	0.0162	-0.2599	0.0167
38	6	-0.2601	0.0158	-0.2598	0.0159	-0.2598	0.0156	-0.2595	0.0158	-0.2593	0.0157	-0.2590	0.0160
39	25	0.0266	0.0406	0.0267	0.0405	0.0269	0.0408	0.0264	0.0406	0.0270	0.0409	0.0268	0.0411
39	51	0.0267	-0.0305	0.0263	-0.0304	0.0269	-0.0306	0.0272	-0.0308	0.0263	-0.0309	0.0266	-0.0312
33	40	0.0674	-0.1201	0.0676	-0.1203	0.0681	-0.1201	0.0676	-0.1198	0.0678	-0.1193	0.0676	-0.1189
33	41	0.0790	-0.1002	0.0787	-0.1003	0.0792	-0.1000	0.0791	-0.0980	0.0793	-0.0977	0.0791	-0.0972
42	49	0.0115	-0.0072	0.0117	-0.0074	0.0120	-0.0070	0.0122	-0.0069	0.0120	-0.0063	0.0119	-0.0060
42	13	0.0292	-0.0181	0.0289	-0.0185	0.0297	-0.0182	0.0294	-0.0179	0.0296	-0.0174	0.0294	-0.0170
42	1	0.0175	0.0109	0.0173	0.0112	0.0180	0.0109	0.0178	0.0106	0.0182	0.0104	0.0179	0.0101
6	25	0.0180	-0.0247	0.0182	-0.0251	0.0184	-0.0247	0.0181	-0.0244	0.0179	-0.0241	0.0181	-0.0238
6	28	0.0474	-0.0340	0.0471	-0.0345	0.0477	-0.0340	0.0478	-0.0337	0.0482	-0.0333	0.0483	-0.0331
6	7	0.0283	0.0185	0.0280	0.0182	0.0284	0.0179	0.0281	0.0175	0.0279	0.0171	0.0277	0.0169
6	43	0.0364	-0.0202	0.0361	-0.0197	0.0368	-0.0194	0.0369	-0.0191	0.0367	-0.0187	0.0364	-0.0183
44	3	0.0464	0.0332	0.0461	0.0329	0.0466	0.0325	0.0468	0.0322	0.0471	0.0318	0.0468	0.0313
3	21	0.0496	0.0316	0.0493	0.0310	0.0499	0.0306	0.0494	0.0302	0.0496	0.0299	0.0494	0.0289
45	41	0.0879	-0.1138	0.0876	-0.1142	0.0882	-0.1139	0.0879	-0.1136	0.0882	-0.1132	0.0880	-0.1129
51	25	0.2638	0.3355	0.2634	0.3352	0.2640	0.3348	0.2638	0.3344	0.2639	0.3341	0.2637	0.3338
47	51	0.1669	0.0606	0.1666	0.0606	0.1670	0.0605	0.1668	0.0605	0.1671	0.0608	0.1668	0.0607
51	24	-0.4846	0.0717	-0.4843	0.0713	-0.4849	0.0710	-0.4851	0.0708	-0.4849	0.0703	-0.4847	0.0699
51	1	0.1733	0.2580	0.1737	0.2576	0.1741	0.2572	0.1739	0.2569	0.1737	0.2565	0.1739	0.2561
40	46	0.0029	0.0054	0.0026	0.0058	0.0031	0.0054	0.0029	0.0052	0.0027	0.0049	0.0029	0.0044
40	22	0.1270	-0.1005	0.1271	-0.1006	0.1274	-0.1007	0.1271	-0.1006	0.1273	-0.1004	0.1274	-0.1006
46	1	0.1509	-0.1180	0.1506	-0.1184	0.1512	-0.1181	0.1509	-0.1178	0.1512	-0.1175	0.1514	-0.1171
46	48	0.1252	-0.0886	0.1253	-0.0890	0.1257	-0.0888	0.1253	-0.0885	0.1250	-0.0882	0.1248	-0.0879
20	26	0.1346	0.0855	0.1343	0.0860	0.1350	0.0857	0.1348	0.0854	0.1351	0.0852	0.1349	0.0849
20	21	-0.0468	0.0260	-0.0464	0.0263	-0.0470	0.0261	-0.0471	0.0259	-0.0473	0.0254	-0.0470	0.0251
50	26	0.0429	0.0682	0.0426	0.0778	0.0421	0.0775	0.0429	0.0772	0.0422	0.0768	0.0420	0.0764
26	37	0.0156	0.0120	0.0152	0.0116	0.0156	0.0112	0.0153	0.0110	0.0156	0.0107	0.0158	0.0102

Table 4.b. Bus Voltages and Phase Angles of the Weak Buses without Facts Devices

BUS NAME	BUS NUMBER	BUS VOLTAGE	ANGLE(DEGREES)
NEW HAVEN	21	0.9201	-32.38
MAKURDI	22	0.9260	-18.23
DAMATURU	32	0.9283	-26.13
GOMBE	33	0.9405	-41.10
MAIDUGURI	34	0.9425	-12.04
JALINGO	45	0.9354	-23.18
ERUNKAN	38	0.9314	-21.32
JOS	40	0.9461	-13.34

Table 5.0a and 5.0b showed the active and reactive power obtained and the improved bus voltages on incorporation of the FACTS devices.

Table 5.A. Active and Reactive Power Flows at Different Loadings with FACTS Devices

CONNECTED BUS		Active and Reactive power Flow for 25% Loading in Per Unit (PU)		Active and Reactive Power Flow for 50% Loading in Per Unit (PU)		Active and Reactive Power Flow for 75% Loading in Per Unit (PU)		Active and Reactive power Flow for 100% Loading in Per Unit (PU)		Active and Reactive Power Flow for 125% Loading in Per Unit (PU)		Active and Reactive Power Flow for 150% Loading in Per Unit (PU)	
From	**To**	**P**	**Q**	**P**	**Q**	**P**	**Q**	**P**	**Q**	**P**	**Q**	**P**	**Q**
49	1	0.1777	0.0729	0.1775	0.0725	0.1774	0.0723	0.1772	0.0725	0.1775	0.0729	0.1779	0.0733
14	6	0.0192	0.0125	0.0199	0.0120	0.0198	0.0123	0.0191	0.0126	0.0195	0.0129	0.0191	0.0121
2	18	0.0558	0.0385	0.0559	0.0383	0.0560	0.0380	0.0563	0.0385	0.0566	0.0387	0.0569	0.0391
2	3	-0.0039	0.0019	-0.0041	0.0017	-0.0038	0.0016	-0.0041	0.0019	-0.0043	0.0021	-0.0048	0.0023
2	4	0.0064	0.0026	0.0065	0.0028	0.0061	0.0027	0.0059	0.0024	0.0060	0.0027	0.0065	0.0029
16	17	-0.0510	0.0569	-0.0512	0.0571	-0.0509	0.0571	-0.0513	0.0573	-0.0515	0.0577	-0.0519	0.0579
5	25	0.1618	0.2951	0.1621	0.2996	0.1619	0.2998	0.1616	0.2996	0.1617	0.2999	0.1614	0.2998
5	6	0.0189	0.0121	0.0187	0.0123	0.0191	0.0124	0.0193	0.0128	0.0194	0.0130	0.0197	0.0133
5	7	0.0287	0.0188	0.0284	0.0190	0.0285	0.0192	0.0286	0.0190	0.0288	0.0193	0.0289	0.0191
8	9	0.0997	0.0623	0.0995	0.0621	0.0993	0.0623	0.0992	0.0627	0.0996	0.0629	0.0998	0.0632
8	31	0.0189	0.0122	0.0188	0.0120	0.0187	0.0124	0.0186	0.0126	0.0189	0.0128	0.0187	0.0134
10	11	0.2180	0.0137	0.2182	0.0135	0.2186	0.0134	0.2192	0.0132	0.2189	0.0135	0.2193	0.0140
10	12	0.0241	0.0168	0.0242	0.0172	0.0239	0.0175	0.0238	0.0173	0.0239	0.0176	0.0241	0.0182
10	13	0.0292	0.0184	0.0290	0.0183	0.0292	0.0186	0.0290	0.0184	0.0292	0.0188	0.0290	0.0189
16	15	0.1317	0.0167	0.1315	0.0163	0.1314	0.0165	0.1313	0.0167	0.1314	0.0169	0.1315	0.0171
18	26	0.2459	0.1785	0.2461	0.1784	0.2453	0.1786	0.2452	0.1789	0.2450	0.1791	0.2453	0.1795
18	3	0.0461	0.0298	0.0457	0.0294	0.0458	0.0292	0.0459	0.0294	0.0461	0.0297	0.0462	0.0299
18	37	0.0157	0.0119	0.0160	0.0121	0.0155	0.0120	0.0154	0.0121	0.0156	0.0124	0.0158	0.0128
19	21	-0.0028	0.0056	-0.0029	0.0053	-0.0033	0.0052	-0.0032	0.0052	-0.0030	0.0055	-0.0033	0.0059
19	22	0.0032	-0.0028	0.0033	-0.0022	0.0031	-0.0021	0.0029	-0.0023	0.0032	-0.0026	0.0032	-0.0024
23	24	0.0883	0.0548	0.0881	0.0547	0.0879	0.0549	0.0878	0.0550	0.0879	0.0553	0.0875	0.0555
11	6	0.1611	-0.0118	0.1602	-0.0120	0.1592	-0.0122	0.1620	-0.0123	0.1662	-0.0125	0.1640	-0.0129
11	15	0.0259	0.0599	0.0258	0.0597	0.0261	0.0599	0.0260	0.0597	0.0261	0.0599	0.0261	0.0602
11	17	0.0611	-0.0552	0.0610	-0.0555	0.0613	-0.0556	0.0612	-0.0555	0.0614	-0.0557	0.0616	-0.0559
11	25	0.0106	0.0848	0.0104	0.0851	0.0103	0.0849	0.0105	0.0847	0.0109	0.0849	0.0110	0.0851
11	26	0.2520	-0.0199	0.2504	-0.0197	0.2492	- 0.0199	0.2512	-0.0201	0.2522	-0.0203	0.2525	-0.0208
11	27	0.0395	0.0303	0.0394	0.0304	0.0390	0.0303	0.0393	0.0301	0.0392	0.0304	0.0394	0.0308
11	9	0.0924	-0.0781	0.0922	-0.0783	0.0925	-0.0786	0.0927	-0.0788	0.0930	-0.0791	0.0933	-0.0797
11	28	0.0479	-0.0347	0.0482	-0.0349	0.0483	-0.0347	0.0485	-0.0349	0.0487	-0.0351	0.0489	-0.0355
27	29	-0.0311	0.0196	-0.0309	0.0198	-0.0310	0.0198	-0.0310	0.0199	-0.0312	0.0201	-0.0314	0.0206
30	3	0.0287	0.0186	0.0289	0.0189	0.0285	0.0191	0.0286	0.0190	0.0284	0.0193	0.0286	0.0196
32	33	0.0369	-0.0945	0.0371	-0.0947	0.0372	-0.0949	0.0374	-0.0950	0.0376	-0.0954	0.0379	-0.0959
32	34	0.0488	-0.0851	0.0489	-0.0853	0.0491	-0.0852	0.0490	-0.0853	0.0491	-0.0851	0.0493	-0.0856
35	37	-0.0185	0.0138	-0.0183	0.0135	-0.0184	0.0133	-0.0187	0.0134	-0.0186	0.0136	-0.0188	0.0139
35	36	-0.0117	0.0092	-0.0115	0.0096	-0.0116	0.0094	-0.0115	0.0093	-0.0117	0.0096	-0.0119	0.0094
9	6	0.2152	0.1552	0.2151	0.1549	0.2150	0.1551	0.2152	0.1554	0.2150	0.1558	0.2153	0.1561
9	38	-0.2609	0.0162	-0.2608	0.0164	-0.2611	0.0167	-0.2612	0.0162	-0.2611	0.0165	-0.2613	0.0168
38	6	-0.2605	0.0159	-0.2602	0.0163	-0.2601	0.0161	-0.2603	0.0164	-0.2602	0.0159	-0.2604	0.0162
39	25	0.0262	0.0405	0.0264	0.0407	0.0260	0.0408	0.0269	0.0406	0.0266	0.0407	0.0268	0.0412
39	51	0.0261	-0.0305	0.0260	-0.0307	0.0265	-0.0308	0.0266	-0.0310	0.0262	-0.0308	0.0264	-0.0312
33	40	0.0678	-0.1205	0.0677	-0.1203	0.0672	-0.1205	0.0671	-0.1206	0.0673	-0.1208	0.0676	-0.1209
33	41	0.0794	-0.1006	0.0792	-0.1005	0.0799	-0.1003	0.0800	-0.1005	0.0801	-0.1009	0.0803	-0.1007
42	49	0.0117	-0.0077	0.0115	-0.0078	0.0111	-0.0079	0.0112	-0.0081	0.0113	-0.0082	0.0115	-0.0087
42	13	0.0296	-0.0183	0.0295	-0.0184	0.0299	-0.0186	0.0298	-0.0188	0.0300	-0.0187	0.0302	-0.0189
42	1	0.0178	0.0113	0.0177	0.0110	0.0177	0.0109	0.1776	0.0110	0.1779	0.0112	0.1777	0.0115
6	25	0.0183	-0.0249	0.0180	-0.0251	0.0182	-0.0249	0.0180	-0.0251	0.0182	-0.0253	0.0181	-0.0252
6	28	0.0477	-0.0343	0.0478	-0.0341	0.0480	-0.0338	0.0479	-0.0336	0.0476	-0.0334	0.0473	-0.0338
6	7	0.0287	0.0187	0.0289	0.0184	0.0287	0.0182	0.0289	0.0184	0.0287	0.0182	0.0283	0.0187
6	43	0.0367	-0.0205	0.0369	-0.0203	0.0368	-0.0201	0.0366	-0.0200	0.0364	-0.0201	0.0362	-0.0204
44	3	0.0466	0.0336	0.0464	0.0337	0.0466	0.0336	0.0465	0.0337	0.0464	0.0338	0.0465	0.0339
3	21	0.0498	0.0318	0.0501	0.0320	0.0503	0.0318	0.0505	0.0316	0.0509	0.0318	0.0506	0.0315
45	41	0.0881	-0.1142	0.0882	-0.1144	0.0884	-0.1140	0.0882	-0.1142	0.0885	-0.1144	0.0887	-0.1145
51	25	0.2641	0.3358	0.2642	0.3361	0.2644	0.3359	0.2645	0.3361	0.2647	0.3362	0.2645	0.3367
47	51	0.1671	0.0607	0.1672	0.0606	0.1673	0.0608	0.1674	0.0609	0.1676	0.0611	0.1676	0.0610
51	24	-0.4849	0.0719	-0.4850	0.0722	-0.4851	0.0720	-0.4853	0.0718	-0.4854	0.0716	-0.4852	0.0718
51	1	0.1736	0.2584	0.1735	0.2585	0.1737	0.2583	0.1736	0.2582	0.1737	0.2580	0.1739	0.2584
40	46	0.0031	0.0057	0.0030	0.0058	0.0031	0.0061	0.0030	0.0063	0.0031	0.0062	0.0033	0.0063
40	22	0.1273	-0.0058	0.1274	-0.0053	0.1276	-0.0051	0.1274	-0.0050	0.1275	-0.0051	0.1276	-0.0054
46	1	0.1511	-0.1186	0.1510	-0.1185	0.1512	-0.1184	0.1511	-0.1182	0.1513	-0.1181	0.1513	-0.1184
46	48	0.1255	-0.0889	0.1254	-0.0891	0.1252	-0.0893	0.1253	-0.0890	0.1252	-0.0895	0.1250	-0.0894
20	26	0.1349	0.0859	0.1348	0.0861	0.1346	0.0862	0.1348	0.0860	0.1349	0.0863	0.1347	0.0865
20	21	-0.0470	0.0266	-0.0472	0.0268	-0.0471	0.0267	-0.0472	0.0268	-0.0474	0.0266	-0.0476	0.0268
50	26	0.0421	0.0687	0.0423	0.0689	0.0422	0.0691	0.0421	0.0693	0.0423	0.0691	0.0422	0.0697
26	37	0.0159	0.0126	0.0161	0.0128	0.0162	0.0128	0.0161	0.0129	0.0162	0.0132	0.0160	0.0138

Table 5.b. Bus Voltages and Phase Angles of the Weak Buses without Facts Devices

BUS NAME	BUS NUMBER	BUS VOLTAGE	ANGLE(DEGREES)
NEW HAVEN	21	0.9621	-34.21
MAKURDI	22	0.9804	-18.21
DAMATURU	32	0.9983	-29.34
GOMBE	33	0.9751	-46.23
MAIDUGURI	34	0.9815	-11.41
JALINGO	45	0.9541	-33.32
ERUNKAN	38	1.0141	-27.21
JOS	40	0.9646	-25.42

Table 6. Total Active and Reactive Power Savings With and Without FACTS Devices at Different Loadings

	Without FACTS Devices		**With FACTS Devices**		**Total Savings**	
Reactive power percentage loadings	Active Power Loss (pu)	Reactive Power Loss(pu)	Active Power Loss(pu)	Reactive Power Loss(pu)	Total Active Power Savings (pu)	Total Reactive Power Savings (pu)
25%	0.0557	0.1259	0.0215	0.0917	0.5355	0.0342
50%	0.0573	0.1346	0.0307	0.0995	0.0266	0.0351
75%	0.0577	0.1352	0.0328	0.1008	0.0249	0.0344

100%	0.0603	0.1361	0.0342	0.1010	0.0261	0.0351
125%	0.0621	0.1382	0.0435	0.1017	0.0186	0.0365
150%	0.0681	0.1394	0.0514	0.1023	0.0167	0.0371

7. Discussion

It is observed that at different percentage loadings ranging from (25%, 50%, 75%, 100%, 125% and 150%), different values of active and reactive power flows as well as the weak bus voltages were obtained as shown in table 4.0a and 4.0b.The heavily loaded active and reactive power lines were also obtained. These include: Katampe-Shiroro(49-1), Akangba-Ikejawest(14-6), Aiyede-Oshogbo(5-25), Alaoji-Onitsha(18-26), Egbin-ikeja West(9-6), Jebba-Oshogbo(51-25), Jebba-Shiroro(51-1), Jos-Makurdi,(40-22), Kaduna-Shiroro(46-1), Kaduna-Kano(46-48), Ajaokuta-Benin(10-11), Benin-Ikeja West(11-6), and Benin-Onitsha(11-26) for the active power lines. The weak bus voltages include Damaturu (32), Gombe (33), Maiduguri (34), Makurdi (22), Jalingo (45), Jos (40),Erunkan(38) and New Haven(21). The heavily loaded reactive power lines include: B-Kebbi-Kainji(23-24), Benin-Oshogbo(11-25), Benin-Egbin(11-9), Benin-Sapele(11-15), Damaturu-Gombe(32-33), Damaturu-Maiduguri(32-34), Gombe-Yola(33-41), Jalingo-Yola(45-41), Ikeja West-Oshogbo(6-25) and Jos-New Haven(40-22).

However, to redistribute the power flows in the entire network and solving the problem of network congestion and bus voltage improvement, FACTS devices were employed at these different loadings (25%-150%). Using GA for optimal location of these devices, eight (8) of the thirteen (13) heavily loaded active power lines were installed with UPFC. These include Akangba-Ikejawest (14-6), Alaoji-Onitsha(18-26), Jebba-Oshogbo(51-25), Jos-Makurdi (40-22), Kaduna-Kano (46-48), Ajaokuta-Benin (10-11), Benin-Ikeja west (11-6),and Benin-Onitsha (11-26). Also of the eight weak buses in the network as shown in table 4.0b, six (6) had UPFC. These include Damaturu (32), Gombe (33), Maiduguri (34), Makurdi (22), Jalingo (45) and Jos (40).GA optimally located six (6) TCSC devices on the ten(10) heavily loaded lines. These include Ikeja West-Oshogbo(6-25), Damaturu-Maiduguri(32-34), Gombe-Yola(33-41), Jos-New Haven(40-22), Benin-Oshogbo(11-25) and B-Kebbi-Kainji(23-24).The result of these is shown in table 5.0a and 5.0b.a summary of the effect of these devices on the heavily loaded power lines resulted to table 6.0.Also a comparison was made with and without FACTS device in the network and the active and reactive power losses were obtained at these different loadings. it was observed that at every percentage loading, there is high saving of both active and reactive power. More so, optimally locating these devices reduced both transmission line losses and congestion, thus improve the overall system stability.

8. Conclusion

The effect of reactively loading the Nigeria 330KV integrated network at different percentages (25%, 50%, 75%, 100%, 125% and 150%) with and without FACTS devices was studied. The heavily loaded active and reactive power lines as well as the bus voltages were identified. Bus voltages below the statutory allowable limit (±5% of 330KV; 313.5KV-346.5KV) were improved and the heavily loaded lines were regulated using UPFC and TCSC FACTS devices.

Comparison of active and reactive power losses with and without FACTS devices at different loadings was obtained. It was observed that on incorporation of TCSC and UPFC devices into the network optimally using GA, showed reduction in transmission line losses, hence results in savings of both active and reactive power.

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Appendix A

S/N	TRANSMISSION LINE		LENGTH (KM)	CIRCUIT TYPE	LINE IMPEDANCE (PU)		
	From	To			Z	B	ADMITTANCE
1	Katampe	Shiroro	144	Double	0.0029 + j 0.0205	0.308	8-j4.808
2	Afam GS	Alaoji	25	Double	0.009 + j0.007	0.104	9.615-j16.129
3	Afam GS	Ikot-Ekpene	90	Double	0.0155 + j0.0172	0.104	9.615-j16.129
4	Afam GS	Port-Harcourt	45	Double	0.006 + j0.007	0.104	9.615-j16.129
5	Aiyede	Oshogbo	115	Single	0.0291 + j0.0349	0.437	3.205-j2.288
6	Aiyede	Ikeja west	137	Single	0.0341 + j0.0416	0.521	2.695-j19.919
7	Aiyede	Papalanto	60	Single	0.0291 + j0.0349	0.437	3.205-j2.288
8	Aja	Egbin PS	14	Double	0.0155 + j0.0172	0.257	16.129-j9.615
9	Aja	Alagbon	26	Double	0.006+j0.007	0.257	6.494-j3.891
10	Ajaokuta	Benin	195	Single	0.0126+j0.0139	0.208	1.429-j12.180
11	Ajaokuta	Geregu	5	Double	0.0155+j0.0172	0.257	6.494-j3.891
12	Ajaokuta	Lokoja	38	Double	0.0155+j0.0172	0.257	8-j4.808
13	Akangba	Ikeja west	18	Single	0.0155+j0.0172	0.065	32+j19.32
14	Aladja	Sapele	63	Single	0.016+j0.019	0.239	5.284-j51.913
15	Alaoji	Owerri	60	Double	0.006+j0.007	0.308	6.494-j3.891
16	Aladja	Delta PS	32	Single	0.016+j0.019	0.239	5.848-j4.184
17	Alaoji	Onitsha	138	Single	0.035+j0.0419	0.524	2.754-j33.553
18	Alaoji	Ikot-Ekpene	38	Double	0.0155+j0.0172	0.257	6.494-j3.891
19	Aliade	New Haven South	150	Double	0.006+j0.007	0.308	16.129-j9.615
20	Aliade	Makurdi	50	Double	0.0205+j0.0246	0.308	4.545-j3.247
21	B-kebbi	Kainji	310	Single	0.0786+j0.0942	1.178	1.235-j0.478
22	Benin	Ikeja west	280	Double	0.0705+j0.0779	1.162	1.637-j12.626
23	Benin	Sapele	50	Double	0.0126+j0.0139	0.208	3.194-j17.555
24	Benin	Delta PS	107	Single	0.016+j0.019	0.239	5.848-j4.184
25	Benin	Oshogbo	251	Single	0.0636+j0.0763	0.954	1.508-j12.932
26	Benin	Onitsha	137	Single	0.0347+j0.0416	0.521	2.8-j33.771
27	Benin	Benin north	20	Single	0.049+j0.056	0.208	8-j4.808
28	Benin	Egbin PS	218	Single	0.016+j0.019	0.239	5.848-j4.184
29	Benin	Omotosho	120	Single	0.016+j0.019	0.365	3.846-j2.739
30	Benin North	Eyaen	5	Double	0.0126+j0.0139	0.208	8-j4.808
31	Calabar	Ikot-Ekpene	72	Double	0.0126+j0.0139	0.208	6.494-j3.891
32	Damaturu	Gombe	135	Single	0.0786+j0.0942	1.178	1.19-j0.848
33	Damaturu	Maiduguri	140	Single	0.0786+j0.0942	1.178	1.19-j0.848
34	Egbema	Omoku	30	Double	0.0126+j0.0139	0.208	8-j4.808
35	Egbema	Owerri	30	Double	0.0126+j0.0139	0.208	8-j4.808
36	Egbin PS	Ikeja west	62	Single	0.0155+j0.0172	0.257	7.308+j57.14
37	Egbin PS	Erunkan	30	Single	0.016+j0.019	0.239	5.848-j4.184
38	Erunkan	Ikeja west	32	Single	0.016+j0.019	0.239	5.848-j4.184
39	Ganmo	Oshogbo	87	Single	0.016+j0.019	0.239	5.848-j4.184
40	Ganmo	Jebba	70	Single	0.0341+j0.0416	0.239	2.615-j1.919
41	Gombe	Jos	265	Single	0.067+j0.081	1.01	1.923-j16.456
42	Gombe	Yola	217	Single	0.0245+j0.0292	1.01	1.391-j2.999
43	Gwagwalada	Lokoja	140	Double	0.0156+j0.0172	0.257	6.494-j3.891
44	Gwagwalada	Shiroro	114	Double	0.0155+j0.0172	0.257	6.494-j3.891
45	Ikeja west	Oshogbo	252	Single	0.0341+j0.0416	0.521	2.695-j1.919
46	Ikeja west	Omotosho	160	Single	0.024+j0.0292	0.365	2.695-j1.919
47	Ikeja west	Papalanto	30	Single	0.0398+0.0477	0.597	2.695-j1.919
48	Ikeja west	Sakete	70	Single	0.0398+j0.0477	0.521	2.695-j1.919
49	Ikot-Abasi	Ikot Ekpene	75	Double	0.0155+j0.0172	0.257	6.494-j3.891
50	Jebba	Oshogbo	157	Single	0.0398+j0.0477	0.597	0.246-j3.092
51	Jalingo	Yola	132	Single	0.0126+j0.0139	0.208	8-j4.808
52	Jebba	Jebba GS	8	Double	0.002+j0.0022	0.033	3.174-j1.594
53	Jebba	Kainji	81	Double	0.0205+j0.0246	0.308	3.607-j40.328
54	Jebba	Shiroro	244	Single	0.062+j0.0702	0.927	1.559-j13.297
55	Jos	Kaduna	197	Single	0.049+j0.0599	0.927	1.873-J1.337
56	Jos	Makurdi	230	Double	0.002+j0.0022	0.308	4.545-J3.247
57	Kaduna	Kano	230	Single	0.058+j0.0699	0.874	1.657-j14.12
58	Kaduna	Shiroro	96	Single	0.0249+j0.0292	0.364	3.935-j3.379
59	Katampe	Shiroro	144	Double	0.0205+j0.0246	0.308	8-j4.808
60	New Haven	Onitsha	96	Single	0.024+j0.0292	0.365	3.935-j33.79
61	New Haven	New Haven South	5	Double	0.0205+j0.0246	0.308	4.545-J3.247
62	Okpai	Onitsha	80	Double	0.006+j0.007	0.104	16.13-J9.615
63	Onitsha	Owerri	137	Double	0.006+j0.007	0.104	16.13-J9.615
64	Ikot Ekpene	New Haven South	143	Double	0.0205+j0.0246	0.257	6.494-j3.891