EFFICIENCY IMPROVEMENT OF NIGERIA 330KV NETWORK USING FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEM (FACTS) DEVICES

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ABSTRACT

This work studied the impact of different FACTS devices (UPFC, TCSC and STATCOM) on voltage improvement and transmission loss reduction in the Nigeria 330KV transmission line network and GA approach for loss optimization. This network consist of 9 generating stations, 28 buses and 29 transmission lines was modeled and simulated using ETAP 4.0 and Matlab Version 7.5.Power losses without FACTS device are 62.90MW and 95.80MVar and weak buses per unit values are: Gombe (0.8909pu), Jos (0.9118pu), Kaduna (0.9178pu), Kano (0.9031) and New Haven(0.9287pu).Incorporating TCSC on the weak lines, an improved per unit bus values ranging from 0.9872pu-0.9997pu was obtained as well as loss reduction of (44.3MW and 78.30MVAR). Incorporating UPFC improved the per unit values within the range of 0.9768pu-0.9978pu. STATCOM gave values between 0.9741pu-1.013pu and reduced line losses to51.8MW and 85.60MVAR.Comparing among the three FACTS devices, UPFC gave a better loss reduction of 48.64% and 27.14%.

KEYWORDS: *TSCS, STATCOM, UPFC, GA, ETAP 4.0, MATLAB 7.5*

I. INTRODUCTION

Nigeria electric power system is undergoing changes as a result of constant power demand increase, thus stretching it beyond their stability and thermal limit. This drastically affects the power quality delivered. Transmission systems should be flexible to respond to generation and load patterns. Solving the problem of increasing power demand is either by building more generating and transmission facilities which is not very economical or environmentally friendly or the use of Flexible Alternating Current Transmission System (FACTS) Devices. FACTS device ensure effective utilization of existing equipment. Comparison of the conventional methods of control (capacitors, reactors, phase shifting transformers etc.) and FACTS devices showed that they are less expensive, but their dynamic behavior and control of current, phase voltage and angles, line impedance are less optimal (1,7,8). The Institute of Electrical-Electronic Engineering (IEEE) defined FACTS as ‘’ power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability’’ (1).Benefits of FACTS device are in two folds: Capable of increasing power transfer over transmission lines and can make their power transfers fully controllable (2, 3, and 4).The focus of this paper is to study how different FACTS devices (UPFC, TCSC and STATCOM) reduce power losses in the Nigeria existing 330KV network. The results obtained are presented.

The description of the remaining part of the paper is as follows: Section 2.0 introduced various FACTS devices, power flow and its technology and configurations. Section 3.0 listed the various FACTS devices used for the study and the parameters they control. Sections 3.1-3.2 discussed various models of FACTS devices used in the control of line reactance, phase angles and bus voltage magnitudes. Sections 4.0 described ETAP Transient Analyzer software used for the modeling. Section 5.0introduced Genetic Algorithm (GA) to optimally place the FACTS devices(STATCOM,UPFC and TCSC) in the Nigeria 330KV network, consisting of nine (9) generating stations, twenty eight (28)buses and forty one (41) transmission lines. Section 7.0 showed results obtained using Newton Raphson (N-R) power flow in MATLAB 7.5 environment. Section 7.0 discussed the results while section 8.0 concluded the work.

II. FACT DEVICES, POWER FLOW AND TECHNOLOGY

Power flow studies gives the steady–state operating condition of the power network, by finding the flow of active and reactive power, voltage magnitudes and phase angles at all nodes of the network. If the power flow study shows voltage magnitudes outside tolerable limit or it is beyond the power carrying capacity of the line, necessary control actions are taken to regulate it. FACTS technology is simply the collection of controllers applied to regulate and control variables such as impedance, current, voltage and phase angles. FACTS controllers can be divided into four (4) groups: Series Compensators, Shunt Compensators, Series–Shunt Compensators and Series-Series Compensators.

2.1 Series Compensators

It controls the effective line parameters by connecting a variable reactance in series with the transmission line. This increases the transmission line capability which in turn reduces transmission line net impedances. Examples of series compensators are Static Synchronous Series Compensators (SSSC) and Thyristor Controlled Series Compensators (TCSC).SSSC injects voltage in series with the transmission line where it is connected while TCSC performs the function of a variable reactance compensator, either in the capacitive or inductive mode. Series compensators operating in the inductive region will increase the electric length of the line there by reducing the lines ability to transfer power. In the capacitive mode will shorten the electrical length of the line, thus increasing power transfer margins (21,22). Adjusting the phase angle difference across a series connected impedance can also control the active power flow.

2.2 Shunt Compensators

The operational pattern is same with an ideal synchronous machine that generates balanced three-phase voltages with controllable amplitude and phase angle. The characteristics enables shunt compensators to be represented in positive sequence power flow studies with zero active power generation and reactive limits(IEEE/CIGRE,1995).The node connected to the shunt compensator represents a PV node which may change to a PQ mode in the event of limits being violated. Examples are Static Synchronous Compensator (STATCOM), Static Var Compensator (SVC) etc.

2.3 Series-Shunt Compensator

It allows the simultaneous control of active power flow, 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 (19, 20). Example of the series-shunt compensator is the unified power flow controller (UPFC) and thyristor controlled phase shifter

2.4 Series-Series Compensator

It is the combination of two or more static synchronous compensators coupled through a common dc link to enhance bi-directional flow of real power between the ac terminals of SSSC and are controlled to provide independent reactance compensation for the adjustment of real power flow in each line and maintain the desired distance of reactive power flow among the power lines (17). Example of series – series compensator is Interline Power Flow Controller (IPFC).

III. POWER FLOW FACTS MODELS FOR THE STUDY

Three (3) FACTS devices are used for this study to regulate the weak bus voltage magnitudes and phase angles, transmission line reactance, active and reactive power flow and transmission loss reduction. These include STATCOM,UPFC and TCSC FACTS devices.

3.1 Power Flow Model of Series Compensators (TCSC)

Conventional series compensators use mechanical switches to add capacitive and inductive reactance in transmission lines (5, 6). The power flow model across the variable reactance is usually operated in either the bypass mode or vernier mode. The reactance of the transmission line is modified by modeling the TCSC (i.e. adding a capacitive or inductive component to the main transmission line reactance).This range of values also depends on the reactance of the line where it is placed. 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 (-0.7 X_{line})-(+0.2 X_{line}).(8, 9). The minimum value of r_{TCSC}= -0.7, and its maximum value = 0.2.

3.2 Power Flow Model of STATCOM

It is connected in shunt and is used to control transmission voltage by reactive power compensation. It is assumed that in an ideal state, STATCOM only exchange reactive power. The STATCOM is modeled as a controllable voltage source in series with the transmission line impedance. The power flow equation of the power system with and without FACT controllers was modeled using (9-11).

3.3 Power Flow Study Using Series and Shunt Compensators (UPFC)

UPFC is used to control the power flow in the transmission systems by controlling line impedance, phase angles and bus voltage magnitudes. The basic structure of UPFC consist of two voltage source inverters (VSI): one connected in parallel and the other in series to the transmission line with these two converters. The modeling equation is shown in (17). UPFC supplies both reactive and active power as shown in equations 3 and 4.

$$p_{12} = \frac{V_1 V_2 \sin\delta}{|X_{12}|} \quad (3)$$

$$Q_{12} = \frac{V_1 V_2 (\cos\delta + 1)}{|X_{12}|} \quad (4)$$

Different algorithms for the various FACT devices (TCSC, UPFC & STATCOM) were formulated using Newton Raphson method for the load flow study and also an evolutionary algorithm (Genetic algorithm) for the optimal placement was employed (17).

IV. ETAP 4.0 (TRANSIENT ANALYZER)

ETAP is a dynamic stability program that incorporates comprehensive dynamic models of prime movers and other dynamic systems. It has an interactive environment for modeling, analyzing, and simulating a wide variety of dynamic systems. It provides the highest performance for demanding applications, such as large network analysis which requires intensive computation, online monitoring and control applications. It is particularly useful for studying the effects of nonlinearity on the behavior of the system. Performing power system transient stability is a very comprehensive task, that requires the knowledge of machine dynamic models, machine control unit models (such as excitation system and automatic voltage regulators, governor and turbine/engine systems and power system stabilizers) numerical computations and power system electromechanical equilibrium phenomenon In summary, it is an ideal research tool (18).

V. 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 (13, 14). 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 genetic algorithm optimization is given in appendix C.

5.1 Initial Population/Selection

It generates and selects the initial population of the binary strings from all possible 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 rated value of FACT devices is also selected after its location is established.

5.2 Encoding And Initialization of the Device

The parameter used for encoding and initialization for TCSC, UPFC and STATCOM optimization using GA is shown for the three devices.

TCSC

The initialization of the TCSC reactance values ranging between (-0.7_{XL}) – (0.2_{XL}) is randomly generated. The next step is to generate numbers sets consisting of 0's and 1's. 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. The last step is to obtain the rating of the TCSC, the values generated between -0.7XL-0.2XL is multiplied with the generated random numbers.

STATCOM

A set of random numbers equal to the number of load buses (made of strings of zeros and ones) is generated. One implies that STATCOM exist in the load bus and zero means it does not exist.

UPFC

A set of random numbers is generated. If there is a UPFC device necessary for the transmission line, a one is generated, and a zero means there is no device necessary. UPFC combines the conditions of both TCSC and STATCOM.

5.3 Fitness Computation of each Device

Fitness computation evaluates each individual population and then compares different solutions (13). It picks the best individuals and uses the ranking process to define the probability of selection.(UPFC,TCSC and STATCOM).This applies to the three FACTS devices.

Reproduction

Though various methods are used in selecting the fittest individual in the reproduction process. These include: rank selection, tournament selection, Boltzmann selection 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 1and range from 0.7-1 for population within the range of 50-300. (15)

Mutation

Mutation introduces some sort of artificial diversification in the population to avoid premature convergence to local optimum (11, 16). It generates the offspring and save the GA process from converging too soon. After this process, then iteration is complete.

VI. CASE STUDY

The Nigeria existing 330KVpower system under study consist of Nine (9) Generating Stations, Twenty eight (28) buses, and twenty nine (29)Transmission lines was used for the study as shown in the figure 1.0.

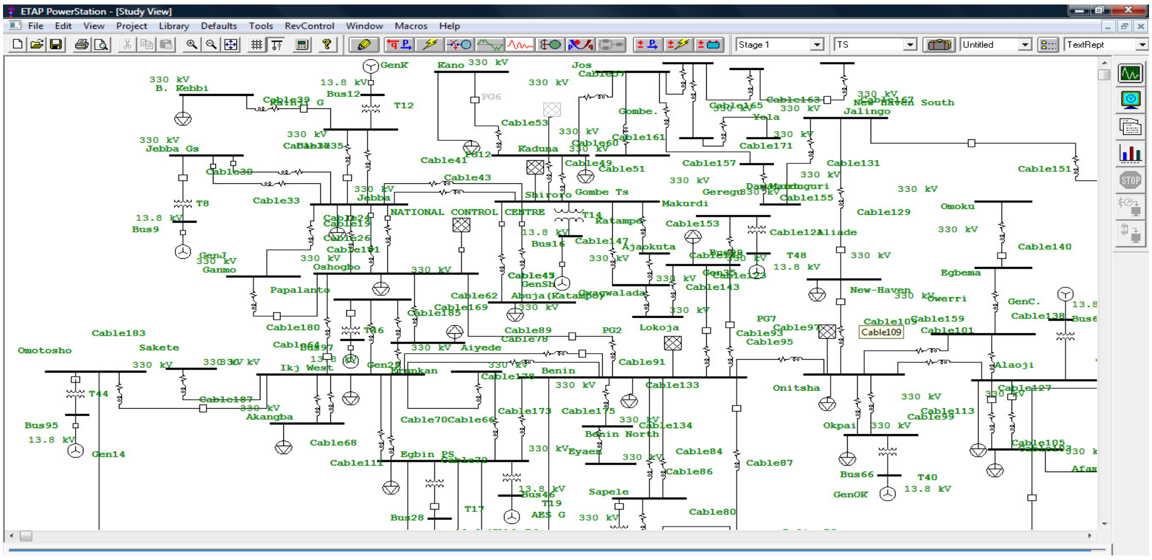

Figure 1.0 model of the Nigeria existing 330KV network

Data used for this analysis and assessment were collected from Power Holding Company of Nigeria (PHCN) from November 2008-October 2011.The transmission line parameter is shown in appendix A. Modeling and analyzing the existing Nigeria 330KV network using Etap 4.0 (Power System Software/Transient Analyzer) was carried out as shown in figure 1.0. Incorporating FACTS devices (STATCOM, TCSC and UPFC) into the N-R power flow algorithm using the relevant equations (5, 6, 7, 9, 11 and 17) were modeled in Matlab Version 7.5 environment.GA was used for optimal placement of these devices in the Nigeria 330KV network. Simulated results obtained were then analyzed. Table 1.0a shows the bus voltages and angles while table 1.0b is the load flow result and figure 2.0b shows plot of bus per unit voltage versus bus number, obtained for the 28 bus network without FACT devices.

Table 1.0a: per unit voltages and phase angle of the Nigeria existing 330KV network.

Bus Nr	Bus Name	Per Unit Voltage	Voltage(KV)	Angle (Degree)
1	Afam PS	1.000	330.00	-4.73
2	AES	1.000	330.00	-6.03
3	Katampe	0.9636	317.98	-23.75
4	Aiyede	0.9596	316.67	-11.23
5	Aja	0.9757	321.98	-5.87
6	Ajaokuta	0.9977	329.24	-7.55
7	Akangba	0.9533	314.59	-14.34
8	Aladja	1.0030	330.99	-3.49
9	Alaoji	0.9699	320.07	-7.28
10	B-kebbi	0.9898	326.63	-8.56
11	Benin	1.0212	336.99	-4.64
12	Calabar	1.0000	330.00	-9.56
13	Delta PS	1.0000	330.00	0.63
14	Egbin PS	1.0000	330.00	0.00
*15	Gombe	0.8909	294.03	-59.34
16	Ikeja west	0.9698	320.02	-9.65
17	Jebba	0.9972	329.09	-6.43
18	Jebba PS	1.0000	330.00	-4.46
*19	Jos	0.9118	300.88	-40.31
*20	Kaduna	0.9178	302.88	-47.75
21	Kainji PS	1.0000	330.00	-5.43
*22	Kano	0.9031	298.02	-43.76
23	Okpai PS	1.0000	330.00	4.64
24	Oshogbo	0.9982	330.00	-7.87
25	Sapele PS	1.0000	330.00	-3.69

26	Shiroro PS	1.0000	330.00	-35.12
*27	New-Haven	0.9287	306.47	-7.42
28	Onitsha	0.9762	322.15	-6.23

Note: The ones in asterisks are below the statutory voltage limits

Table 1.0b: Load Flow Results Obtained For the Existing 330KV Network

Connected Bus Numbers		Line Flows Without FACTS Devices				Line Losses Without FACTS Devices	
		Sending End		Receiving End			
		Psend (pu)	Q send (pu)	P received (pu)	Q received (pu)	Real power loss (pu)	Reactive power loss (pu)
17	24	0.0948	0.0601	0.0919	0.0557	0.0029	-0.0044
17	18	0.0868	0.0613	0.0847	0.0587	-0.0021	0.0026
21	17	0.0789	0.0889	0.0765	0.0842	0.0024	0.0047
21	10	0.0808	0.0499	0.0782	0.0448	0.0026	0.0051
17	26	0.0963	0.0143	0.0931	0.0100	0.0032	0.0043
26	3	0.1049	0.1698	0.1023	0.1595	-0.0026	-0.0103
20	26	0.0834	0.0119	0.0806	0.0175	0.0028	-0.0056
22	20	0.0908	0.0806	0.0877	0.0742	0.0031	0.0064
20	19	0.0701	0.0804	0.0674	0.0746	0.0027	0.0058
15	19	0.0914	0.0125	0.0878	0.0196	0.0036	0.0071
24	4	0.0820	0.0412	0.0792	0.0371	0.0028	0.0041
24	16	0.0742	0.0214	0.0707	0.0168	0.0035	0.0046
4	16	0.0918	0.0195	0.0887	0.0140	0.0031	0.0055
16	7	0.0989	0.1139	0.0954	0.1078	0.0035	0.0061
16	14	0.0806	0.0108	0.0778	0.0155	0.0028	0.0047
14	5	0.0948	0.0587	0.0922	0.0650	0.0026	0.0063
16	11	0.0834	0.0093	0.0796	0.0169	0.0038	-0.0076
25	8	0.0732	0.0152	0.0708	0.0104	0.0024	0.0048
13	8	0.0848	0.0189	0.0822	0.0252	-0.0026	0.0063
11	25	0.0964	0.0438	0.0943	0.0494	0.0021	0.0056
11	13	0.0807	0.0772	0.0772	0.0828	0.0035	-0.0056
16	11	0.0934	0.0093	0.0895	0.0120	0.0039	0.0027
24	11	0.0669	0.1037	0.0705	0.0972	0.0036	0.0065
6	11	0.0945	0.0213	0.0908	0.0219	0.0037	0.0068
11	28	0.0818	0.0125	0.0793	-0.0178	-0.0025	0.0053
28	23	0.0982	0.0584	0.0948	-0.0656	0.0034	0.0072
28	9	0.0806	0.0114	0.0767	-0.0160	0.0039	0.0046
9	1	0.0937	0.0459	0.0901	-0.0393	0.0036	0.0066
27	28	0.0808	0.1050	0.0780	0.0994	-0.0028	0.0056
TOTAL LOSSES						**0.0629**	**0.0958**

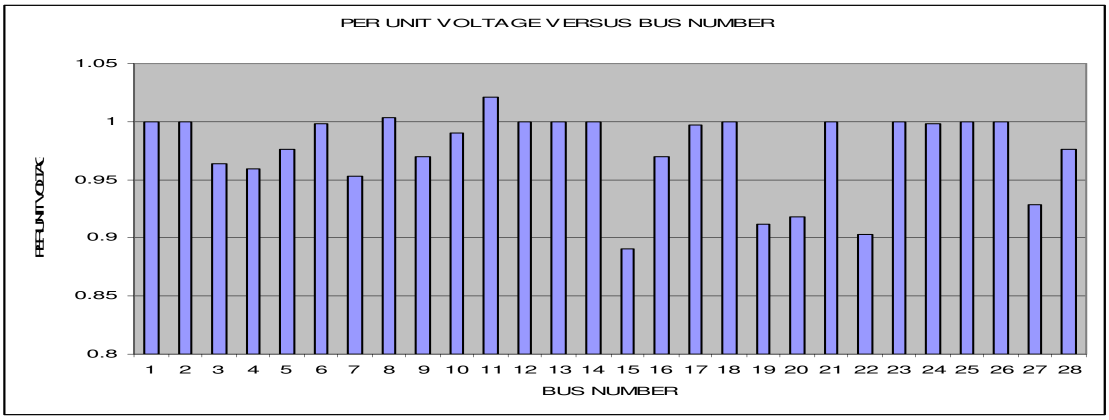

Figure 2.0: Plot of per unit bus voltage versus bus number for the existing 330KV network.

Its total active and reactive power loss is found to be 0.0629pu and 0.0958pu respectively. The allowable statutory voltage limits is between 313.5-346.5KV (0.95pu-1.05pu) at a nominal voltage of 330KV.However five (5) buses in the network are below this statutory limit. These include: Kaduna (302.88KV), Kano (298.02KV), Gombe (294.03KV), Jos (300.88KV) and New Haven (306.47KV).
On incorporation of FACTS devices, different phase voltages, phase angles and transmission lines power flow are obtained for the three different FACTS devices (STATCOM,UPFC and TCSC).Table 2.0a is the general GA table used for the device optimization.

Table 2.0a: Parameters Used by GA for 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

VII. Results Obtained In The Nigeria 330KV Existing Power Network Using STATCOM

Five (5) STATCOM devices with their various sizes as determined by the GA are placed on the Nigeria existing 330KV power network. This is shown in table 2.0b.

Table 2.0b: Parameter of STATCOM Device

STATCOM BUS	E_P(pu)	δ_P(pu)	Q_{sh}(pu)
15	1.015	-4.962	-0.2.456
19	1.024	-6.934	-0.532
20	1.435	-3.454	-0.453
22	1.022	-6.452	-0.3432
27	0.987	-8.674	-0.6545

Phase angles, Bus voltages and power flow result obtained when STATCOM were incorporated in the network is shown in table 2.0c and 2.0d respectively.

Table 2.0c: Bus Voltages with STATCOM at Location Specified by GA

GA With STATCOM				
Bus Nr	**Bus Name**	**Per Unit Voltage**	**Voltage(KV)**	**Angle (Degree)**
1	Afam PS	1.031	340.23	-5.89
2	AES	1.020	336.6	-8.06
3	Katampe	0.9816	323.93	-23.79
4	Aiyede	1.0075	332.48	-10.45
5	Aja	1.010	333.30	-6.21
6	Ajaokuta	1.011	333.63	-9.34
7	Akangba	0.9697	320.00	-15.86
8	Aladja	1.0079	332.61	-5.63
9	Alaoji	0.9812	323.80	-9.22
10	B-kebbi	1.0041	331.35	-12.09
11	Benin	1.0145	334.79	-8.62
12	Calabar	1.0311	340.26	12.54
13	Delta PS	1.0361	341.91	-6.28
14	Egbin PS	1.06	349.80	0.00
15	Gombe	0.9918	327.29	-37.20
16	Ikeja west	0.9841	324.75	-11.42
17	Jebba	0.9921	327.39	-9.94
18	Jebba PS	1.0010	330.33	-8.45
19	Jos	0.9874	325.84	-42.51
20	Kaduna	0.9968	328.94	-39.17

21	Kainji PS	1.0241	337.95	-10.35
22	Kano	0.9768	322.34	-40.88
23	Okpai PS	1.0121	333.99	-8.85
24	Oshogbo	0.9960	328.68	-10.34
25	Sapele PS	1.0180	335.94	-7.95
26	Shiroro PS	1.0311	340.26	-39.01
27	New-Haven	0.9741	321.45	-12.75
28	Onitsha	0.9810	323.73	-9.70

Incorporating STATCOM device in the N-R power flow algorithm using GA as the optimization tool, an improved voltage profile was obtained as compared to table 1.0b. Table 2.0d shows the load flow result when STATCOM devices was incorporated using GA for its optimal placement. Figure 3.0 shows a plot of bus per unit voltage values versus bus numbers on incorporation of STATCOM in the network using GA.

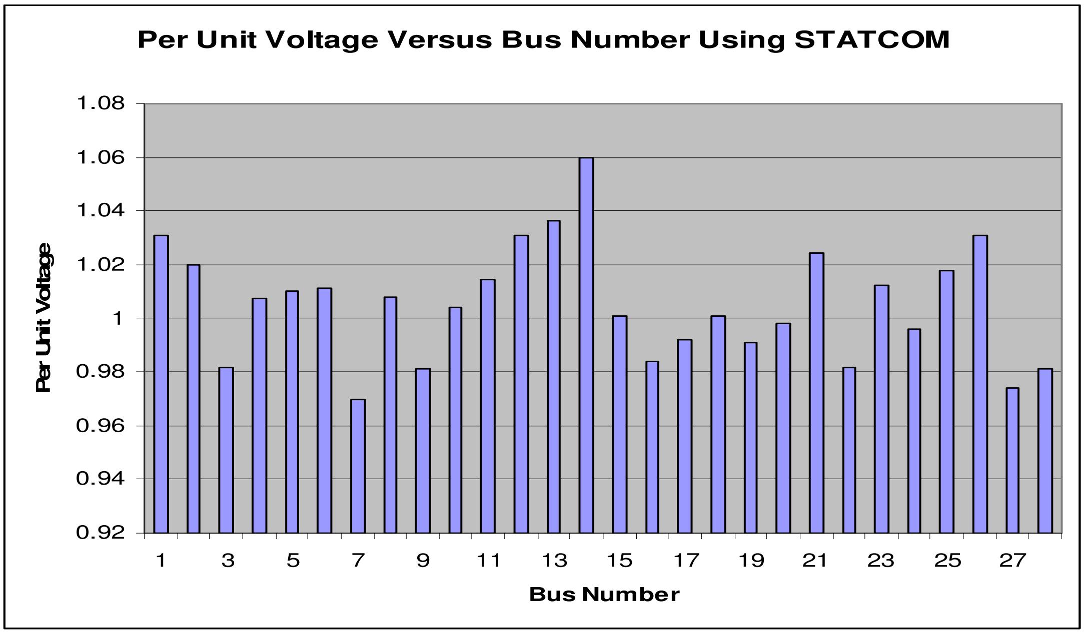

Figure 3.0 plot of per bus unit voltage values versus bus numbers on incorporation of STATCOM in the network using GA

Table 2.0d. Load Flow result obtained with STATCOM using GA

Connected Bus Numbers		Line Flows With FACTS Devices (STATCOM)				Line Losses With FACTS Devices (STATCOM)	
		Sending End		Receiving End			
		Psend pu)	Q send (pu)	P received (pu)	Q received (pu)	Real power loss (pu)	Reactive power loss (pu)
17	24	0.0954	0.0604	0.0933	0.0566	0.0021	-0.0038
17	18	0.0873	0.0616	0.0859	0.0598	-0.0014	0.0018
21	17	0.0794	0.0889	0.0778	0.0848	0.0016	0.0041
21	10	0.0812	0.0499	0.0793	0.0452	0.0019	0.0047
17	26	0.0966	0.0147	0.0941	0.0110	0.0025	0.0037
26	3	0.1052	0.1701	0.1033	0.1604	-0.0019	-0.0097
20	26	0.0838	0.0171	0.0818	0.0121	0.0020	-0.0050
22	20	0.0912	0.0810	0.0889	0.0753	0.0023	0.0057
20	19	0.0706	0.0809	0.0686	0.0759	0.0020	0.0050
15	19	0.0918	0.0193	0.0890	0.0128	0.0028	0.0065
24	4	0.0824	0.0416	0.0804	0.0381	0.0020	0.0035
24	16	0.0746	0.0217	0.0718	0.0177	0.0028	0.0040
4	16	0.0922	0.0198	0.0897	0.0149	0.0025	0.0049

16	7	0.0992	0.1141	0.0966	0.1084	0.0026	0.0057
16	14	0.0811	0.0111	0.0791	0.0152	0.0020	0.0041
14	5	0.0951	0.0591	0.0934	0.0534	0.0017	0.0057
16	11	0.0838	0.0097	0.0811	0.0167	0.0027	-0.0070
25	8	0.0737	0.0158	0.0720	0.0117	0.0017	0.0041
13	8	0.0851	0.0194	0.0831	0.0136	0.0020	0.0058
11	25	0.0967	0.0442	0.0951	0.0391	0.0016	0.0051
11	13	0.0811	0.0776	0.0783	0.0725	0.0028	-0.0051
16	11	0.0938	0.0098	0.0908	0.0120	0.0030	0.0022
24	11	0.0671	0.1041	0.0642	0.0972	0.0029	0.0069
6	11	0.0948	0.0219	0.0920	0.0157	0.0028	0.0062
11	28	0.0822	0.0128	0.0803	-0.0175	-0.0019	0.0047
28	23	0.0985	0.0589	0.0957	-0.0521	0.0028	0.0068
28	9	0.0808	0.0119	0.0778	-0.0159	0.0030	0.0040
9	1	0.0939	0.0463	0.0910	-0.0403	0.0029	0.0060
27	28	0.0813	0.1054	0.0793	0.1004	-0.0020	0.0050
TOTAL LOSSES						**0.0518**	**0.0856**

Table 3.0a shows the voltages and phase angles of each of the buses in the 330KV Network with the application of TCSC using GA, while table 3.0b shows the load flow result obtained. Figure 4.0 shows a plot of bus per unit voltage values versus bus numbers on incorporation of TCSC in the network using GA

Table 3.0a: Voltages and Angles with TCSC at Location Specified by GA

Bus Nr	Bus Name	Per Unit Voltage	Voltage(KV)	Angle (Degree)
1	Afam PS	1.042	343.86	-4.82
2	AES	1.025	338.25	-6.74
3	Katampe	0.9838	324.654	-22.75
4	Aiyede	1.0124	334.092	-8.24
5	Aja	0.9861	325.413	-5.54
6	Ajaokuta	1.0101	333.333	-7.26
7	Akangba	0.9643	318.219	-14.67
8	Aladja	1.0032	331.056	-3.82
9	Alaoji	0.9897	326.601	-7.63
10	B-kebbi	0.9987	329.571	-8.88
11	Benin	1.0215	337.095	-4.33
12	Calabar	1.0364	342.012	-9.22
13	Delta PS	1.0416	343.728	-2.73
14	Egbin PS	1.06	349.8	0.00
15	Gombe	0.9997	329.901	-41.31
16	Ikeja west	0.9710	320.43	-9.99
17	Jebba	0.9898	326.634	-6.71
18	Jebba PS	0.9991	329.703	-4.81
19	Jos	0.9872	325.776	-38.21
20	Kaduna	0.9968	328.944	-44.23
21	Kainji PS	1.0412	343.596	-5.11
22	Kano	0.9758	322.014	-42.76
23	Okpai PS	1.0211	336.963	4.32
24	Oshogbo	0.9982	329.406	-7.62
25	Sapele PS	1.0231	337.623	-3.66
26	Shiroro PS	1.0341	341.253	-34.72
27	New-Haven	0.9788	323.004	-7.09
28	Onitsha	0.9812	323.796	-6.57

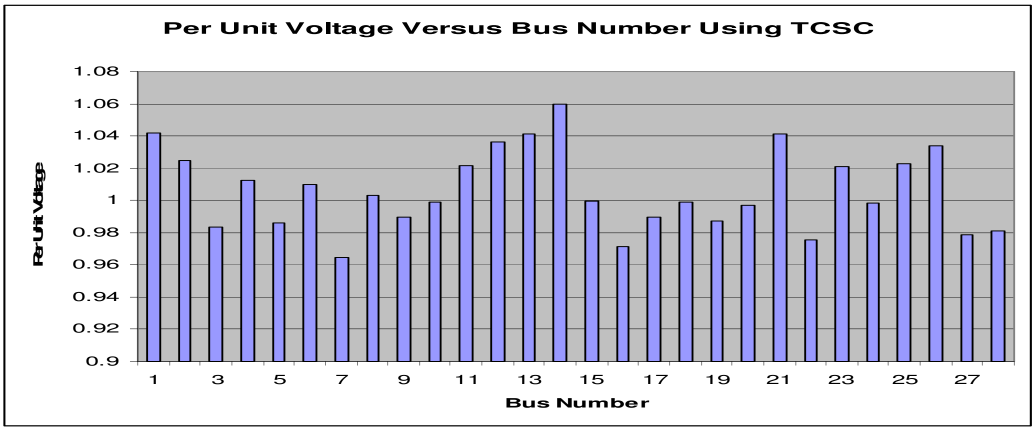

Figure 4.0 shows a plot of bus per unit voltage values versus bus numbers on incorporation of TCSC in the network using GA

Table 3.0b: load flow results on incorporation of TCSC in the network using GA

Connected Bus Numbers		Line Flows With FACTS Devices (TCSC)				Line Losses With FACTS Devices (TCSC)	
		Sending End		Receiving End			
		Psend pu)	Q send (pu)	P received (pu)	Q received (pu)	Real power loss (pu)	Reactive power loss (pu)
17	24	0.0956	0.0604	0.0945	0.0570	0.0011	-0.0034
17	18	0.0875	0.0616	0.0860	0.0602	-0.0015	0.0014
21	17	0.0796	0.0889	0.0783	0.0852	0.0013	0.0037
21	10	0.0815	0.0499	0.0799	0.0458	0.0016	0.0041
17	26	0.0969	0.0147	0.0947	0.0114	0.0022	0.0033
26	3	0.1055	0.1701	0.1039	0.1608	-0.0016	-0.0093
20	26	0.0841	0.0171	0.0824	0.0125	0.0017	-0.0046
22	20	0.0914	0.0810	0.0895	0.0757	0.0019	0.0053
20	19	0.0709	0.0809	0.0726	0.0763	0.0017	0.0046
15	19	0.0921	0.0193	0.0899	0.0132	0.0025	0.0061
24	4	0.0827	0.0416	0.0810	0.0385	0.0017	0.0031
24	16	0.0749	0.0217	0.0724	0.0181	0.0025	0.0036
4	16	0.0926	0.0198	0.0904	0.0153	0.0022	0.0045
16	7	0.0999	0.1141	0.0976	0.1089	0.0023	0.0052
16	14	0.0816	0.0111	0.0799	0.0148	0.0017	0.0037
14	5	0.0954	0.0591	0.0940	0.0539	0.0014	0.0052
16	11	0.0841	0.0097	0.0817	0.0163	0.0024	-0.0066
25	8	0.0739	0.0158	0.0725	0.0121	0.0014	0.0037
13	8	0.0854	0.0194	0.0837	0.0139	0.0017	0.0055
11	25	0.0971	0.0442	0.0958	0.0394	0.0013	0.0048
11	13	0.0816	0.0776	0.0791	0.0731	0.0025	-0.0045
16	11	0.0941	0.0098	0.0914	0.0117	0.0027	0.0019
24	11	0.0675	0.1041	0.0649	0.0977	0.0026	0.0064
6	11	0.0952	0.0219	0.0927	0.0161	0.0025	0.0058
11	28	0.0825	0.0128	0.0809	-0.0172	-0.0016	0.0044
28	23	0.0989	0.0589	0.0964	-0.0524	0.0025	0.0065
28	9	0.0811	0.0119	0.0784	-0.0156	0.0027	0.0037
9	1	0.0942	0.0463	0.0916	-0.0407	0.0026	0.0056
27	28	0.0816	0.1054	0.0799	0.1008	-0.0017	0.0046
TOTAL LOSSES						**0.0443**	**0.0783**

Table 3.0c shows the different transmission lines location of the network under study were TCSC are installed with their different values

Table 3.0c GA based placement of TCSC on the lines

Line number	X_{TCSC}
15-19	-0.0636

20-19	-0.0342
20-22	-0.0546
20-26	-0.1465
27-28	-0.0264

It was found that the total real power loss is reduced to 0.094pu and the reactive loss is 0.1639pu.Using GA for optimally placing UPFC on the network resulted in bus voltage improvement. This is shown in table 4.0a, while table 4.0b is the load flow results obtained. Figure 4.0 shows a plot of bus per unit voltage values versus bus numbers on incorporation of UPFC in the network using GA. The various ratings of UPFC used for the study and their locations in the network is shown in table 4.0c

Table 4.0a: Bus Voltage obtained on optimal location of UPFC using GA

Bus Nr	Bus Name	Per Unit Voltage	Voltage(KV)	Angle (Degree)
1	Afam PS	1.044	344.52	-7.82
2	AES	1.027	338.91	-8.74
3	Katampe	0.9858	325.314	-26.75
4	Aiyede	1.0224	334.092	-9.24
5	Aja	0.9872	337.392	-6.54
6	Ajaokuta	1.0121	333.993	-9.26
7	Akangba	0.9663	318.879	-16.67
8	Aladja	1.0042	331.386	-4.82
9	Alaoji	0.9898	326.634	-5.63
10	B-kebbi	0.9997	329.901	-10.88
11	Benin	1.0225	337.425	-3.33
12	Calabar	1.0374	342.342	-9.22
13	Delta PS	1.0426	344.058	-3.73
14	Egbin PS	1.06	349.80	0.00
15	Gombe	1.0010	330.33	-41.31
16	Ikeja west	0.9770	322.41	-11.69
17	Jebba	0.9898	326.634	-9.65
18	Jebba PS	0.9993	329.769	-6.03
19	Jos	0.9912	327.096	-28.11
20	Kaduna	0.9980	329.34	-43.38
21	Kainji PS	1.0422	343.927	-9.11
22	Kano	0.9818	323.99	-34.76
23	Okpai PS	1.0221	337.293	4.32
24	Oshogbo	0.9992	329.736	-7.62
25	Sapele PS	1.0241	337.953	-3.66
26	Shiroro PS	1.0351	341.583	-34.72
27	New-Haven	0.9798	323.334	-7.09
28	Onitsha	0.9842	324.786	-6.57

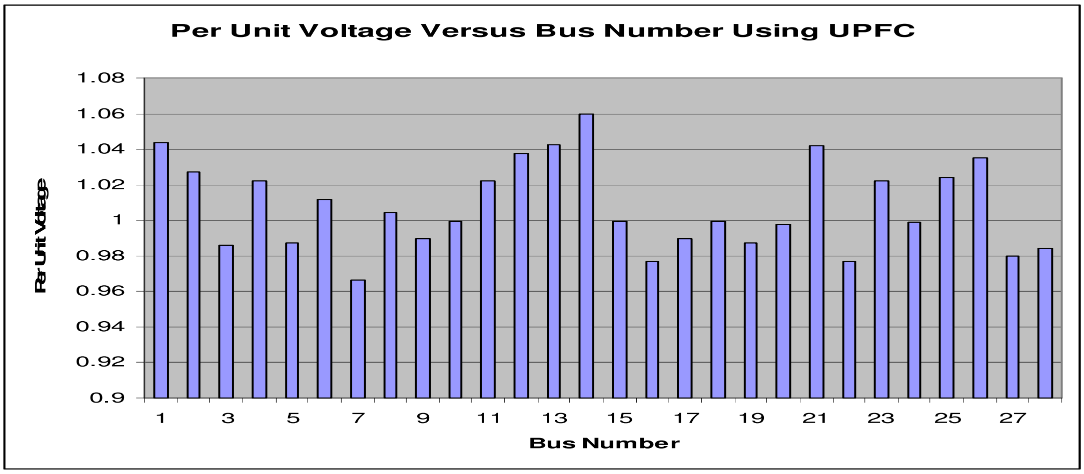

Figure 4.0 plot of bus per unit voltage values versus bus numbers on incorporation of UPFC

Table 4.0b: Load Flow result obtained on Optimal Location of UPFC using GA

Connected Bus Numbers		Line Flows With FACTS Devices (UPFC)				Line Losses With FACTS Devices (UPFC)	
		Sending End		Receiving End			
		Psend pu)	Q send (pu)	P received (pu)	Q received (pu)	Real power loss (pu)	Reactive power loss (pu)
17	24	0.0959	0.0608	0.0951	0.0580	0.0008	-0.0028
17	18	0.0880	0.0619	0.0869	0.0609	-0.0011	0.0010
21	17	0.0801	0.0892	0.0792	0.0862	0.0009	0.0030
21	10	0.0819	0.0502	0.0808	0.0466	0.0011	0.0036
17	26	0.0971	0.0152	0.0954	0.0123	0.0017	0.0029
26	3	0.1058	0.1706	0.1068	0.1618	-0.0010	-0.0088
20	26	0.0846	0.0175	0.0837	0.0135	0.0009	-0.0040
22	20	0.0919	0.0814	0.0911	0.0768	0.0008	0.0046
20	19	0.0712	0.0812	0.0702	0.0770	0.0010	0.0042
15	19	0.0925	0.0198	0.0904	0.0144	0.0021	0.0054
24	4	0.0832	0.0420	0.0821	0.0385	0.0011	0.0027
24	16	0.0752	0.0221	0.0732	0.0393	0.0020	0.0030
4	16	0.0931	0.0202	0.0913	0.0162	0.0018	0.0040
16	7	0.0998	0.1146	0.0981	0.1098	0.0017	0.0048
16	14	0.0819	0.0116	0.0808	0.0149	0.0011	0.0033
14	5	0.0958	0.0597	0.0948	0.0550	0.0010	0.0047
16	11	0.0846	0.0102	0.0827	0.0163	0.0019	-0.0061
25	8	0.0742	0.0166	0.0734	0.0133	0.0008	0.0033
13	8	0.0858	0.0198	0.0847	0.0147	0.0011	0.0051
11	25	0.0975	0.0447	0.0965	0.0403	0.0010	0.0044
11	13	0.0819	0.0781	0.0799	0.0740	0.0020	-0.0041
16	11	0.0945	0.0102	0.0924	0.0117	0.0021	0.0015
24	11	0.0678	0.1051	0.0660	0.0991	0.0018	0.0060
6	11	0.0957	0.0221	0.0938	0.0167	0.0019	0.0054
11	28	0.0829	0.0132	0.0816	-0.0172	-0.0013	0.0040
28	23	0.0992	0.0592	0.0970	-0.0531	0.0022	0.0061
28	9	0.0815	0.0121	0.0795	-0.0154	0.0020	0.0033
9	1	0.0946	0.0465	0.0925	-0.0413	0.0021	0.0052
27	28	0.0819	0.1057	0.0807	0.1016	-0.0012	0.0041
TOTAL LOSSES						**0.0323**	**0.0698**

Table 4.0c: Ratings of UPFC used as specified by GA

Location	Rate	Size (MVA)
15	-0.60	2.00
19	-1.00	1.0
20	-0.42	2.0
22	0.32	-1.0
27	0.65	-2.0

VIII. DISCUSSION OF RESULT

This work analyzed the Nigeria 330KV power system, consisting of Nine (9) Generating stations, Twenty eight buses and twenty nine (29) transmission lines with and without FACTS (TCSC,UPFC and STATCOM) devices using N-R power flow algorithm and GA for optimization. Power flow studies were carried out with and without FACTS devices. The weak buses were Gombe (0.8909pu), Jos(0.9118pu),Kaduna(0.9178pu),Kano(0.9031pu) and new haven(0.9287pu).Total active and reactive power losses were obtained without FACTS devices as 0.0629pu and 0.0958pu respectively. Incorporating TCSC of different rates and sizes as shown in table3.0c on Gombe-Jos, Kaduna-Jos, Kaduna-Jos, Kaduna-Kano, Kaduna-Shiroro and New Haven-Onitsha transmission lines, an improved bus voltage values as well as active and reactive power loss reduction to 0.0443pu and 0.0783pu respectively and improved bus voltage values of Gombe (0.9997pu), Jos (0.9872pu), Kaduna (0.9968pu), Kano (0.9758pu) and new Haven (0.9788pu). Furthermore, Gombe, Jos, Kaduna, Kano and New-Haven also had UPFC and STATCOM incorporated separately in the network with their different sizes and ratings as shown in tables2.0 and 4.0 respectively. Improved bus voltage values and transmission loss reduction was also obtained. The results obtained on placement of STATCOM are Gombe (0.9918pu), Jos (0.9871pu), Kaduna (0.9968pu), Kano (0.9768pu) and new haven (0.9741pu). Active and reactive power losses obtained are 0.0518pu and 0.0856pu respectively. Bus voltages obtained on placement of UPFC are Gombe (1.0010pu), Jos (0.9912pu), Kaduna (0.9980pu), Kano (0.9818pu) and new haven (0.9798pu). The active and reactive power losses were also reduces to 0.0323pu and 0.0698pu respectively. Tables 6.0a and 6.0b summarized the results obtained on with and without these devices (STATCOM, UPFC and TCSC) respectively. Comparison was made on the three FACTS devices in terms of loss reduction and bus voltage improvement. It was found that though they all minimized losses, but UPFC reduced the transmission loses most.

Table 6.0a: Losses With and Without FACTS Devices in the Nigeria 330KV Power Transmission Line Network

	WITH FACT DEVICES						WITHOUT FACT DEVICE
PER UNIT VALUE	UPFC	UPFC %LOSS SAVINGS	TCSC	TCSC %LOSS SAVINGS	STATCOM	STATCOM % LOSS SAVINGS	
Active	0.0323	48.64%	0.0443	29.57%	0.0518	17.64%	0.0629pu
Reactive	0.0698	27.14%	0.0783	18.26%	0.0856	10.65%	0.0958pu

Table 6.0b: Bus Voltages With and Without FACTS Devices in the Nigeria 330KV Power Transmission Line Network

	Weak buses voltages without FACTS Devices (per unit)	Improved buses with FACTS Devices (per unit)		
Buses	Values	UPFC	TCSC	STATCOM
Gombe	0.8909	1.0010	0.9997	0.9918
Jos	0.9118	0.9912	0.9872	0.9871
Kaduna	0.9178	0.9980	0.9968	0.9968
Kano	0.9031	0.9818	0.9758	0.9768
New-Haven	0.9287	0.9798	0.9788	0.9741

IX. CONCLUSION

The study revealed that with the appropriate placement of FACT device(s), using Genetic Algorithm, losses were minimized compared to when the network had no device. Also basic transmission line parameters such as line impedance, voltage magnitude, phase angles wereregulated to operate within the maximum tolerable power carrying capacity of the lines. The optimal number of TCSC, UPFC and STATCOM with their respective ratings were determined and placed in their appropriate positions. This algorithm is effective in deciding the placement of FACTS devices and in the reduction of both active power and reactive power losses by improving voltage profile and ensuring that the heavily loaded lines are relieved.

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APPENDIX A

Transmission Line Parameters for the 330KV Network.

Line Between Buses And The Number Of Circuits			Length of Line (km)	Line Impedance	
FROM	TO	CIRCUIT TYPE		R (P.U)	X (P.U)
Kainji	Jebba PS	Double	81	0.0015	0.0113
Jebba	Jebba PS	Double	8	0.0001	0.0007

Shiroro	Jebba PS	Double	244	0.0045	0.0342
Shiroro	Kaduna	Double	96	0.0017	0.0132
Shiroro	Abuja	Double	144	0.0025	0.0195
Egbin	Ikeja West	Double	62	0.0011	0.0086
Egbin	Aja	Double	16	0.0003	0.0019
Ikeja West	Akangba	Double	17	0.0004	0.0027
Ikeja west	Benin	Double	280	0.0051	0.0039
Afam IV	Alaoji	Double	25	0.0006	0.0043
Okpai	Onitsha	Double	28	0.0005	0.0042
Sapele	Benin	Double	50	0.0009	0.0070
Ajaokuta	Benin	Double	195	0.0035	0.0271
Jebba PS	Oshogbo	Triple	249	0.0020	0.0154
Kainji	Birnin Kebbi	Single	310	0.0122	0.0916
Kaduna	Kano	Single	230	0.0090	0.0680
Kaduna	Jos	Single	196	0.0081	0.0609
Jos	Gombe	Single	264	0.0118	0.0887
Oshogbo	Ibadan	Single	115	0.0045	0.0345
Oshogbo	Ikeja West	Single	252	0.0099	0.0745
Oshogbo	Benin	Single	251	0.0099	0.0742
Aiyede	Ikeja West	Single	137	0.0054	0.0405
Sapele	Aladja	Single	63	0.0025	0.0186
Delta IV	Aladja	Single	32	0.0009	0.0072
Delta IV	Benin	Single	107	0.0042	0.0316
Onitsha	Alaoji	Single	138	0.0054	0.0408
Onitsha	New Haven	Single	96	0.0038	0.0284
Benin	Onitsha	Single	137	0.0054	0.0405
Oshogbo	Aiyede	Single	115	0.0023	0.0241

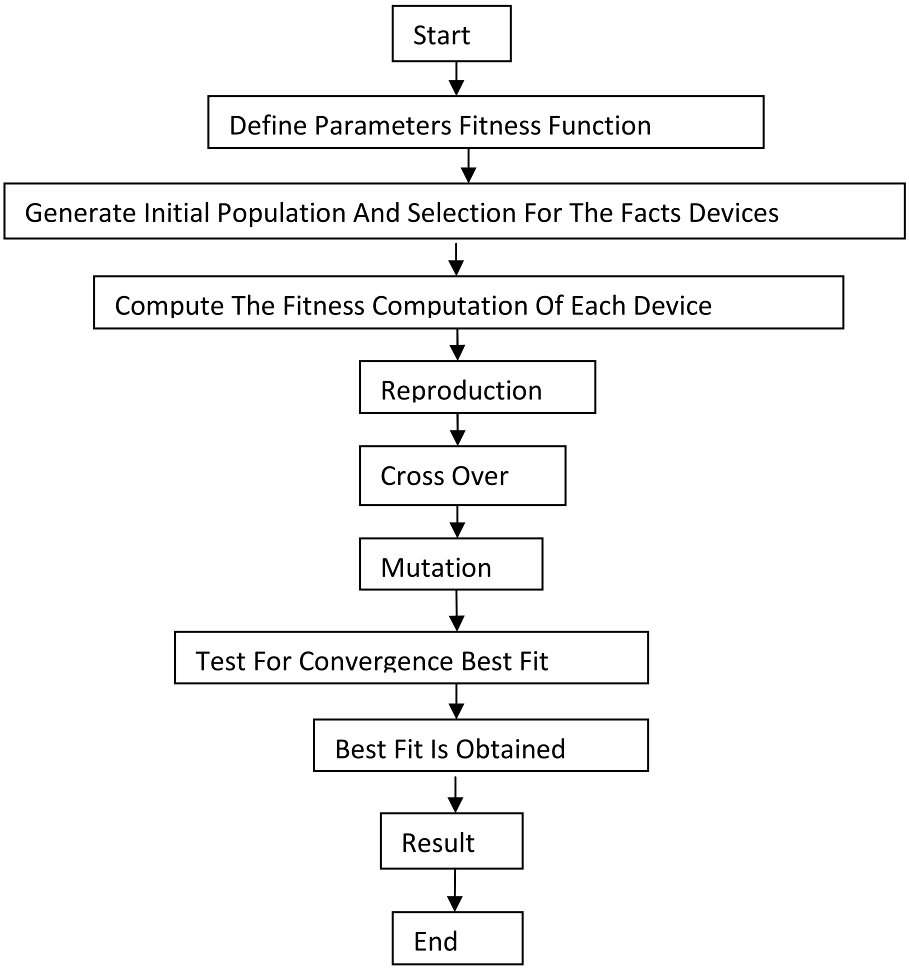
APPENDIX B

PHCN Power Stations

S/N	**Name**	**Gen MW**	**Gen MVR**
1	Delta PS	281.00	-13.00
2	Egbin PS	912.00	-262.00
3	AES	234.00	-32.00
4	Okpai	237.00	68.00
5	Sapele Ps	170.00	-61.00
6	Afam I-VI PS	560.00	148.00
7	Jebba PS	402.00	-49.00
8	Kainji PS	259.00	-128.00
9	Shiroro PS	409.00	-223.00
TOTAL POWER GENERATED		**3,452**	**-552**

APPENDIX C

Flow Chart for Genetic Algorithm



Authors Biography

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