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Optimal Location of Ipfc in Nigeria 330 KV Integrated Power Network Using Ga Technique

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Abstract

The Nigeria 330 KV integrated power system currently consist of the existing network, National Independent Power Projects (NIPP), and the Independent Power Producers (IPP). This network consist of Seventeen generating stations, Sixty four Transmission lines and Fifty two buses. Loss reduction and bus Voltage improvement control mechanism is still based on conventional devices (synchronous generators/condensers, tap changers, reactors and inductors) and building more generating stations and transmission lines as an alternative to meet the ever increasing power demand. This work modeled and analyzed the application of Interline Power Flow Controller (IPFC),which is a modern control Flexible Alternating Current Transmission System (FACTS)device on the network using Genetic Algorithm (GA) for its optimal placement and an option for power improvement. The result obtained showed improvement of weak bus voltages and loss reduction with and without IPFC devices on incorporation in the network. It is recommended that FACTS devices be incorporated into the power network for improved efficiency and not necessarily building more stations and transmission lines, as this is the current practice in Nigeria. This should be an integral part of the planning process for both the existing, NIPP and IPP in the country so as to meet the vision 2020 goal.

Keywords: Nigeria; Phcn; Nipp; Ipp; Ipfc; Fact

Introduction

Nigeria power system is gradually transforming into complex interconnected network of different components. This complexity is as a result of the deregulation of the electricity industry and expansion of the network by NIPP and IPP to meet the increasing energy demand. Due to varying load demand patterns and its inability to meet both active and reactive power demand during operation coupled with the lack of sensitive equipment to detect and stabilize these challenges, there is large number of disturbances occurring continuously, thus resulting in violation of both bus voltages, frequency limits and poor power quality. Assessing the network performance will involve power/load flow studies and its control and system stability analyses. Power flow control enhances both varying loads and voltage compensation. Varying load support minimizes voltage changes at transmission terminals (buses), enhances network stability, voltage profile regulation and raise transmission efficiency [1-3]. Voltage compensation on the other hand improve active power of the network by raising its power factor and also decreases harmonic components due to large loads fluctuations from non linear equipments. System stability is determined by carrying out transient studies on the network. Table 1 shows the generators available and installed capacities while Table 2 gives bus voltages.

Power system stabilizers (PSSs) are conventional devices used in controlling excitation and improve system stability [4-6]. However, it can damp only local and not inter-area mode of oscillations and cause variation in voltage profile under severe disturbances that could even result to leading power factor operation and eventual loss of synchronism. Series and shunt VAR compensators were also the conventional methods of enhancing transmission and generation efficiency in electrical networks by modifying the impedance at the connected terminals. This improves the overall performance. Conventional compensators consist of fixed and rotating capacitors that use mechanical switching mechanism, though their effectiveness and reliability still poses challenge in power industry. These functions are normally carried out with mechanically controlled shunt and series banks of capacitors and non-linear reactors. However, when there is an economic and technical justification, the reactive power support is provided by electronic means (FACTS devices) as opposed to mechanical means, enabling near instantaneous control of reactive power, voltage magnitude, transient stability and transmission line impedance at the point of compensation. FACTS controllers initially was mainly used in solving various steady state control problems such as voltage control regulation, power flow control, transfer and enhancement ,but in recent times, its function have been extended to damping the inter-area modes and transient enhancement [7,8].

Concept of Facts Devices

FACTS devices is a concept of Electric Power Research Institute (EPRI) in which power electronic based controllers are used to regulate power flows, transmission voltage and mitigate dynamic disturbances [1,9]. The goal is for improvement of power quality, control of flows at different loading conditions, better utilization of existing as well as new and upgraded facilities (generation, transmission and distribution stations). These devices are very relevant in Nigeria power network for efficiency improvement of the network considering the enormous challenges inherent in the system and also the on-going deregulation/unbundling in the electricity market [10,11]. Proposed terms and definitions of these devices and their various configurations was carried out by [12]. FACTS controllers are classified into two generations. These are the first and second generation and Table 3 showed their differences [13,14].

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S/N	Station	State	Turbine	Installed Capacity	Available Capacity
1	Kainji	Niger	Hydro	760	259
2	Jebba	Niger	Hydro	504	402
3	Shiroro	Niger	Hydro	600	408
4	Egbin	Lagos	Steam	1320	900
5*	Trans-Amadi	Rivers	Gas	100	7.3
6*	A.E.S (Egbin)	Lagos	Gas	250	233
7	Sapele	Delta	Gas	1020	170
8	Ibom	Akwa-Ibom	Gas	155	25
9	Okpai	Delta	Gas	900	223
10	Afam I-V	Rivers	Gas	726	60
11*	AfamVI (Shell)	Rivers	Gas	650	550
12	Delta	Delta	Gas	912	281
13	Geregu	Kogi	Gas	414	120
14*	Omoku	Rivers	Gas	150	28
15*	Omotosho	Ondo	Gas	304	88
16*	Olorunshogo (1)	Ogun	Gas	100	54
17*	Olorunshogo (2)	Ogun	Gas	200	114
18*	Okpai (Agip)	Delta	Gas	480	480
19**	Calabar	Cross River	Gas	563	Nil
20**	Ihorvbor	Edo	Gas	451	Nil
21**	Sapele	Delta	Gas	451	Nil
22**	Gbaran	Bayelsa	Gas	225	Nil
23**	Alaoji	Abia	Hydro	961	Nil
24**	Egbema	Imo	Gas	338	Nil

Table 1: Generators Installed and Available Capacities.

S/N	BUSES	S/N	BUSES	S/N	BUSES	S/N	BUSES
1	Shiroro	14	Akangba	27	Benin North*	40	Jos
2	Afam	15	Sapele	28	Omotosho*	41	Yola*
3	Ikot-Ekpene*	16	Aladja	29	Eyaen*	42	Gwagwalada*
4	Port-Harcourt*	17	Delta PS	30	Calabar	43	Sakete*
5	Aiyede	18	Alaoji	31	Alagbon*	44	Ikot-Abasi
6	Ikeja west	19	Aliade*	32	Damaturu*	45	Jalingo*
7	Papalanto*	20	New Haven	33	Gombe	46	Kaduna
8	Aja*	21	New Haven South*	34	Maiduguri	47	Jebba GS
9	Egbin PS	22	Makurdi*	35	Egbema*	48	Kano
10	Ajaokuta	23	B-kebbi	36	Omoku*	49	Katampe
11	Benin	24	Kainji	37	Owerri*	50	Okpai
12	Geregu*	25	Oshogbo	38	Erunkan*	51	Jebba
13	Lokoja*	26	Onitsha	39	Ganmo*	52	AES

Table 2: Buses and Per Unit Voltage Values Forthe 330 kV Integrated Network.

First Generation	Second Generation
It employs conventional reactors, tap changing transformers and thyristor switched capacitors for the control of power systems parameters.	Voltage Source Converters (VSCs) and Gate Turn-Off (GTO) Thyristor Switched Converters technology is employed.
Examples include Thyristor Controlled Series controllers (TCSCs), Static Var Compensator (SVCs) and the thyristor controlled phase shifters (TCPs). [13] and [14]	Static Synchronous Series Controllers (SSSCs), Unified Power Flow Controllers (UPFCs), Static Synchronous Controllers (STATCOMs) and the Interline Power Flow Controllers (IPFCs).
Solid State switches are used in the circuit arrangement (Series and Shunt) controls both on and off state to realize reactive impedance variations in the network. In situation of losses, they cannot be used for power compensation and exchange.	Self commutated DC to AC converters that can generate both capacitive and inductive power without the use of reactor banks and capacitors are employed. They are applied in the control of line impedance, active and reactive power flows, phase shifting, and shunt and series compensations.

Table 3: Differences between first and second generation controllers.

Facts Devices Configurations and Applications

FACTS technologies can essentially be defined as solid state power electronic based devices that produces a compensated response to the transmission network that are interconnected through transformers, generators, transmission lines and other power equipment [9,15]. According to [16], FACTS controllers are classified into four groups: Series, Shunt, Combined Series-Series, and Combined Series Shunt Controllers.

Series controllers

Series controllers injects voltage in series that must stay in quadrature with the transmission line current connected to it. They work as a controllable voltage source [8]. The variation of the injected voltage with respect to the transmission line current makes the series controllers a variable reactance in either the inductive mode or the capacitive mode. According to [17,18], series controllers cancels part of the lines reactance thus increasing its maximum power, reduce transmission angle at a given level of power transfer and increases load, thus results in absorbing less of the line charging reactive power. Examples include: Thyristor Controlled Series Controllers (TCSC), Thyristor Switched Series controllers (TSSC) and Static Synchronous Series Controllers (SSSC) According to [3,7,9,15], series controllers are more effective than shunt controllers in power system damping oscillation and power flow application because they work directly with the lines. TCSC was used for this study. TCSC increases stability margin of systems and has proved to be very effective in damping Sub synchronous resonance (SSR) and power oscillations [19,20].

Shunt controllers

They control the amount of reactive power injected or absorbed by voltage regulation at its terminals using the voltage source converter connected on the secondary side of the coupling transformer. Shunt controllers can either draw capacitive or inductive current and it is achieved when it operates either in the inductive or capacitive mode [21,22]. Shunt capacitive controllers improves power factor. Connection of inductive load results in lagging power factor. In order to correct this, the shunt controllers when connected, draws current leading the source voltage, while the shunt capacitive controllers' regulates Ferranti effect in long transmission lines [23]. STATCOM is used for dynamic compensation of power transmission systems, providing support and increasing transient stability margin. Examples of shunt connected FACTS controllers include: Thyristor Controlled Reactor (TCR), Thyristor Switched Capacitor (TSC), Static Synchronous Controllers (STATCOM) and Static Var Controllers (SVC). The SVC is conventionally used to stabilize a bus bar voltage and improve dynamic oscillation in power system [9].

Combined series-series controllers

It can either be combination of separate series controllers operating in coordinated manner or a unified controller in which the series controller provides series compensation independently for each line through the power DC link [24]. The simple way of modeling IPFC was first reported by [25]. It works only if simultaneous control is exerted on the nodal voltage magnitude, active power flow and reactive power injected from one bus to the other. The concept of IPFC is an extension of SSSC, except that the injected voltage does not have to be in quadrature with the line current. Thus, implying that both voltage magnitude and phase angles of the injected voltage can be controlled on one line. The steady state operation of the IPFC was investigated by [26] and developed a mathematical model of the IPFC and used it to investigate the flexibility of power flow control in the presence of operating constraints of the IPFC and stated possibilities of using improved control strategies for better efficiency in a network. According to [27], the line current depends on the transferred power through the line, thus implying that the injection of rated power by the IPFC depends on the original line power flow. Interline power flow controller (IPFC) is an example.

Combined series-shunt controllers

The UPFC is designed to control selectively or simultaneously all parameters affecting flow of power in a transmission network and also can independently control both real and reactive flow in the line unlike every other FACTS controller [28]. Its arrangement can either be combination of shunt and series controllers with effective coordinated control or unified power flow series and shunt controllers [16]. Series and Shunt part inject current and voltage respectively into the transmission network and can exchange power between these two controllers through the power link [29,30] used UPFC to simultaneously regulate power flow through transmission lines (overload and loop flow minimization) and also minimizes power losses without generators rescheduling. The UPFC consist of a STATCOM and a DVR (Direct Voltage Regulator), both sharing a common capacitor on their DC side and a unified control system. According to [29], UPFC controllers can control network security under large perturbations control actions associated to generators and load. Examples of combined series-shunt controllers are the Thyristor Controlled Phase Shifting Transformers (TCPST) and Unified Power Flow Controllers (UPFC).

FACTS devices ensure system stability by ensuring the following in a network: controlling and regulating excess current or reactive power flowing through transmission lines, inter area damping of system oscillations and the control on occurrence of stability situations in cases of overloaded lines or faults occurring in the synchronous generators. These controllers are able to provide adequate damping for the oscillation modes of interest for several different operating conditions, in order to improve network stability [30]. Though installing FACTS controllers for the purpose of only stability improvement is not an economical practice (Table 4).

FACTS controllers are used for the control of voltage, impedance, stability, phase angles and power transfer capabilities and ensure that power flows appropriately through the lines in either a simple or very complex power network. Hassan MO presented steady state modeling of STATCOM and TCSC for power flow control [3] study using Newton-Raphson algorithm, by modeling STATCOM as a controllable voltage source in series with the line impedance and proposed firing angle model for efficiency improvement using TCSC was proposed [31]. The algorithm developed in the presence of STATCOM and TCSC shows excellent convergence characteristics. Assessment of the steady state response of FACTS devices was investigated by [4,8] and presented nodal admittance model for series compensators, phase shifter and unified power flow controller. Active and reactive power flow and voltage magnitude are also controlled at the UPFC terminals [7,9]. The controller can also be adjusted to control either of these parameters or none of these. In spite of the increasing use of FACTS devices worldwide, there are no reported cases of installation of FACTS device in the Nigeria 330 KVtransmission network [32,33].

Ga Application in Power Systems

According to [34-40], GA transforms individual mathematical parameters into a new population (next generation), using genetic operations similar to the corresponding operations of genetics in nature. The work of [41] determined simultaneously the actual rated values and location using genetic algorithm and concluded that GA as a search tool is very accurate and fast. GA for placement of phase shifters in the French network was studied by [42]. GA as an optimization technique to solve congestion problems in power systems using UPFC was carried out by [42] by optimally placing them in the network. It can be applied to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective functions is discontinuous, non-differentiable, stochastic or highly nonlinear [43,44]. GA was applied to practical

Issues	Problem	Corrective Action	Conventional Solution	New Equipment (FACTS)
Voltage limits	Low voltage at heavy load	Supply reactive power	Shunt capacitors, Series capacitors	TCSC,STATCOM
	High voltage at light load	Remove reactive power control	Switch EHV line and/or shunt capacitor	TCSC,TCR
		Absorb reactive power	Switch Shunt capacitor, Shunt reactor, SVC	TCR,STATCOM
	High voltage following outage	Absorb reactive power	Add reactor	TCR
		Protect equipment	Add arrestor	TCVL
	Low voltage following outage	Supply reactive power limit	Switch Shunt capacitor, reactor, SVC, switch series capacitor	STATCOM,TCSC
		Prevent overload	Series reactor, PAR	IPFC,TCPAR,TCSC
	Low voltage and overload	Supply reactive power limit overload	Combination of two or more equipment	IPFC,TCSC,UPFC,STATCOM
Thermal Limits	Line/transformer overload	Reduce overload	Add line/transformer	TCSC,TCPAR,UPFC
			Add series reactor	IPFC,TCR
	Tripping of parallel circuit	Limit circuit loading		IPFC,TCR,IPFC
Short circuit levels	Excessive breaker fault	Limit short circuit current	Add series reactor, fuses, new circuit breaker	TCR,IPFC,UPFC
		Change circuit breaker	Add new circuit breaker	
		Rearrange network	Split bus	IPFC

Table 4: Application of Various FACTS Devices.

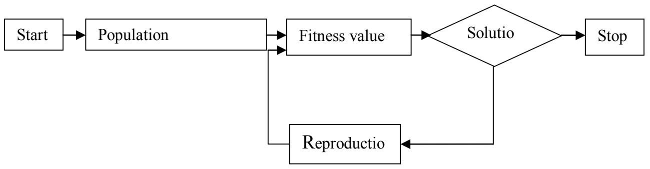

Figure 1: GA flow chart iteration process.

51 and 224 bus systems for loss minimization [45]. Optimal location of FACTS devices in managing transmission line congestion was done by [45] using GA as the optimization tool. Design of a static Var compensator and TCSC for damping control in a power system was carried out by [41] and concluded that the damping can be enhanced by having decentralized control as determined by GA. Power system stability can be improved over a wide range of operating/load conditions by the use of a GA based power system stabilizers (PSSs).

GA Flow Chart Iteration Process

It involves representation of problem statement as set of parameters. These parameters are called genes and are linked together to form a string(s) known as chromosomes. GA solve set of parameter sets with finite length, thus making the search unrestricted by continuous function or by the existence of a derivative function. Continuous functions are represented by floating-point numbers to enable it request for less storage and more accurate.

Major component of GA include initial population, natural selection, mating and mutation (Figure 1).

Initial population

Initial population provides the GA with a large sampling of search space, though not all population makes up the next iterative population.

Natural selection

At this stage, some of the chromosomes are discarded based on survival of the fitness. The best then survive to the next generation.

Mating

At the stage, attributes not in the master population are defined and prevents like GA from converging too fast.

Initialization of IPFC FACT controllers

Applying FACTS devices to power flow study results in non-linear equations, which is initialized to ensure that there quadratic convergent solutions when N-R algorithm is used. This is done by choosing 1.0 pu voltage and 0 phase angle.

Optimal Location of FACTS Devices using GA Fitness Function

Locating these devices optimally during normal and overload conditions is achieved using GA in order to improve the overall performance of the transmission grid. The criteria for optimal placement depends on some fitness function that involves voltage profile, bus network, line parameters, voltage violation reduction, line loading conditions/ratings, active and reactive power limits of generators, system configuration and current system operating points.

Describing the fitness function mathematically gives

Min fitness F_T (A, B)

Subject to $E_T(A, B)=0.0$; $I_T(A, B) \leq 0.0$;

F_T (A, B)=Fitness function to be optimized; E_T (A, B)=Equality constraints (active and reactive power); I_T(A, B)=inequality constraints of the FACTS devices targeted at parameters ranges limits such as bus voltage, phase angle, active and reactive power generation. A=voltage magnitude and phase angles states of the electrical network, B=control variables to be optimized.

Bus voltage violation optimization

$$\mathrm{A_T}(\mathrm{A},\mathrm{B}) = \sum_{i=1}^{i=1N_B} F(V_B) \tag{1}$$

$$F(V_B) = 0 if\, 0.95 \leq Va \leq 1.05 \tag{2}$$

$$\text{Otherwise}\, F(V_B) = \log\varphi(F(V_B) * abs\left(\frac{\mathrm{Va(nominal)} - \mathrm{Va}}{\mathrm{V}a(nominal)}\right) * \left(\frac{1}{\mathrm{Iin}}\right) \tag{3}$$

Where:

$F(V_B)$=Violation function of bus voltage; V_a=Voltage magnitude at bus a; $V_{a\ (nominal)}$=nominal voltage magnitude at bus a; $\varphi(F(V_B)$= index value for percentage of bus voltage against the allowable limit;

Iin=integer coefficient to regulate voltage variations; N_B=number of buses in the system.

Overloaded lines violation optimization

$$A_T(A,B) = \sum_{i=1}^{i=1N_T} F\left(L_O\right) \tag{4}$$

$$F\left(L_O\right) = 0 if\ \ Ia\ operating \le Ia \max \max rate \tag{5}$$

Otherwise

$$F\left(L_0\right) \log \varphi(F\left(L_O\right) * abs\left(\frac{\mathrm{I}\left(\mathrm{MVA}\right)\mathrm{operating}}{\mathrm{I}\left(\mathrm{MVA}\right)\mathrm{max.rate})}\right)\left(\frac{\mathrm{I}\left(\mathrm{MVA}\right)\mathrm{operating}}{\mathrm{I}\left(\mathrm{MVA}\right)\mathrm{max.rate})}\right) * \left(\frac{1}{\mathrm{Iin}}\right) \tag{6}$$

Where: $F\left(L_0\right) = V$ iolation function of bus voltage

I_a=Current Volt-Ampere power in line a; $I_{a\ (\mathrm{max.rate})}$=Volt-Ampere maximum power rate of line a; $\varphi F\left(L_0\right) =$ Index value for percentage of allowable branch loadings; Iin=Integer coefficient to regulate overload conditions; N_T=Number of transmission lines in the network.

Line numbers	X_{TCSC}
33-40	-0.0654
45-41	-0.0732
49-1	-0.0341
32-34	-0.217
40-22	0.342
38-25	-0.1543
45-41	0.2343

Table 5: GA based IPFC placement.

Overloaded lines and bus voltages optimization

$$A_T\left(A,B\right) = \sum_{i=1}^{N_T} F\left(L_O\right) + \sum_{i=1}^{N_B} F\left(V_B\right) \tag{7}$$

Equality constraints

$$P_{FL} = P_G - P_D\ \left(V,\ \theta\right);\ Q_{GL} = Q_G - Q_D\ \left(V,\ \theta\right) \tag{8}$$

Inequality Constraints

Power limits of generation:

$$P_{G(a)}^{Min} \le P_{G(a)} \le P_{G(a)}^{Max}; Q_{G(a)}^{Min} \le Q_{G(a)} \le Q_{G(a)}^{Max}\ a=1,2,3\ldots\ldots n_G \tag{9}$$

Limits of bus voltages:

$$V_a^{Min} \le V_a \le V_a^{Max} \qquad a=1,2,3\ldots\ldots\ldots n_B \tag{10}$$

Limits of phase angles:

$$\delta_a^{Min} \le \delta_a \le \delta_a^{Max}\ a=1,2,3\ldots\ldots\ldots n_B \tag{11}$$

Limits of power lines:

$$P_{ab} \le P_{ab}^{Max}\ a=1,2,\ 3\ldots\ldots n_T \tag{12}$$

Limits of FACTS Devices:

IPFC:

$$V_{VR}^{Min} \le V_{VR} \le V_{VR}^{Max};\ V_{CR}^{Min} \le V_{CR} \le V_{CR}^{Max} \tag{13}$$

Results

The load flow result obtained without incorporating these FACTS devices is 90.30 MW + 53.30 Mvar and the weak buses outside the allowable tolerable limit were also identified with their per unit values [11]. When IPFC FACTS devices were then incorporated into the

Bus Number	Bus Name	PU Voltages	Angles (degrees)	Bus Number	Bus Name	PU Voltages	Angles (degrees)
1	Shiroro	1.040	-36.32	27	Benin north	1.043	-23.16
2	Afam	1.036	-24.45	28	Omotosho	1.052	-18.23
3	Ikot-Ekpene	1.040	-18.23	29	Eyaen	1.024	-9.34
4	Port-Harcourt	1.023	-13.34	30	Calabar	1.036	-7.34
5	Aiyede	1.036	-15.23	31	Alagbon	0.995	-10.56
6	Ikeja west	1.002	-23.41	32	Damaturu	0.962	-12.32
7	Papalanto	1.041	-16.23	33	Gombe	0.993	-22.15
8	Aja	1.022	-23.42	34	Maiduguri	0.961	-6.34
9	Egbin PS	1.038	-33.45	35	Egbema	1.033	-12.10
10	Ajaokuta	0.989	-9.15	36	Omoku	1.045	-26.21
11	Benin	1.030	-11.32	37	Owerri	1.023	-6.21
12	Geregu	1.042	-10.24	38	Erunkan	0.982	-14.23
13	Lokoja	1.025	-14.32	39	Ganmo	0.984	-23.03
14	Akangba	1.019	21.23	40	Jos	0.997	-10.41
15	Sapele	1.027	-21.12	41	Yola	0.994	-16.21
16	Aladja	1.001	-14.23	42	Gwagwalada	0.998	-23.21
17	Delta PS	1.047	-11.34	43	Sakete	0.986	-9.45
18	Alaoji	1.037	-9.39	44	Ikot-Abasi	1.024	-11.45
19	Aliade	1.039	-23.43	45	Jalingo	0.959	-6.11
20	New Haven	1.055	-13.58	46	Kaduna	0.992	-10.23
21	New Haven South	0.965	-19.31	47	Jebba GS	1.023	-11.22
22	Makurdi	0.981	-16.62	48	Kano	0.994	-11.25
23	B-kebbi	0.988	9.46	49	Katampe	1.001	-9.28
24	Kainji	1.014	-11.45	50	Okpai	1.034	-23.15
25	Oshogbo	1.046	-18.34	51	Jebba	1.045	-17.37
26	Onitsha	1.022	-29.23	52	AES	1.023	-32.11

Table 6: Voltages and Angles with IPFC at Location Specified by GA.

		Line Flows with FACTS Devices (IPFC)				**Losses with FACTS DEVICES (IPFC)**	
Connected Bus		**Sending End**		**Receiving End**		**Losses**	
FROM	**TO**	**P_{SEND}(pu)**	**Q_{SEND}(pu)**	**$P_{RECEIVED}$(pu)**	**$Q_{RECEIVED}$(pu)**	**Real Power Loss (pu)**	**Reactive Power Loss(pu)**
49	1	0.1181	-0.0772	-0.1199	0.0678	0.0018	0.0094
14	6	-0.1939	-0.1210	0.1934	0.1204	0.0005	-0.0006
2	18	-0.0440	-0.0296	0.0434	0.0302	-0.0006	0.0006
2	3	0.0046	0.0028	-0.0040	-0.0024	0.0006	-0.0006
2	4	-0.0039	0.0022	0.0044	-0.0030	-0.0005	0.0008
16	15	0.0526	-0.0563	-0.0518	0.0558	-0.0008	0.0005
5	25	-0.1621	0.0986	0.1627	-0.0978	0.0006	-0.0008
5	6	-0.0212	-0.0140	0.0209	0.0138	0.0003	0.0002
5	7	-0.0277	-0.0176	0.0271	0.0170	0.0006	0.0006
8	9	-0.0929	0.0679	0.0858	0.0619	0.007	0.006
8	31	-0.0181	-0.0115	0.0176	0.0111	0.0005	0.0004
10	11	-0.0196	-0.0134	0.0177	0.0126	0.0019	0.0008
10	12	0.0245	0.0158	-0.0241	-0.0152	0.0004	0.0006
10	13	-0.0284	-0.0177	0.0279	0.0180	0.0005	0.0003
16	17	0.1306	0.0162	-0.1315	-0.0161	0.0009	0.0001
18	26	0.2163	-0.1781	-0.2169	0.1784	0.0006	0.0003
18	3	0.0451	0.0299	-0.0467	-0.0304	0.0016	0.0005
18	37	-0.0147	-0.0111	0.0152	0.0116	0.0005	0.0005
19	21	-0.0078	-0.0050	0.0084	0.0046	-0.0006	-0.0004
19	22	0.0032	0.0058	-0.0028	-0.0060	-0.0004	0.0002
23	24	-0.0878	-0.0543	0.0881	0.0554	0.0003	0.0011
11	6	0.0157	0.0121	-0.0150	-0.0124	0.0007	-0.0003
11	15	-0.0249	0.0586	0.0257	-0.0581	0.0008	0.0005
11	17	-0.0604	0.0541	0.0601	-0.0536	0.0003	0.0004
11	25	0.0178	-0.0120	- 0.0174	0.0160	-0.0004	-0.0004
11	26	0.0249	0.0184	-0.0251	-0.0184	-0.0002	0.0001
11	27	0.0384	-0.0295	-0.0381	0.0291	-0.0003	0.0004
11	9	-0.0913	-0.0767	0.0907	0.0761	-0.0006	0.0006
11	28	0.0484	0.0341	-0.0482	-0.0338	-0.0002	0.0003
27	29	0.0301	0.0169	-0.0297	-0.0152	-0.0004	0.0017
30	3	0.0293	0.0192	-0.0295	-0.0189	-0.0002	0.0003
32	33	0.0360	0.0231	-0.0356	-0.0225	-0.0004	-0.0006
32	34	0.0479	0.0345	-0.0474	-0.0340	-0.0006	0.0005
35	37	0.0172	0.0103	-0.0150	-0.0094	-0.0022	-0.0009
35	36	0.0112	0.0089	-0.0113	-0.0091	-0.0001	-0.0002
9	6	0.2182	0.1539	-0.2148	-0.1541	0.0034	-0.0002
	38	0.2634	0.1647	-0.2605	-0.1601	0.0029	-0.0001
38	6	0.2611	0.1589	-0.2601	-0.1588	0.0010	-0.0046
39	25	0.1137	-0.4055	-0.1128	0.4053	0.0009	-0.0002
39	51	0.2040	0.2348	-0.2012	-0.2344	0.0028	-0.0004
33	40	0.0679	0.1203	-0.0674	-0.1197	0.0005	-0.0006
44	41	0.0784	0.0999	-0.0782	-0.0996	-0.0002	-0.0003
42	49	-0.0109	-0.0168	0.0103	0.0164	-0.0006	-0.0004
42	13	0.0315	0.0184	-0.0311	-0.0177	-0.0004	0.0007
42	1	-0.0177	-0.0111	0.0175	0.0105	0.0002	0.0006
6	25	-0.0175	0.0262	0.0170	-0.0257	0.0005	0.0005
06	28	-0.0474	-0.0335	0.0476	0.0331	0.0002	0.0004
6	7	0.0288	0.0184	-0.0283	-0.0176	0.0005	-0.0008
6	43	0.0356	0.0197	-0.0351	-0.0191	-0.0005	-0.0006
44	3	0.0450	0.0328	-0.0444	-0.0325	0.0006	0.0003
3	21	0.0493	0.0309	-0.0491	-0.0307	-0.0002	0.0002
45	41	0.0810	-0.1108	-0.0806	0.1102	-0.0004	0.0006
51	25	0.2645	-0.3288	-0.2585	0.3220	0.0062	0.0068
51	47	-0.1669	0.6052	0.1671	-0.6038	0.0002	0.0014
51	24	-0.2841	0.0711	0.2836	-0.0705	0.0005	0.0006
51	1	0.1681	-0.2524	-0.1673	0.2476	0.0016	0.0048
40	46	0.0251	0.0073	-0.0243	-0.0068	0.0008	-0.0005
40	22	-0.0016	-0.0050	0.0010	0.0020	0.0006	0.0030

46	1	-0.1504	-0.1170	0.1501	0.1165	0.0003	0.0005
46	48	0.1213	0.0802	-0.1192	-0.0799	0.0021	-0.0003
20	26	-0.1282	0.0782	0.1248	0.0711	0.0034	0.0071
20	21	-0.0461	-0.0255	0.0456	0.0251	0.0005	0.0004
50	26	-0.2203	0.0572	-0.2103	-0.0472	0.010	0.0070
26	37	0.0144	-0.0114	-0.0150	0.0107	0.0006	-0.0007
Total Transmission Losses						**0.0443**	**0.0783**

Table 7: Power Flow Result Obtained with IPFC usingGA for Optimal Placement of the Device.

Newton-Raphson (N-R) power flow algorithm in Matlab environment and optimally sizing and placement on the identified lines(Gombe-Jos,Jalingo-Yola,Katamkpe-Shiroro,Damaturu-Miaduguri,Jos-Makurdi and Erunkan-Oshogbo transmission lines as shown in Table 5 using GA, results obtained are shown in Tables 6 and 7 respectively.

Discussion

The obtained results based on the test case (Nigeria 330 kv integrated power system) showed that there was obvious improvement in voltage profile and improvement in power transfer in the network. The essence of using GA is to ensure that they are optimally placed in the network since these devices are very expensive. The factors that were considered in achieving these optimality involves the generator limits (active and reactive power limits), bus data, line data and transformers sizes. These results have shown that the placement of these devices for compensation in the network has saved 50 MW of active power. These placements are achieved using GA approach. The power loss without the FACTS devices is 90.30 MW+J53.94 MVAR. Upon optimal placement of FACTS devices (IPFC) on Gombe-Jos, Kaduna-Jos, Kaduna-Kano, Kaduna-Shiroro and Newhaven-Onitsha transmission lines as shown in Table 5, power losses reduced to 44.30 MW+J78.30 MVAR. The weak bus voltages as identified in [13] were also improved to the allowable tolerable limits of 0.95 pu-1.05 pu as shown in Table 6. This table as also shown that the entire 52 buses and sixty four transmission lines.

Conclusion/Recommendation

Considering the total cost of building generating stations, transmission lines and obtaining right of ways, it becomes very pertinent for Nigeria to use these electronic based power electronic devices. As at the time of investigating and making these findings, Nigeria power network is yet to consider the use of these devices in improving the efficiency even with the enormous transformations going on in this sector. This will do the country good if such important devices are considered and incorporated into her power network

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