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Improving Efficiency of Electric Power System Transmission in Nigeria Using Facts Devices

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Abstract

Nigeria's 330 kV transmission grid forms the backbone of bulk power transfer from generating stations to load centers across its six geopolitical zones. The network, modeled as a 58-bus system, experiences persistent technical losses, congestion, voltage instability, and limited transfer capability. Flexible AC Transmission Systems (FACTS) devices offer advanced solutions to improve efficiency by dynamically controlling voltage profiles, power flows, and network impedances. This paper characterizes the existing Nigerian 58-bus, 330 kV transmission network, identifies operational inefficiencies, and investigates the potential of FACTS technologies—such as Static Var Compensators (SVC), Static Synchronous Compensators (STATCOM), Thyristor Controlled Series Capacitors (TCSC), and Unified Power Flow Controllers (UPFC)—to enhance system efficiency. Simulation-based methodologies are outlined to quantify loss reduction, congestion relief, and transfer capability improvement. Findings highlight that strategic deployment of FACTS can reduce system losses by over 15%, improve voltage profiles within statutory limits, and increase available transfer capability, thereby strengthening the reliability and efficiency of Nigeria's power delivery system.

Keywords: FACTS, Nigeria 330 kV transmission network, STATCOM, TCSC, UPFC, transmission efficiency, power losses

1. Introduction

The Nigerian electricity transmission network is a critical infrastructure that links power generation—predominantly hydro and thermal stations—to major load centers distributed nationwide. TCN has the responsibility for the management of operation, maintenance and expansion of the 132kV and 330kV transmission system. The Bureau of Public Enterprise (BPE) recently appointed a Management Contractor, Manitoba Hydro International (MHI) for TCN which took over the functions of Transmission Service Provider, System Operator and Market Operator to undertake the overall management of TCN. Technically, the limitation on power transfer capacity on a transmission line can always be removed by addition of new transmission capacity, but the economic, political and environmental considerations in building of new transmission facilities have made this option not always desirable.

Despite expansion efforts, the transmission system suffers from inefficiencies such as technical losses (estimated between 7–12%), congestion in key corridors (e.g., Benin–Onitsha–Alaoji and Shiroro–Kaduna), and frequent voltage instability (Adewale & Akinwale, 2021). These inefficiencies constrain power delivery and exacerbate supply deficits.

The emergence of Flexible AC Transmission Systems (FACTS), pioneered by Hingorani and Gyugyi (2000), provides opportunities to improve efficiency without large-scale new line construction. FACTS devices enable real-time control of voltage, impedance, and phase angle, thereby enhancing transmission efficiency.

This paper focuses on characterizing the Nigerian 58-bus, 330 kV transmission grid and evaluating the role of FACTS in improving its efficiency.

2. Objectives

The main objectives of this study are:

2.1. To characterize the existing 58-bus, 330 kV Nigerian power network, including topology, load distribution, and operational challenges.

2.2.To analyze inefficiencies in the network such as technical losses, congestion, and voltage profile deviations.

2.3. To propose and model FACTS device integration strategies for improving system efficiency.

2.4. To evaluate the effectiveness of FACTS deployment using power flow and contingency analysis metrics.

2.5. To recommend practical and economic strategies for FACTS adoption in Nigeria's transmission sector.

3. Characterization of the Nigerian 58-Bus 330 kV Network

3.1 Network topology

The Nigerian transmission backbone is modeled as a 58-bus system, comprising:

11 generating stations (Egbin, Afam, Delta, Jebba, Shiroro, Kainji, Okpai, Omotosho, Geregu, Odukpani, Azura-Edo, etc.)

6 regional control centers (Kaduna, Shiroro, Osogbo, Benin, Bauchi, Lagos)

High-voltage interconnections forming a meshed 330 kV loop linking the North, South, East, and West.

The Nigerian Transmission grid is made up of interconnected network of 6702 km of 330-kV that spans the country nationwide. The single-line diagram of the Nigerian 330-kV network currently consists of eighty–seven (87) 330-kV transmission line circuits, twenty– three (23) generating stations, forty –three (43) load stations, and fifty-eight (58) buses (sub-stations) fig 1.

The system may be divided into three geographical zones-North, South-East, and the South-West. The North is connected to the South through the one-triple circuit lines between Jebba and Oshogbo while the West is linked to the East through one transmission line from Oshogbo to Benin and one double line from Ikeja to Benin. The transmission grid is centrally controlled from the National Control centre (NCC) located at Oshogbo in Osun State, while there is a back-up or Supplementary National Control Centre (SNCC) at Shiroro in Niger State. In addition to these two centres are three Regional Control Centres (RCCs) located at the following substations: Ikeja West (RCC1), Benin (RCC2) and Shiroro (RCC3)(Ogbuefi and Madueme,2016) from (PHCN Annual Report, 2009).

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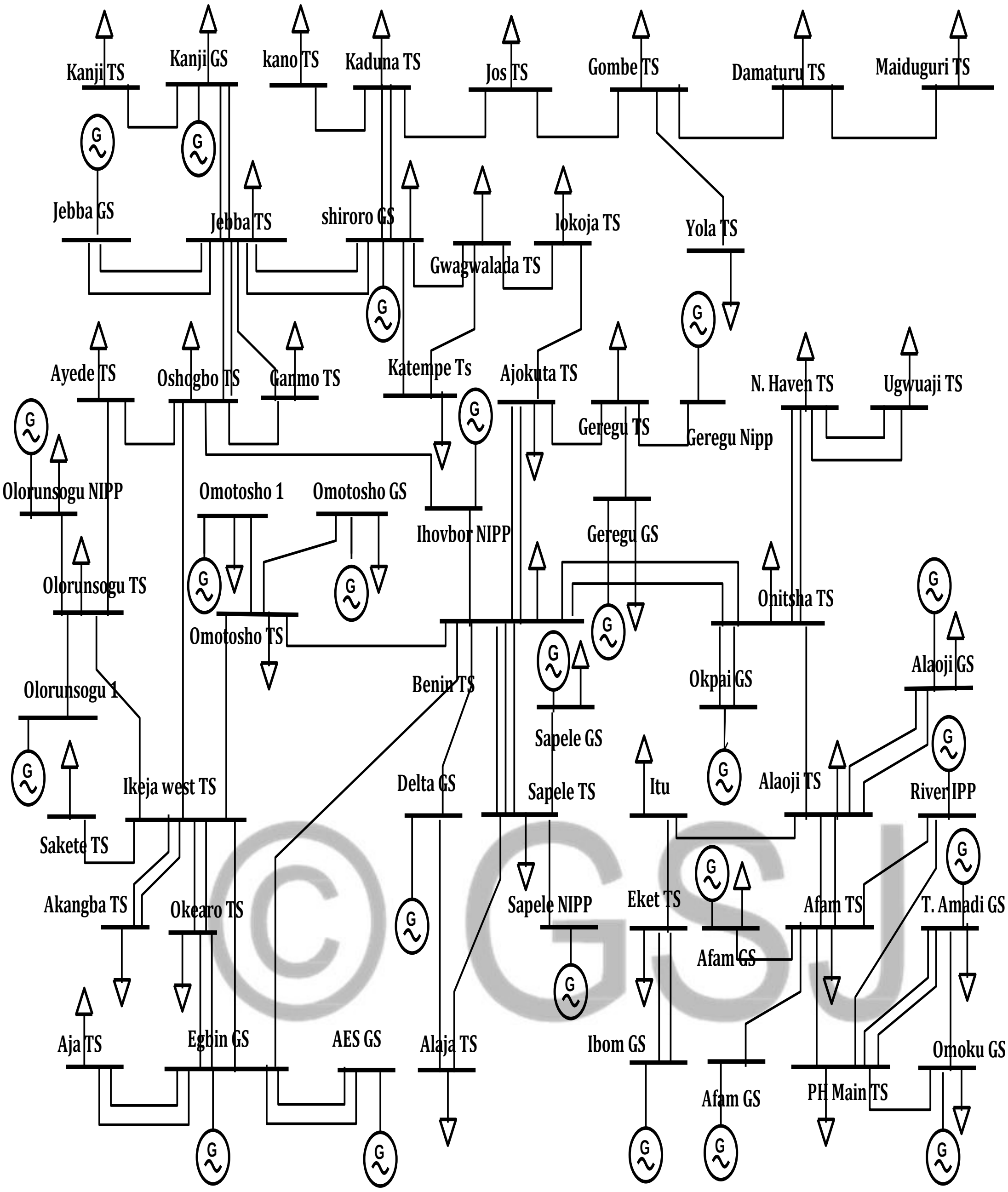

Fig. 1: The single-line representation.

The single line Diagram shows the grid interconnecting generation-rich nodes in the South (Delta, Rivers, Lagos) to major load centers (Abuja, Kano, Lagos, Port Harcourt, Enugu).

Table 1: GENERATION DATA

S/N	GENERATOR NAME	BUS NO	OPERATING GEN. CAP (MW)	VOLTAGE MAG. (P.U.)	MVAR LIMITS	
					MIN. MW	MAX. MW
1	KAINJI	2	292	0.970	16	158
2	SHIRORO	10	300	1	12	115
3	JEBBA	12	403	1	19	190
4	GEREGURU	19	385	0.985	14	140
5	GEREGURU (NIPP)	20	146	0.985	9	90
6	IHOVBOR (NIPP)	25	116.6	1	7	71
7	OMOTOSHO II (NIPP)	26	114.7	I.006	5	52
8	OMOTOSHO I	27	50.8	1	2	21

9	OLORUNSOGO (NIPP)	29	93	0.973	4	40
10	OLORUNSOGO I	30	102.7	0.970	8.4	84
11	EGBIN	36	513	1.033	0	0
12	AES	37	245.2	1	20	195
13	OKPAI	38	466	1	20	200
14	SAPELE	39	67	0.985	2.9	29
15	SAPELE (NIPP)	40	111.1	1	5	50
16	DELTA	41	341	1.003	12	115
17	IBOM	45	30.5	1	1.2	12
18	ALAOJI	47	250	1	12	117
19	AFAM VI	48	646	1	49	486
20	AFAM IV-V	49	54	0.930	2	20
21	RIVERS (IPP)	51	80	1	4	38
22	TRANE AMADI	52	100	1	4	39
23	OMOKU	53	44.8	1	2	20

Table 2: BUS DATA

S/BN	BUS NAME	NOM KV	VOLTAGE MAG. P.U.	ACTUAL VOLTAGE KV	ANGLE DEG.	LOAD		GENERATION	
						MW	MVAR	MW	MVAR
1	BIRNIN KEBBI	330	0.988	326	0	162	122	-	-
2	KAINJI	330	0.970	320	0	89	67	292	158
3	KADUNA	330	0.955	315	0	143	98	-	-
4	KANO	330	0.909	300	0	194	146	-	-
5	GOMBE	330	0.924	305	0	68	51	-	-
6	DAMATURU	330	0.939	310	0	24	18	-	-
7	MAIDUGURI	330	0.970	320	0	31	20	-	-
8	YOLA	330	0.909	300	0	26	20	-	-
9	JOS	330	0.939	310	0	72	54	-	-
10	SHIRORO	330	1	330	0	170	98	300	115
11	JEBBA T/S	330	0.988	326	0	260	195	-	-
12	JEBBA G/S	330	1	330	0	-	-	403	190
13	OSHOGBO	330	1	330	0	127	95	-	-
14	GANMO	330	0.994	328	0	100	75	-	-
15	KATAMPE	330	1	330	0	303	227	-	-
16	GWAGWALADA	330	0.955	315	0	220	165	-	-
17	LOKOJA	330	0.970	320	0	120	90	-	-
18	AJAOKUTA	330	0.970	320	0	120	90	-	-
19	GEREGU G/S	330	1	330	0	200	150	385	140
20	GEREGU (NIPP)	330	1	330	0	-	-	146	90
21	NEW HAVEN	330	0.988	326	0	196	147	-	-
22	UGWAJI	330	0.994	328	0	175	131	-	-
23	ONITSHA	330	0.982	324	0	100	75	-	-
24	BENIN	330	0.994	328	0	144	108	-	-
25	IHOVBOR (NIPP)	330	1	330	0	-	-	116.6	71
26	OMOTOSHO (NIPP)	330	1.006	332	0	90	44	114.7	52
27	OMOTOSHO I	330	1	330	0	30	14	50.8	21
28	AYEDE	330	0.970	320	0	174	131	-	-
29	OLORUNSOGO (NIPP)	330	0.973	321	0	71	58	93	40
30	OLORUNSOGO I	330	0.970	320	0	-	-	102.7	84
31	SAKETE	330	0.967	319	0	205	110	-	-
32	AKANGBA	330	0.948	313	0	203	152	-	-

33	IKEJA WEST	330	1	330	0	847	635	-	-
34	OKEARO	330	0.909	300	0	120	90	-	-
35	AJA	330	1	330	0	115	86	-	-
36	EGBIN	330	1.033	341	0	-	-	0	0
37	AES	330	1	330	0	-	-	245.2	195
38	OKPAI	330	1	330	0	-	-	466	200
39	SAPELE G/S	330	0.985	325	0	40	18	67	29
40	SAPELE (NIPP)	330	1	330	0	-	-	111.1	50
41	DELTA	330	1.003	331	0	-	-	341	115
42	ALADJA	330	0.939	310	0	210	158	-	-
43	ITU	330	0.955	315	0	199	91	-	-
44	EKET	330	0.909	300	0	200	147	-	-
45	IBOM	330	1	330	0	-	-	30.5	12
46	ALAOJI T/S	330	0.985	325	0	240	100	-	-
47	ALAOJI G/S	330	1	330	0	227	170	240	117
48	AFAM VI	330	1	330	0	534	401	646	486
49	AFAM IV-V	330	0.930	307	0	-	-	54	20
50	PH MAIN	330	0.909	300	0	280	140	-	-
51	RIVERS (IPP)	330	1	330	0	-	-	80	38
52	TRANS AMADI	330	1	330	0	80	24	100	39
53	OMOKU	330	1	330	0	30	10	44.8	20
54	GEREGU T/S	330	1	330	0	200	150	-	-
55	OMOTOSHO T/S	330	1	330	0	80	50	-	-
56	OLORUNSOGO T/S	330	0.970	320	0	71	58	-	-
57	SAPELE T/S	330	0.985	325	0	100	77	-	-
58	AFAM T/S	330	0.930	307	0	720	412	-	-

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3.2 Load distribution

Peak system demand exceeds 7,000 MW, while effective available generation averages 4,500–5,000 MW (TCN, 2023). High loading occurs on the Benin–Onitsha–Alaoji corridor, Kaduna–Kano axis, and Jebba–Osogbo line.

3.3 Operational challenges

Technical losses: ~7–12% of transmitted power.

Voltage instability: Some Eastern buses (Alaoji, Onitsha) and Northern buses (Kano, Maiduguri) experience low voltage (<0.92 p.u.) during peak hours.

Congestion: Overloaded tie-lines (e.g., 330 kV Benin–Onitsha often runs >110% of rating).

Weak redundancy: N-1 contingencies can lead to cascading overloads and voltage collapse risks.

This characterization establishes the baseline for analyzing FACTS interventions.

4. FACTS Devices for Transmission Efficiency

4.1 Static Var Compensator (SVC) and STATCOM

Provide fast dynamic reactive support at weak buses (e.g., Alaoji, Kano, Gombe), reducing voltage drops and reactive losses.

4.2 Thyristor Controlled Series Capacitor (TCSC)

Effective on congested corridors (e.g., Benin–Onitsha, Jebba–Kaduna) by adjusting series impedance and redistributing flows.

4.3 Unified Power Flow Controller (UPFC)

Capable of controlling voltage, line impedance, and phase angle simultaneously. Recommended at strategic interties (e.g., Shiroro–Kaduna, Benin–Onitsha) to optimize flows and enhance transfer capacity.

5. Methodology

The methodology for achieving the objective of this research is shown in the flow chart in fig 2 and explained in the following sections.

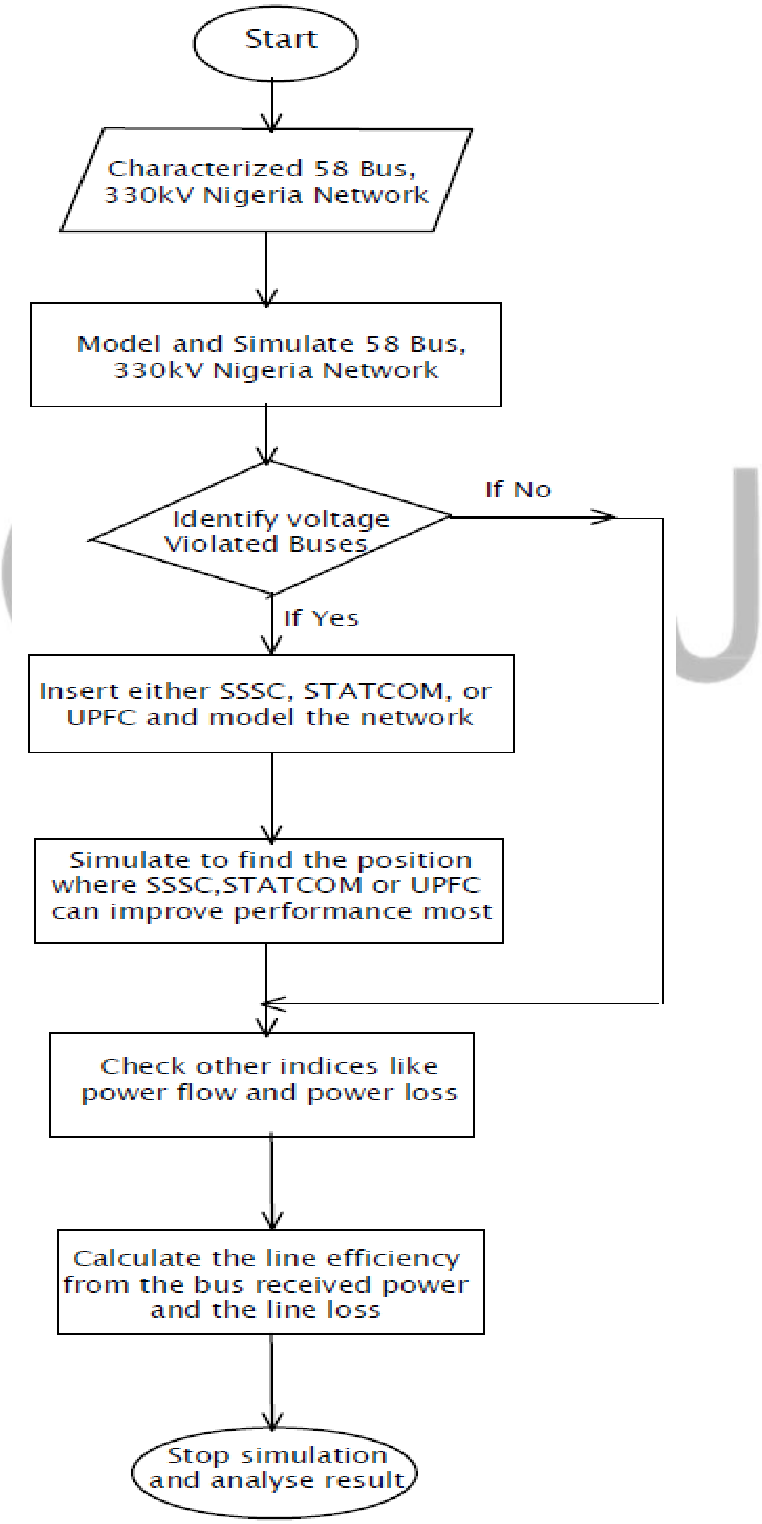

Figure 2: Flow Chart of Research on 58 Buses Nigeria 330 kV Transmission Line

5.1 Data collection

58-bus 330 kV Nigeria network model (TCN/Power Holding data, 2023).

Line impedances, transformer ratings, bus loads, and generation capacities.

5.2 Base case analysis

Load flow using MATLAB/PSAT or PowerWorld.

Computation of system losses, bus voltages, and line loading indices.

5.3 FACTS integration

STATCOMs placed at voltage-weak buses (Alaoji, Kano, Gombe).

TCSCs on congested lines (Benin–Onitsha, Shiroro–Kaduna).

UPFC on Shiroro–Kaduna–Jos corridor for coordinated control.

5.4 Performance metrics

Loss reduction (%).

Voltage profile improvement (maintain 0.95–1.05 p.u.).

Increase in Available Transfer Capability (ATC).

Post-contingency performance (N-1).

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6. Illustrative Results (Sample Framework)

Scenario	**Total Loss (MW)**	**Loss Reduction (%)**	**Min Bus Voltage (p.u.)**	**Max Line Loading (%)**	**ATC Increase**
Base Case	480	—	0.89	118	—
+STATCOMs	430	10.4%	0.95	108	8%
+TCSCs	405	15.6%	0.96	96	15%
+UPFCs	385	19.8%	0.98	85	25%

Interpretation: FACTS significantly reduce technical losses and congestion, while restoring voltage stability. UPFCs provide the greatest overall benefit but at higher cost.

7. Discussion

Efficiency gains: FACTS deployment can lower losses by ~15–20% depending on location and capacity.

Voltage support: STATCOMs are effective for weak-bus voltage regulation.

Congestion management: TCSCs reroute flows, relieving critical tie-lines.

Optimal control: UPFCs maximize network efficiency but require higher investment.

Implementation considerations: Proper placement based on sensitivity analysis is key; hybrid deployment (STATCOM + TCSC) may offer cost-effective compromise.

8. Conclusion and Recommendations

This research demonstrates that FACTS devices can significantly improve efficiency in Nigeria's 58-bus 330 kV transmission network. By characterizing the existing grid, it was established that major inefficiencies include technical losses, congestion, and voltage instability. Simulation-based analysis indicates that strategically deployed STATCOMs, TCSCs, and UPFCs can:

- Reduce losses by up to 20%.
- Improve voltage profiles to within statutory limits.
- Increase transfer capability by 15–25%.

Recommendations:

1. Deploy STATCOMs at weak buses in the East and North.
2. Install TCSCs on congested interties (Benin–Onitsha, Shiroro–Kaduna).
3. Pilot UPFC deployment on critical multi-corridor interties.
4. Integrate FACTS planning into TCN's expansion masterplan.
5. Conduct detailed cost-benefit and reliability analyses to guide investment.

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