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# Analysis of Power Losses on Sub-Transmission Lines in Akure Transmission Network

Arotiowa Joel Ilesammi[1]; Tpl Akomolafe Olawale Tayo[2]; Afolabi Ezekiel Bode[3]; Ayanleke Bolaji Blessing[4]; Aminu Odunayo Peter[5]; Olakunle Taiwo Joshua[6]; Odeyemi Adegboyega Bidemi[7]; Ogundare Alaba Georger[8]; Adepitan Oluwaseun David[9]

[1,2,3,4,5,6,7,8,9]Centre for Space Life Sciences, National Space Research and Development Agency (Nasrda) University of Ibadan Campus, Ibadan, Oyo State, Nigeria

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**Abstract: This research work comprehensively determines and analyzes the electrical power losses incurred within the Akure sub-transmission network (132 kV / 33 kV system) through rigorous mathematical evaluation, line parameter modeling, and multi-year graphical trend analysis based on empirical operational data obtained from the Power Holding Company of Nigeria (PHCN), Akure Business Unit. The empirical findings reveal that actual recorded power losses from the sending-end to receiving-end stations vastly exceed the theoretical, design-calculated transmission losses. A deep diagnostic investigation identified that this severe disparity is primarily driven by physical technical defects: broken strands of overhead conductors, loose and burnt jumper connections, unauthorized substitution of damaged line sections with undersized conductor wires during emergency line repairs, poorly married or improper twisting joints of stranded conductors resulting from substandard technical workmanship, and severe sustained transformer overloading. Additional contributing operational and environmental factors—including high winding temperatures, failing cooling systems, and overgrown vegetation contacting high-tension corridors—are thoroughly documented. Strategic technical and operational interventions are recommended to restore grid reliability and mitigate energy dissipation.**

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## I. INTRODUCTION

In modern electrical power utility engineering, energy loss during transmission and distribution represents one of the most critical indicators of operational efficiency and network health. Power losses in an electrical network are fundamentally divided into primary sub-systems: transmission, sub-transmission, primary distribution, and secondary distribution lines. Statistically, the major proportion of overall utility energy losses occurs within primary and secondary distribution lines, whereas high-voltage transmission and sub-transmission networks traditionally account for a smaller percentage of baseline technical losses under ideal design conditions (Gupta, 1998). Consequently, primary and secondary distribution infrastructure must be systematically planned, modeled, and continuously monitored to ensure operational energy dissipation remains within strict acceptable standard margins. Nevertheless, as bulk electrical energy is transferred across vast geographical spans from central power generation stations down to municipal distribution centers, significant power and energy losses are inevitably incurred across the high-voltage transmission and sub-transmission corridors.

These power losses occurring within an electrical power system grid are broadly classified into two distinct technical categories:

- *Technical Losses:*

These represent the inherent physical dissipation of electrical power caused by the intrinsic physical properties, electrical resistance, inductive reactance, and electromagnetic characteristics of the network components and high-voltage equipment involved in conveying power. Technical losses are physically measurable and predictable through standard circuit equations, including ohmic conductor heating ($I^2R$ losses), electromagnetic core losses in transformers (hysteresis and eddy currents), skin effect, and atmospheric corona discharges.

- *Non-Technical Losses:*

These represent energy losses caused by external operational actions, administrative errors, unmetered usage,

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illegal power tapping, commercial theft, metering inaccuracies, and system conditions that theoretical technical loss computations fail to capture. Non-technical losses are significantly harder to quantify precisely because they represent unaccounted-for energy flows that lack explicit logging instrumentation within routine station operations.

Understanding the exact mechanics and magnitude of both technical and non-technical loss components on sub-transmission corridors is essential for utility engineers, grid operators, and energy planners, as line dissipation directly impacts system capacity, voltage stability, utility financial viability, and regional power quality.

### *A. Electricity Development in Nigeria: Historical Perspective*

The historical evolution of electric power infrastructure in Nigeria spans over a century of technological adaptation, administrative restructuring, and network expansion. The genesis of commercial electricity generation in Nigeria dates back to 1898, when the first isolated power generation plant was installed in the colony of Lagos, operating with a modest generating capacity to serve localized municipal requirements.

To centralize, integrate, and standardize power utility operations across the country, the Federal Government enacted the landmark Electricity Corporation of Nigeria (ECN) Ordinance No. 15 of 1950. This statutory ordinance consolidated all existing electricity undertakings which were previously managed under the Public Works Department alongside various isolated municipal and local authority power undertakings across the country, bringing them under a unified national utility body.

As national demand for bulk power escalated during the post-independence industrialization era, the Federal Parliament established the Niger Dams Authority (NDA) in 1962. The NDA was charged with the responsibility of constructing, commissioning, and maintaining major hydro-electric dams and associated civil works along the River Niger basin. The construction of Nigeria's flagship hydroelectric project, the Kainji Dam, commenced in March 1964 and was successfully completed on schedule in December 1968, injecting substantial bulk hydro generation into the emerging national grid.

In September 1967, recognizing the operational imperative of unifying generation and transmission infrastructure, the Federal Military Government initiated plans to merge the ECN and the NDA into a single unified public utility authority. An international consulting firm, Shawmut Limited of Canada, was commissioned to conduct a comprehensive technical, financial, and organizational feasibility study regarding the proposed structural merger. Shawmut Limited submitted its final technical recommendations in November 1971.

Consequently, by virtue of Decree No. 24 promulgated on June 29, 1972, the Electricity Corporation of Nigeria (ECN) and the Niger Dams Authority (NDA) were officially merged to create the National Electric Power Authority (NEPA). NEPA formally commenced operational existence on April 1, 1972, with the statutory mandate to maintain an efficient, coordinated, continuous, and economical system of electricity supply across all geographical regions of Nigeria. On January 6, 1973, a General Manager was appointed to oversee national grid unification.

In subsequent years, as part of market unbundling and power sector reform, NEPA was restructured and renamed the Power Holding Company of Nigeria (PHCN). At its foundational stage, the core bulk generation capacity of the national grid relied on four major baseline power stations:

- *Baseline Generation Infrastructure of the Early National Grid*

- Ijora Thermal Power Station: Installed capacity of 60 MW (steam/gas turbine generation in Lagos).
- Afam Thermal Power Station: Installed capacity of 811 MW (natural gas turbine generation in the Niger Delta).
- Delta Thermal Power Station (Ughelli): Installed capacity of 1,208 MW (gas turbine power plant).
- Kainji Hydroelectric Power Station: Installed capacity of 760 MW (hydro-power station on the River Niger).

## II. LITERATURE REVIEW & GRID STRUCTURE

High-voltage transmission lines possess key structural and operational features: they are engineered to convey massive quantities of bulk electrical energy over extensive physical distances at elevated voltage levels to minimize line current and line losses (Raina and Singal, 1995). National transmission backbones are standardly operated at extra-high voltages (EHV) of 330 kV and high voltages (HV) of 132 kV. The selection of system voltage levels for bulk power delivery is fundamentally governed by the total active power magnitude to be transferred and the total physical transmission distance.

Transmitting electrical power at extra-high voltages significantly reduces the current magnitude required for a given active power payload ($P = \sqrt{3} \cdot V \cdot I \cdot \cos \varphi$), thereby exponentially decreasing resistive Joule heating losses ($P_{loss} = 3\ I^2R$) along the line conductors. An integrated power system architecture fundamentally comprises four interconnected operational functional blocks:

- Generation: The fundamental conversion of primary energy resources (hydro, natural gas, steam, solar) into electrical energy, standardly generated at generator terminal voltages between 11 kV and 25 kV.
- Transmission: The bulk transportation of generated electrical power across regional load centers using extra-high-voltage line networks (330 kV and 132 kV grid backbones).
- Distribution: The conveyance of stepped-down bulk electrical energy from regional transmission substations to industrial, commercial, and residential consumers via sub-

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transmission (33 kV) and primary distribution (11 kV) networks.
- Consumption: The end-user utilization of electrical energy, where it is converted into mechanical, thermal, optical, or chemical work.

Within the Nigerian national grid architecture, electrical energy generated at 11 kV–25 kV is stepped up via generator transformers to 330 kV or 132 kV for transmission across the National Grid. At major regional transmission substations, high-voltage transformers step down 132 kV grid power to a 33 kV sub-transmission secondary level. This 33 kV sub-transmission network feeds local business district injection substations, where transformers step down the voltage to 11 kV. Finally, distribution transformers step down 11 kV power to secondary distribution lines operating at 415 V (three-phase, 4-wire) and 240 V (single-phase) for end-user consumers.

Technical literature confirms that line losses vary substantially based on the characteristics of connected load types. Power losses are highest when feeding constant-power loads and lowest when feeding constant-impedance loads. Furthermore, losses under mixed load conditions are demonstrably higher than under constant-power loads when the mixed load exhibits a strong constant-power characteristic (Journal of Electrical Engineering, Vol. 41/1). Klemen and Gorald (2000) demonstrated that excessive line losses are frequently induced by unbalanced and non-linear three-phase loads, where orthogonal current decomposition proves that non-active current components generate excessive line heating without contributing to useful energy delivery.

Additionally, Doug Whyte (1999) highlighted that high rates of technical loss are directly correlated with the physical quality and rated specification of installed line materials, current density, and environmental atmospheric conditions including ambient air temperature, wind velocity, and direction.

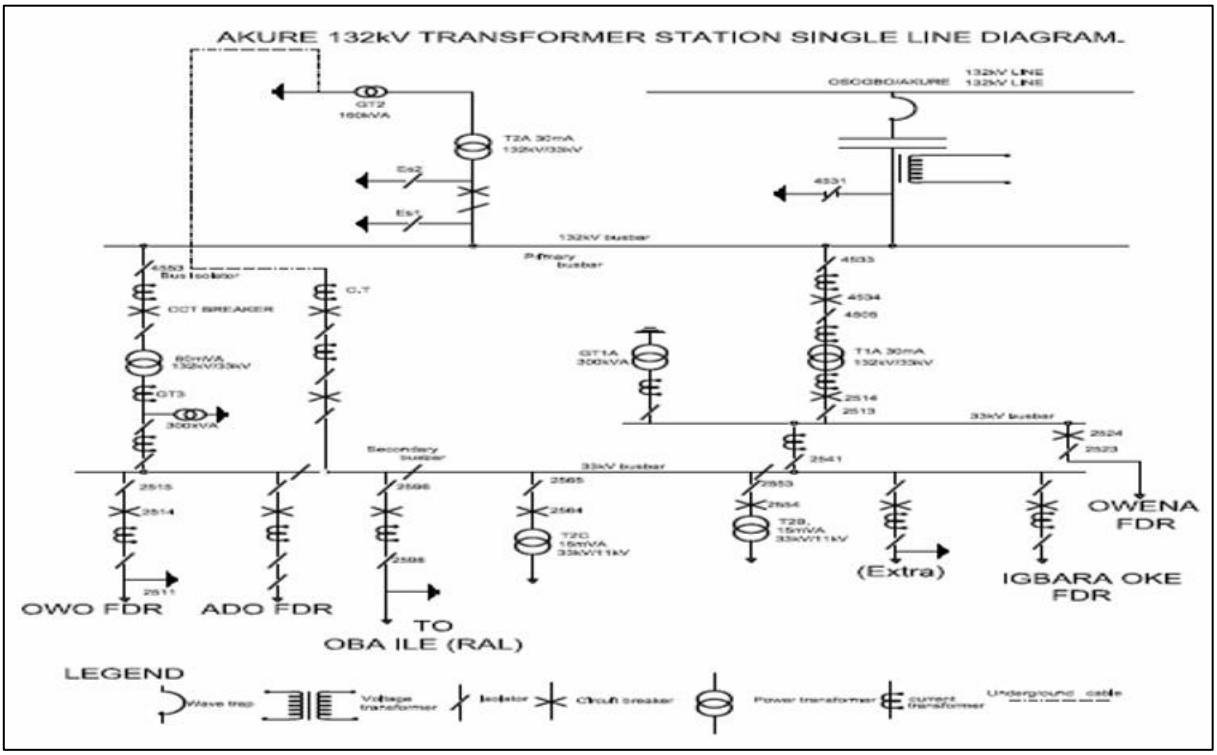


Fig 1 Akure 132KV Transformre Station Single Line Diagram

Table 1 Major Power Generation Stations Contributing to the Nigerian National Grid

| Station Name | Plant Type | Location / Category | Primary Fuel / Energy Source |
|---|---|---|---|
| Egbin Power Station | Thermal (Gas / Steam) | Lagos State | Natural Gas |
| Delta Power Station | Thermal (Gas Turbine) | Ughelli, Delta State | Natural Gas |
| Afam Power Station | Thermal (Gas Turbine) | Rivers State | Natural Gas |
| Sapele Power Station | Thermal (Gas / Steam) | Delta State | Natural Gas |
| Ijora Power Station | Thermal (Gas Turbine) | Lagos State | Natural Gas / Distillate |
| Kainji Hydro Station | Hydroelectric | Niger State | Water (River Niger) |
| Jebba Hydro Station | Hydroelectric | Kwara / Niger State | Water (River Niger) |
| Shiroro Hydro Station | Hydroelectric | Niger State | Water (Kaduna River) |
| IPP Stations (Geregu, Omotosho, Olorunsogo, AES, Okpai, Omoku) | Independent Power Producer (IPP) Gas Turbines | Various Locations (Kogi, Ondo, Ogun, Lagos, Delta, Rivers) | Natural Gas |

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## III. TECHNICAL LOSS MECHANICS IN POWER SYSTEMS

Technical power losses represent the physical dissipation of energy inherent to the flow of electric current through real physical conductors, transformers, switchgear, and line equipment. The primary physical loss components occurring on sub-transmission and transmission lines are categorized into three distinct phenomena:

➢ *Conductor Resistance ($I^2R$) Losses*

Conductor resistance loss (ohmic loss) constitutes the single largest component of total technical energy loss in overhead electrical power networks (Suriyamongkol, 2002). When electric current flows through a metallic conductor, the intrinsic electrical resistance of the material opposes electron motion, converting electrical energy into thermal energy that dissipates into the surrounding atmosphere. The total active power loss in a balanced three-phase transmission line is strictly proportional to the square of the line current and the effective high-frequency line resistance:

$$P_loss = 3 \cdot I^2 \cdot R$$

Where:

I = Line current flowing through each phase conductor (Amperes).

R = Total effective AC resistance per phase conductor (Ω).

It is vital to emphasize that total line power loss cannot be computed as $V^2 / R$ using line-to-line operational voltage, because V does not represent the actual potential drop along the physical length of the line conductor (Nagrath, 1987).

➢ *Radiation & Skin Effect Losses*

When alternating current (AC) flows through a physical conductor, it generates an internal and external time-varying magnetic flux. The internal magnetic flux linkages are denser near the central axis of the conductor than near its outer surface. Consequently, the inductive reactance along the inner concentric filaments of the conductor is higher than near the outer boundary. This non-uniform reactance forces the alternating current density to concentrate heavily near the outer surface ("skin") of the conductor—a phenomenon known as Skin Effect.

Skin effect effectively reduces the usable cross-sectional conduction area of the physical wire, thereby elevating its effective AC resistance (R_ac) above its static DC resistance (R_dc). According to Gupta (1993), the increase in effective line resistance due to skin effect in standard distribution and sub-transmission conductors is approximately 3% to 5%. Skin effect becomes increasingly severe in large-diameter conductors and at higher system operating frequencies.

➢ *Corona Effect Power Loss*

Corona discharge occurs when an overhead transmission line operates at a high voltage that exceeds the breakdown strength of the surrounding ambient air (disruptive critical voltage). The electric field intensity at the surface of the conductor ionizes the adjacent air molecules. When the potential gradient at the conductor surface exceeds the dielectric strength of dry air (approximately 30 kV/cm peak or 21.2 kV/cm RMS at standard temperature and pressure), the surrounding air becomes conductive.

This ionization causes a visible violet luminous glow around the conductors, accompanied by a distinct hissing noise, localized ozone generation, mechanical conductor vibration, and direct energy dissipation into the atmosphere. Because corona losses are generally negligible on line voltages below 100 kV under normal weather conditions (Gupta, 1993), corona loss is minor on 33 kV sub-transmission lines compared to 132 kV and 330 kV grid lines.

## IV. TRANSFORMER LOSS MECHANICS

Power transformers represent critical nodes in sub-transmission networks. Electrical energy losses in power transformers generate internal thermal energy that must be dissipated via oil circulation and cooling fans. Total transformer losses consist of two primary components: No-Load Losses (Core/Iron Losses) and Load Losses (Copper/Winding Losses).

➢ *No-Load Losses (Iron / Core Losses)*

No-load losses represent the baseline thermal power required to magnetize the transformer's laminated steel core whenever the unit is energized, regardless of whether the secondary winding is supplying load current. No-load losses depend strictly on applied system voltage and frequency, remaining virtually constant under normal operational conditions. Core loss consists of two physical phenomena:

- Hysteresis Loss: Power consumed in continuously re-orienting magnetic domains within the core material during each alternating current cycle. Hysteresis loss is directly proportional to frequency (f) and the peak magnetic flux density (B_max) raised to the Steinmetz exponent (B_max^1.6).
- Eddy Current Loss: Circulating electrical currents induced within the conductive steel core laminations by the alternating magnetic flux. Eddy current loss is proportional to the square of the frequency ($f^2$) and the square of peak flux density ($B_max^2$). It is minimized by utilizing thin, high-permeability silicon steel laminations coated with insulating varnish.

➢ *Load Losses (Copper / Winding Losses)*

Load losses vary directly with the square of the load current passing through the transformer windings. Load loss comprises two sub-components: ohmic resistance loss ($I^2R$) within primary and secondary copper/aluminum windings, and stray eddy current losses induced in metallic structural enclosures, core clamps, and tank walls by leakage flux.

When a power transformer operates under heavy load or experiences non-linear harmonic current pollution, severe

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localized hot-spots develop within the windings. Elevated operating temperatures accelerate the thermal degradation of cellulose winding insulation, drastically shortening the operational lifespan of the transformer.

➢ *Mathematical Formulation & Line Parameters*

To mathematically analyze sub-transmission line performance, a short transmission line model (line length typically < 80 km and voltage < 20 kV - 33 kV) is applied. For short line models, line shunt capacitance is negligible, allowing the circuit to be represented as a lumped series impedance consisting of resistance (R) and inductive reactance (X_L).

For a short transmission line, current continuity dictates that sending-end current equals receiving-end current:

$$I_S = I_R = I$$

The sending-end line-to-neutral voltage vector (V_S) is the vector sum of the receiving-end line-to-neutral voltage (V_R) and the internal line impedance voltage drop:

$$V_S = V_R + I \cdot Z = V_R + I \cdot (R + j\, X_L)$$

The total DC conductor resistance is evaluated based on material resistivity (ρ), total route length (L), and cross-sectional Conductor Area (A):

$$R = (\rho \cdot L) / A$$

Voltage regulation represents the percentage change in receiving-end voltage magnitude when a full rated load at a specified power factor is disconnected while maintaining sending-end voltage constant:

$$\% \text{ Voltage Regulation} = [(|V_S| - |V_R|) / |V_R|] \times 100\%$$

To evaluate overhead conductor performance, line conductors are standardly stranded to enhance mechanical flexibility during stringing and prevent fatigue fracture caused by wind-induced aeolian vibrations. The primary conductor materials utilized in sub-transmission and distribution construction include:

- Copper: High electrical conductivity and superior tensile strength. Resists atmospheric corrosion but exhibits high material cost and heavy weight.
- All-Aluminum Conductor (AAC): Low density (one-third copper weight) and low cost, but exhibits lower tensile strength, limiting span lengths.
- Aluminum Conductor Steel Reinforced (ACSR): Consists of a central core of galvanized steel strands surrounded by outer layers of aluminum strands. Combines high electrical conductivity of aluminum with high mechanical tensile strength of steel, widely adopted across all transmission voltages.
- Galvanized Steel: Used for extremely long river crossings or earth wires; exhibits high resistance and high inductive reactance.

## V. METHODOLOGY & DATA COLLECTION

To conduct a rigorous diagnostic evaluation of power loss mechanics within the Akure regional sub-transmission infrastructure, empirical operational field data was collected over a five-year monitoring window (2006 through 2010) from the Power Holding Company of Nigeria (PHCN), Akure Business District, Ondo State, Nigeria.

➢ *The Primary Data Collection Methodology Involved:*

- Injection Substation Operational Logs: Field site visitations to the Akure 132 kV Transmission Injection Substation to extract daily hourly operational log sheets, capturing peak active power (MW), reactive power (MVAr), line currents, and operating voltages sent to outgoing sub-transmission feeders.
- Receiving-End Control Room Logs: Simultaneous extraction of receiving-end operational log entries from the RAC 33 kV control room and the T2 Control Room to measure actual delivered power, voltage regulation, and feeder loadings.
- Physical Network Specification & Mapping: Comprehensive technical parameters for the 33 kV sub-transmission feeders were obtained from the Planning, Construction, and Maintenance Department of PHCN Akure Business District. All evaluated 33 kV sub-transmission line feeders utilize stranded 150 mm² ACSR conductors with an aluminum electrical resistivity $\rho = 2.82 \times 10^{-8}\ \Omega\cdot m$.
- Analytical Computation & Simulation: Theoretical baseline transmission losses and exact voltage regulation were calculated using standard circuit equations, while historical power loss trends, multi-year comparisons, and graphical charts were synthesized using spreadsheet analysis software.

➢ *Empirical Loss Analysis: RAC 33 KV Feeder*

The RAC 33 kV sub-transmission feeder serves as a critical power arterial within the Akure business district, supplying bulk energy to major commercial and residential distribution transformers. The feeder design specifications and theoretical baselines are established as follows:

- Feeder Rating & Voltage: 15 MVA capacity operating at nominal 33 kV.
- Operating Power Factor: 0.8 lagging.
- Full Load Capacity: P = 15 MVA × 0.8 = 12 MW.
- Theoretical Calculated Line Loss: Under ideal design conditions at full 12 MW load, the expected line power loss is calculated as 0.20 MW, yielding expected receiving-end delivered power of 11.80 MW.

However, comparative analysis between theoretical loss calculations and empirical field operational data logged at the 132 kV injection station and RAC control room reveals extraordinary loss escalation between 2006 and 2010.

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➢ *Year 2006 Performance Analysis*

In 2006, actual monthly peak power losses on the RAC feeder fluctuated between 0.55 MW and 1.19 MW, representing loss levels nearly 3 to 6 times higher than theoretical design projections (0.20 MW). The lowest monthly peak loss occurred in January at 0.56 MW, while the maximum loss occurred in September, reaching 1.19 MW.

➢ *Year 2007 Performance Analysis*

In 2007, power dissipation remained severely elevated. The lowest monthly loss was recorded in February at 0.50 MW. However, peak monthly losses escalated heavily in January (1.05 MW) and December (0.98 MW), driven by intense dry season peak loading and poor joint conductivities.

➢ *Year 2008 Performance Analysis*

During 2008, sub-transmission loss severity widened further. The lowest monthly peak loss recorded was 0.76 MW in July. Maximum loss peaked in January 2008 at 1.50 MW, reflecting severe line current overheating and unbalanced load distribution across phases.

➢ *Years 2009-2010 Performance Analysis*

By 2009 and 2010, the RAC feeder experienced catastrophic technical loss degradation. Monthly peak power losses reached 2.10 MW in December 2009. Losses peaked at 2.24 MW in January 2010—over 11 times the theoretical design loss margin (0.20 MW). November 2010 recorded the minimum loss for that year at 0.76 MW.

Table 2 Monthly Peak Power Losses (MW) on RAC 33 kV Feeder (2006–2010)

| Month | 2006 Loss (MW) | 2007 Loss (MW) | 2008 Loss (MW) | 2009 Loss (MW) | 2010 Loss (MW) |
|---|---|---|---|---|---|
| January | 0.56 | 1.05 | 1.50 | 1.65 | 2.24 |
| February | 0.62 | 0.50 | 1.10 | 1.72 | 1.95 |
| March | 0.70 | 0.68 | 1.18 | 1.80 | 1.82 |
| April | 0.81 | 0.74 | 1.25 | 1.85 | 1.70 |
| May | 0.88 | 0.80 | 0.95 | 1.60 | 1.55 |
| June | 0.95 | 0.85 | 0.88 | 1.50 | 1.40 |
| July | 1.02 | 0.91 | 0.76 | 1.42 | 1.25 |
| August | 1.10 | 0.82 | 0.84 | 1.35 | 1.10 |
| September | 1.19 | 0.78 | 0.92 | 1.48 | 0.95 |
| October | 1.05 | 0.86 | 1.05 | 1.68 | 0.88 |
| November | 0.92 | 0.90 | 1.20 | 1.90 | 0.76 |
| December | 0.85 | 0.98 | 1.38 | 2.10 | 1.30 |
| Annual Peak (MW) | 1.19 | 1.05 | 1.50 | 2.10 | 2.24 |

*A. Empirical Loss Analysis: T2B & T2C 33 KV Feeders*

A rigorous evaluation was similarly conducted for the T2B and T2C 33 kV sub-transmission feeders originating from the Akure 132 kV injection station. The primary technical parameters for the T2B feeder are:

- Line Length: 45 meters (short inter-station tie feeder).
- Feeder Impedance: $Z = 0.418 + j\ 3.5328\ \Omega$.
- Rated Transformer Capacity: 15 MVA, 33 kV, 0.8 power factor.
- Theoretical Calculated Line Loss: Under full 12 MW load, the expected line loss is calculated as 0.03 MW (expected receiving power 11.97 MW).9.1 T2B Feeder Performance.

➢ *Analysis*

Despite its short physical length, actual daily maximum losses on the T2B feeder drastically exceeded the theoretical benchmark of 0.03 MW:

- 2006: Daily losses ranged from 0.20 MW to 0.50 MW. Monthly peak loss reached 0.28 MW in January and April, peaking at 0.32 MW in November.
- 2007: Daily losses escalated to 0.30–0.60 MW. Monthly peak loss rose progressively from 0.44 MW in January to 0.72 MW in April (the 2007 annual peak), followed by a secondary peak of 0.68 MW in July.
- 2008: Daily losses expanded to 0.40–0.80 MW. Peak loss occurred in January 2008 at 0.94 MW, with August recording 0.84 MW.
- 2009–2010: Daily losses ranged between 0.50–0.80 MW (2009) and 0.60–1.00 MW (2010). Monthly losses peaked in July 2009 at 1.08 MW—over 36 times the theoretical baseline loss (0.03 MW). January 2009 recorded 0.93 MW, while September 2009 recorded 0.84 MW.

➢ *T2C Feeder Performance Analysis*

The T2C sub-transmission feeder exhibited severe cumulative annual power loss inflation across the five-year monitoring period. Total annual losses recorded on T2C were logged as follows:

- 2006 Total Annual Losses: 135.1 MW.
- 2007 Total Annual Losses: 153.6 MW (a 13.7% increase over 2006).
- 2008 Total Annual Losses: 222.5 MW (a 44.9% increase over 2007).
- 2009 Total Annual Losses: 269.0 MW (a 20.9% increase over 2008).
- 2010 Total Annual Losses: 266.3 MW (sustained near-peak loss level).

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Table 3 Cumulative Annual Energy Losses (MW) across Akure Sub-Transmission Feeders

| Feeder Identity | 2006 Annual Loss | 2007 Annual Loss | 2008 Annual Loss | 2009 Annual Loss | 2010 Annual Loss |
|---|---|---|---|---|---|
| T2B 33 kV Feeder | 94.3 MW | 196.4 MW | 245.8 MW | 321.01 MW | 315.5 MW |
| T2C 33 kV Feeder | 135.1 MW | 153.6 MW | 222.5 MW | 269.0 MW | 266.3 MW |
| RAC 33 kV Feeder | 289.4 MW | 520.7 MW | 612.3 MW | 745.2 MW | 730.1 MW |

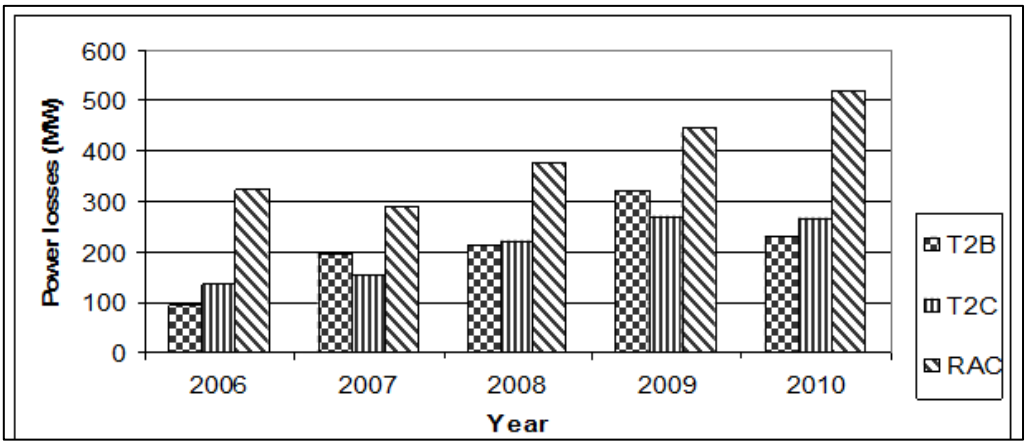


Fig 2 T2C Feeder Performance Analysis

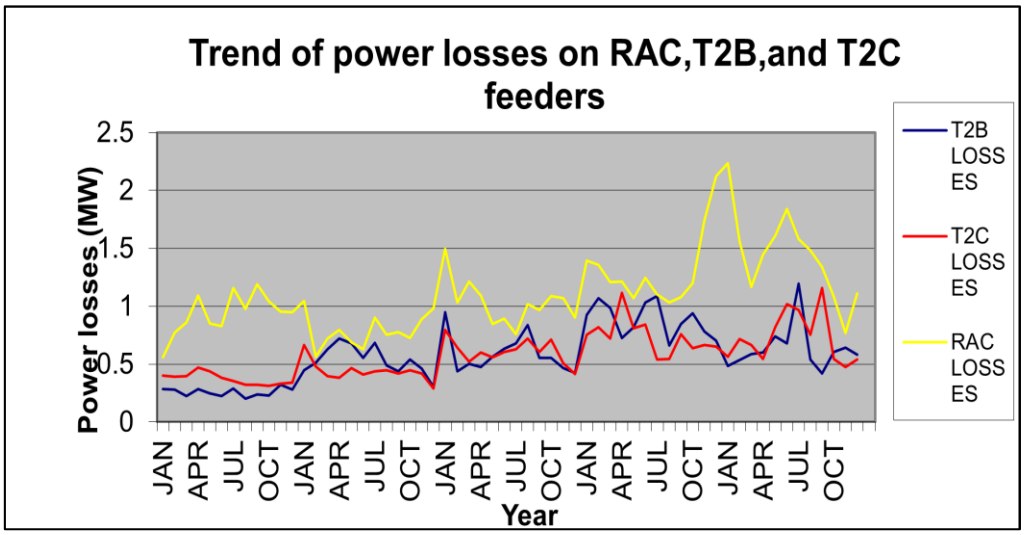


Fig 3 Trend of Power Losses on RAC, T2B, and T2C Feeders

## VI. DIAGNOSTIC ANALYSIS OF NETWORK FAILURE FACTORS

A comprehensive physical audit of the Akure sub-transmission network identified specific structural, operational, and maintenance factors responsible for the dramatic variance between theoretical design losses and actual field losses:

- *Transformer Winding Overheating & Cooling System Failure:*

Excessive temperature rise within power transformer windings—most severe on T2B transformers—was traced directly to the complete mechanical failure of secondary forced-air cooling fans. Operating under sustained high load without adequate forced cooling elevated oil and winding temperatures, driving up transformer AC resistance and winding copper losses.

- *Sustained Network Overloading & Low Power Factor:*

Uncontrolled load growth on 33 kV sub-transmission feeders frequently forced transformers and line conductors to operate far beyond rated current thresholds. Severe overloading causes excessive reactive power draws, depressing line voltage and lowering operating power factors. Because line losses scale quadratically with current ($P_{loss} \propto I^2$), operating at low power factors dramatically amplifies ohmic energy dissipation.

- *Substandard Jointing & Wire Sizing (Workmanship Deficiencies):*

Operational field repairs conducted by untrained utility staff introduced major technical defects. During emergency clearing of wire cuts or conductor snaps, damaged 150 mm² ACSR conductors were frequently spliced with severely undersized conductor wires. Furthermore, "married joints" (hand-twisted splices) were executed without standard

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compression sleeves, creating high-resistance localized hotspots that dissipated immense power as heat.

➢ *Loose and Burnt Jumper Connections:*

Jumper connections at line cross-arms and disconnect switches were frequently loose or thermally degraded (burnt). High contact resistance across loose jumper clamps created severe voltage drops and continuous power losses.

➢ *Vegetation Encroachment & Ground Leakage Current:*

Poor corridor maintenance allowed tree branches and dense foliage along high-tension line rights-of-way to make physical contact with energized 33 kV conductors. This created continuous high-resistance ground leakage paths, allowing currents to leak directly into the ground through trees.

➢ *Degraded Substation Termination Infrastructure:*

Outgoing high-voltage Raychem cable terminals at injection substations exhibited severe insulation breakdown and physical weathering, causing localized stress concentrations and leakage currents.

*A. Comparative Evaluation: Theoretical vs. Actual Losses*

The comparative synthesis between theoretical design performance and empirical field data highlights a profound operational gap within the Akure sub-transmission network. Under nominal design specifications using 150 mm² ACSR conductors, sub-transmission line losses should strictly remain below 2% to 3% of total transmitted active power.

➢ *Summary of Theoretical vs. Empirical Operational Loss Discrepancies*

- RAC 33 kV Feeder: Theoretical full-load loss = 0.20 MW (1.67% of 12 MW load). Actual logged monthly peak losses reached 1.19 MW in 2006, escalating to 2.10 MW in 2009 and 2.24 MW in 2010 (representing an actual loss fraction of 18.67% of delivered power).
- T2B 33 kV Feeder: Theoretical full-load loss = 0.03 MW (0.25% of 12 MW load). Actual logged peak losses escalated from 0.32 MW in 2006 up to 1.08 MW in July 2009 (representing an actual loss magnitude 36 times higher than design limits).
- Cumulative Substation Dissipation: Total annual energy dissipated across T2B, T2C, and RAC feeders expanded from 518.8 MW in 2006 to over 1,335.2 MW in 2009, severely compromising utility revenues and network voltage stability.

## VII. CORRECTIVE RECOMMENDATIONS & REMEDIAL STRATEGIES

To eliminate excessive sub-transmission losses, restore system voltage stability, and safeguard network infrastructure across the Akure business district, the following technical and maintenance interventions must be implemented urgently:

➢ *Transformer Cooling System Overhaul:*

Execute immediate maintenance on all substation power transformers. Specifically, repair and replace the failed secondary cooling fan assembly on the T2B transformer bank to restore forced-air heat extraction, reduce oil winding temperatures, and eliminate excess winding copper resistance.

➢ *Cable Termination Renewal:*

Re-terminate all outgoing high-voltage Raychem cable terminals using new, factory-certified Raychem termination kits and high-dielectric vulcanized rubber insulation to eliminate terminal tracking and ground leakage.

➢ *Standardized Conductor Replacement:*

Eliminate all improper wire splices on the RAC and secondary feeders. Replace all undersized emergency patch wires and burnt jumpers with standard, fully rated 150 mm² ACSR conductors matching original design specifications.

➢ *Compression Jointing Standard Implementation:*

Prohibit manual hand-twisted "married joints." Enforce strict utility compliance requiring hydraulic compression sleeves and standard tension clamps for all overhead conductor splices and jumper taps to ensure minimal contact resistance.

➢ *Conductor Strand Repair:*

Conduct physical line inspections to identify and replace all broken conductor strands, loose jumper clamps, and mechanically fatigued line spans using proper compression repair sleeves.

➢ *Right-of-Way Vegetation Management:*

Establish a continuous scheduled vegetation clearance program to prune trees, clear overhanging foliage, and maintain a clean physical clearance corridor along all 33 kV and 132 kV high-tension line corridors, completely eliminating tree-contact ground leakage currents.

➢ *Reactive Power Compensation & Load Balancing:*

Install automatic power factor correction capacitor banks at primary substations and rebalance single-phase load connections across the three phases to eliminate zero-sequence neutral currents and reduce reactive current line loading.

## VIII. CONCLUSION

This research work presented a thorough diagnostic and mathematical investigation of power loss mechanics on the sub-transmission network supplying the Akure business district. The empirical findings establish conclusively that actual power losses on the 33 kV sub-transmission lines vastly exceed theoretical design margins. This severe loss escalation is driven by a combination of unmaintained cooling systems, severe line overloading, improper technical repairs, high-resistance conductor joints, undersized wire replacements, and vegetation ground leaks.

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By implementing the recommended technical interventions including transformer cooling repairs, standardized 150 mm² ACSR conductor replacement, hydraulic compression jointing, cable re-termination, and aggressive right-of-way vegetation clearing—PHCN grid operators can drastically curtail technical energy losses, improve network voltage regulation, and significantly enhance power supply reliability across the Akure transmission network.

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