

# Low Voltage in Nigerian Power Systems: Causes and Remedies

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**Abstract:** *This paper presents Low voltage in Nigerian power systems: causes and remedies. A comprehensive analysis of what causes low voltages (voltage sags) in the Nigerian power systems were explored. Remedies that could offer long term stability in the Nigerian power systems were proffered based on empirical knowledge and experience. Issues such as Generation-Demand Imbalance and Frequency Oscillations, Ohmic Losses in the Radial Network, and Bottlenecks in Distribution Infrastructure were thoroughly examined. The proffered remedies are very germane.*

**Keywords:** *Voltage, power, systems, dip, sags, generation, frequency.*

## I. INTRODUCTION

Low voltage in power systems, often referred to as voltage drop or sag, occurs when the electricity supply drops below the normal operating range (typically 220-240V or 110-120V). This issue leads to malfunctioning equipment, slow motors, flickering lights, and increased energy bills. The reliability of Nigeria's power infrastructure remains severely compromised by chronic voltage instability and frequent systemic failures. Low voltage (defined as the delivery of power significantly below the 415 V three-phase or 230 V single-phase nominal ratings) prevents the efficient operation of industrial and domestic equipment. This technical fragility was exemplified as recently as December 29, 2025, when a major system disturbance led to a near-total loss of generation, cutting supply to zero across major franchises including Benin, Eko, and Ikeja. Data from the first quarter of 2025 indicates that daily voltages frequently breached statutory limits, falling as low as 296.56 kV against the Grid Code's minimum requirement of 313.50 kV. Resolving these issues necessitates a hybrid approach involving technical upgrades, regulatory decentralization, and robust protection of physical assets.

Voltage sags are present in power systems but it is only during the past decade that customers are becoming more sensitive to the inconvenience caused [1]. Voltage sag can cause serious problems to sensitive loads, because these loads often drop off-line due to voltage sag. As a result, some industrial facilities experience production outage that results in economic losses [2, 3, and 4]. In several processes such as semiconductor manufacturing or food processing plants, the voltage dip of very short duration can cost a substantial amount of money [5]. Voltage dip is the main power quality problem for the semiconductor and continuous manufacturing industries, and also to the hotels and telecom sectors [6]. International Joint Working Group (JWG) C4.1110 sponsored by CIGRE, CIRED and UIE has addressed a number of aspects of the immunity of equipment and installations against voltage dips and also identified areas where additional work is required. The work took place between 2006 and 2009 and resulted in a technical brochure distributed via CIGRE and UIE [7]. The most common approach to obtain the sag magnitude is to use rms voltage. There are other alternatives such as rms voltage of fundamental component and peak voltage [8, 9].

## II. TECHNICAL DYNAMICS OF VOLTAGE DEGRADATION

### 2.1 Generation-Demand Imbalance and Frequency Oscillations

A core driver of instability is the massive gap between installed generation capacity (~13,000 MW) and actual daily output, which often hovers around 5,000 MW. This deficit forces the grid to operate near its lower frequency limits. When load demand exceeds generation, the system frequency drops; if it falls below 48.75 Hz, automated protective relays trigger generator shutdowns to prevent mechanical damage,

often resulting in a cascading total grid collapse. The swing equation describes the relationship between generation-demand imbalance and frequency oscillation and it is given by the following equation:

$$\Delta P = \left(\frac{2H}{s}\right) \left(\frac{df}{dt}\right) \dots\dots\dots (1)$$

Where,  
 ΔP is power imbalance (generation-demand),  
 H is inertia constant,  
 S is system capacity,  
 f is frequency,  
 $\left(\frac{df}{dt}\right)$  is rate of change of frequency.

For frequency oscillation, the equation can be represented as:

$$\Delta f = \frac{\Delta P}{D} \dots\dots\dots (2)$$

Where,  
 Δf is frequency deviation,  
 ΔP is power imbalance,  
 D is load damping coefficient.

### 2.2 Ohmic Losses in the Radial Network

The Nigerian National Grid (NNG) is predominantly a radial network, which lacks the inherent redundancy found in ring or mesh configurations. This structure is particularly vulnerable to technical losses during long-distance transmission from southern gas-fired plants to northern load centers. These losses are primarily resistive and follow the Joule heating principle

$$P_{(loss)} = I^2 R \dots\dots\dots (3)$$

where I represents the current and R the conductor resistance. As voltage drops, the current must increase to satisfy power demand, which exponentially raises I<sup>2</sup>R losses and further depresses the voltage profile according to the following equation:

$$\Delta V = I(R \cos \phi + X \sin \phi) \dots\dots\dots (4)$$

where φ is the power factor angle.

### 2.3 Bottlenecks in Distribution Infrastructure

The distribution segment is the primary site of consumer-level voltage depression. Key infrastructure challenges include:

- Transformer Saturation: Distribution transformers account for an estimated 40% of technical losses. Chronic overloading occurs due to unplanned urban expansion and illegal taps, leading to thermal degradation and voltage sags. The saturation equation for a transformer relates the

magnetizing current (I<sub>m</sub>) to the flux density (B) according to the following equation:

$$B = \frac{V}{4.44fNA} \dots\dots\dots (5)$$

Where,  
 B is flux density (Tesla),  
 V is applied voltage (volts),  
 f is frequency (Hz),  
 N is number of turns,  
 A is core cross-sectional area (m<sup>2</sup>).

When B exceeds the saturation flux density (B<sub>sat</sub>), the core saturates, causing a sharp increase in I<sub>m</sub>. The saturation current is often approximated by:

$$I_{sat} \approx \frac{B_{sat}AN}{\mu\ell} \dots\dots\dots (6)$$

Where,  
 μ is core permeability,  
 ℓ is core length.

- Feeder Impedance: Many 11kV and 33kV lines utilize undersized or dilapidated conductors, which possess high resistance-to-reactance (r/x) ratios, causing significant voltage drops across the distribution string.
- Load Imbalance: In many residential areas, unequal distribution of loads across phases results in one phase being significantly more depressed than others, damaging sensitive equipment.

## III. SOCIO-ECONOMIC AND NON-TECHNICAL CONSTRAINTS

3.1 Infrastructure Vandalism as "Economic Treason"  
 Vandalism has emerged as a critical threat to grid stability. In the first quarter of 2025 alone, over 109 transmission towers were destroyed across Nigeria, with the Port Harcourt region losing 62 towers in 13 separate incidents. These acts of sabotage are now characterized as "economic treason" because they divert essential capital—such as the N9 billion spent in 2024—away from modernization and into basic infrastructure restoration.

3.2 Energy Theft and the ATC&C Loss Trap  
 Aggregate Technical, Commercial, and Collection (ATC&C) losses reached 35.22% by late 2024. Energy theft, particularly meter bypassing, costs distribution

companies (DisCos) over N2.5 billion in monthly revenue. This financial shortfall prevents DisCos from settling debts to the Transmission Company of Nigeria (TCN), which currently exceed N450 billion, effectively stalling over 100 critical transmission projects.

Technical component	Primary Cause of failure	Impact on Quality of supply
Transmission line	Radial design and long distances	High resistive losses and voltage sags
Substations	Aging circuit breakers and switchgears	Frequent tripping and slow restoration
Transformers	Chronic overloading and lack of planning	Voltage depression which gives about 40% of technical losses
Grid control	Manual coordination and monitoring	Inability to respond to rapid transients

#### IV. REMEDIATION STRATEGIES AND STRATEGIC MODERNIZATION

##### 4.1 Short-Term Technical Fixes

- **Reactive Power Support:** The installation of shunt capacitor banks is the most effective immediate remedy for localized voltage depression. Research in Igwuruta (Port Harcourt) demonstrated that an optimal 48,000 kVAR capacitor bank could improve voltage profiles to within the 95%–105% statutory limit, providing bus improvements of up to 18.4%.
- **Grid Automation (SCADA/EMS):** TCN is currently prioritizing the upgrade of Supervisory Control and Data Acquisition (SCADA) systems. Modernizing these controls can reduce fault detection and isolation times from 60 seconds (manual) to just 5 seconds, significantly lowering the risk of total system collapse.
- **Network Maintenance:** Replacing frayed conductors and repairing faulty joints can immediately reduce technical losses at the distribution level.

##### 4.2 Long-Term Structural and Regulatory Reforms

- **Decentralization (Electricity Act 2023):** This landmark legislation ends the federal monopoly on power regulation, allowing states to manage their own generation and distribution markets. By mid-2025, 12 states had enacted their own electricity acts, fostering the growth of "embedded" generation closer to load centers to eliminate long-distance transmission losses.
- **Advanced Conductor Technology:** TCN is exploring the use of High-Temperature Low-Sag (HTLS) conductors like Aluminum Conductor Composite Core (ACCC). These cables can carry higher loads with 8% lower resistive losses than conventional ACSR conductors.
- **FACTS and STATCOMs:** Static Synchronous Compensators (STATCOMs) provide instantaneous reactive power compensation, maintaining stable voltage even during rapid load changes or renewable energy fluctuations.
- **Closing the Metering Gap:** Port Harcourt Electricity Distribution (PHED) targets the installation of 135,000 smart meters to eliminate estimated billing and improve the financial liquidity required for network expansion.

#### V. CONCLUSION

Low voltage in the Nigerian power system is a multi-dimensional challenge stemming from technical aging, reactive power imbalances, and economic sabotage. While radial line losses and vandalism present immediate risks, the transition to an automated "smart" grid and the sub-national energy markets enabled by the Electricity Act 2023 offer a viable path to stability. Sustained investment in reactive power compensation (STATCOMs/Capacitors) and advanced conductor technology (ACCC) is essential for achieving a reliable grid that can support Nigeria's industrial and economic growth.

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