

## Conductor under-sizing and its role in voltage drop-driven system instability: A field-based analysis

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### Abstract

Voltage drop is a critical but frequently underestimated factor in the performance and safety of low-voltage electrical systems. This paper investigates the systemic impact of undersized conductors, focusing on their contribution to excessive voltage drops under normal operating conditions. Drawing from field observations and simplified calculations, the study shows that installations using 1.0 mm<sup>2</sup> or 1.5 mm<sup>2</sup> cables over extended distances often exceed regulatory voltage drop limits, leading to thermal buildup, equipment malfunction, and gradual system degradation. The analysis reveals that these conditions are often overlooked due to cost-cutting, inadequate technical training, and a lack of post-installation testing. The findings emphasize the need for improved design practices, routine under-load voltage measurements, and stricter inspection protocols. By addressing this overlooked issue, significant improvements can be made in energy efficiency, system longevity, and end-user satisfaction, particularly in residential, institutional, and rural electrification projects.

**Keywords:** Poor electrical practices, under-sized conductors, voltage drops, electrical wiring

### Introduction

Voltage drop is a fundamental concept in electrical engineering, defined as the reduction in voltage as electrical current flows through the resistive and inductive components of a conductor. While its theoretical treatment is well established in textbooks and standards like IEC 60364-5-52 and BS 7671, its real-world implications are often underestimated, misunderstood, or outright ignored, particularly in developing regions and informal installations. The consequences of excessive voltage drop range from reduced equipment performance to fire hazards and premature system failures. In many observed cases, voltage drop is not a result of distance or load magnitude alone but rather of undersized conductors, poor installation techniques, and failure to adhere to established guidelines. These practices are sometimes driven by cost-cutting, space constraints, or simple lack of awareness.

The issue becomes especially critical in long feeder runs (e.g., street lighting, rural electrification), high-start current devices (e.g., motors, refrigerators, pumps), undersized wiring in high-load consumer units, and Shared neutral conductors among multiple phases or circuits.

This paper investigates the impact of undersized conductors on voltage stability, using simplified analytical models and field experience to demonstrate how this overlooked practice results in unacceptable voltage drops that compromise both functionality and safety. The study further emphasizes the cascading effects of improper conductor sizing in combination with poor termination, conductor heating, and substandard materials.

### Literature Review

Voltage drop is a well-recognized phenomenon in electrical systems, defined as the reduction in voltage that occurs when electrical current flows through a conductor with finite impedance. While this is a basic principle addressed in most electrical engineering curricula, its field application—particularly regarding conductor sizing—remains

inconsistently applied.

### 1. Voltage Drop in Standards and Regulations

Standards such as IEC 60364-5-52 and BS 7671:2018 (Regulation 525.1) provide guidance on allowable voltage drops in fixed installations. For example, BS 7671 recommends a maximum voltage drop of

- 3% for lighting circuits, and
- 5% for other uses (e.g., socket outlets, motors).

These percentages translate into allowable drops of

$$\begin{aligned}\text{Lighting: } 0.03 \times 230 \text{ V} &= 6.9 \text{ V} \\ \text{Other circuits: } 0.05 \times 230 \text{ V} &= 11.5 \text{ V}\end{aligned}$$

However, multiple field surveys, including those by Adekoya and Kolapo (2020) <sup>[1]</sup> and Oladeji *et al.* (2018) <sup>[5]</sup>, show that installations in residential and institutional buildings in Sub-Saharan Africa often exceed these limits due to undersized cables, especially in long-distance runs or circuits with shared conductors.

### 2. Causes of Undersizing in Practice

Undersizing conductors may result from several overlapping factors:

- Cost-cutting measures in low-budget projects.
- Ignorance or misinterpretation of load calculations.
- Use of locally available but substandard cables with higher resistance.
- Improper derating in environments with high ambient temperature or multiple current-carrying conductors in a single conduit.

According to Meier (2016) <sup>[4]</sup>, the practice of "just using whatever wire is available" is prevalent in informal construction sectors, where installation is often based on rule-of-thumb rather than engineering calculation.

### 3. Impact on Equipment and Safety

Undersized conductors create higher-than-expected resistance, leading to:

1. Voltage loss at the load end,
2. Excessive conductor heating (which in turn increases resistance further),
3. Reduced starting torque and efficiency in motors,
4. Dim lighting and nuisance tripping of voltage-sensitive equipment,
5. Fire risk from insulation breakdown or loose connections.

Wang *et al.* (2019) [6] showed that even a 5% increase in conductor resistance due to undersizing could lead to a temperature rise of over 30°C under full-load current in a poorly ventilated trunking system.

### 4. Inadequacy of Testing and Commissioning Practices

While insulation resistance and polarity tests are routinely performed during commissioning, voltage drop testing is often neglected, especially in domestic and light commercial projects. Many contractors assume that as long as the breaker ratings are correct and conductors are continuous, the circuit is safe. This assumption ignores long-term degradation due to overload, excessive heating, or latent voltage drop effects that only appear during full load.

Oladeji *et al.* (2018) [5] reported that 40% of surveyed residential circuits exceeded the 5% allowable voltage drop under full-load conditions — most of them because the installed cable sizes were insufficient for the actual distances and connected loads.

### 5. Summary of Knowledge Gaps

Area	Current Practice	Observed Gap
Conductor sizing	Based on rule-of-thumb or cost-saving	Rarely reflects real distance and load
Load estimation	Often generic or underestimated	No consideration for peak current or diversity
Voltage drop testing	Rarely performed	Faults discovered only after usage
Awareness of heating effects	Poor	Fire risks and degradation overlooked

This review highlights that while voltage drop is theoretically understood, its practical enforcement remains weak, especially in emerging economies and informal building projects. The following sections offer analytical examples and field-based observations to illustrate the full extent of the issue and guide appropriate mitigation strategies.

### Methods

This study combines practical field observations, simplified electrical analysis, and sample voltage drop calculations to investigate the effects of undersized conductors in low-voltage installations. The methodology is structured to reflect real-world conditions encountered in both urban and rural settings, especially where installations deviate from regulatory standards due to informal practices or cost-saving constraints.

#### 1. Field Site Sampling

Field assessments were conducted at:

- Residential compounds with multiple tenants and long feeder run.

- Institutional buildings (e.g., schools, clinics) with mixed lighting and appliance loads.
- Small commercial outlets operating motors, refrigerators, and welding equipment.

These sites were chosen for their observable symptoms of voltage drop — such as flickering lights, motor startup delays, and user-reported power “fluctuations.” Cable types and sizes were documented visually or via test stripping, and run lengths were estimated using floor plans or physical tracing.

### 2. Simplified Voltage Drop Calculations

The voltage drop across a conductor was analyzed using the standard formula:

$$V_d = I \times (R \times L)$$

Where:

- $V_d$  = voltage drop (V)
- $I$  = current (A)
- $R$  = resistance per meter of conductor ( $\Omega/\text{m}$ )
- $L$  = one-way length of conductor (m)

For circuits with both live and return conductors (e.g., single-phase), the effective length is:

$$L_{eff} = 2 \times L$$

Resistance values were based on standard conductor tables for copper at 20°C. Adjustments for ambient temperature or conductor heating were not included to maintain simplicity, though these are discussed later in the analysis.

#### Example Calculation

A 1.5 mm<sup>2</sup> copper conductor (with resistance  $\approx 0.0121 \Omega/\text{m}$ ) is used to feed a 12 A lighting circuit over a 35 m one-way distance.

$$R = 0.0121 \Omega/\text{m}, \quad L = 35 \text{ m}, \quad I = 12 \text{ A}$$

Effective length:

$$L_{eff} = 2 \times 35 = 70 \text{ m}$$

Voltage drop:

$$V_d = I \times R \times L_{eff} = 12 \times 0.0121 \times 70 = 10.164 \text{ V}$$

Percentage voltage drop (for 230 V supply):

$$\%V_d = \frac{10.164}{230} \times 100 \approx 4.42\%$$

Although within the 5% limit, this value is marginal — and could exceed limits under higher ambient temperatures or extended usage.

### 3. Visual Inspection and Thermal Clues

During field visits, thermal signs such as warm cable sheaths, discolored insulation near terminals, and loosened conductors at circuit breakers were used to confirm heating effects consistent with undersized conductors. In locations with intermittent load shedding, time-lag effects were also noted (e.g., voltage drop occurring several minutes after appliances were turned on).

### 4. Limitations

- Load currents were estimated or inferred from connected device ratings and usage patterns.
- Exact conductor lengths and buried cable conditions could not always be verified.
- Harmonic effects and power factor considerations were excluded.

Despite these limitations, the methodology provides a realistic assessment of how undersized conductors impact voltage stability in day-to-day installations.

### Technical Analysis and Results

This section analyzes how undersized conductors contribute to voltage instability, drawing on field measurements and simplified calculations. The analysis emphasizes how minor oversights in sizing can lead to significant deviations in voltage delivery, thermal buildup, and equipment degradation over time.

#### 1. Conductor Size vs. Load Distance

A key factor influencing voltage drop is the conductor's cross-sectional area (CSA) relative to the circuit length and current. Field measurements revealed that 1.0 mm<sup>2</sup> and 1.5 mm<sup>2</sup> copper conductors were frequently used beyond their recommended distances, particularly for lighting and socket circuits.

##### Example 1

In a residential compound, a 1.0 mm<sup>2</sup> copper conductor (resistance  $\approx 0.018 \Omega/\text{m}$ ) was used to supply a 10 A lighting circuit covering a detached annex, approximately 40 m away from the distribution board.

$$I = 10 \text{ A}, R = 0.018 \Omega/\text{m}, L = 2 \times 40 = 80 \text{ m}$$

$$V_d = I \times R \times L = 10 \times 0.018 \times 80 = 14.4 \text{ V}$$

Percentage voltage drop:

$$\%V_d = \frac{14.4}{230} \times 100 \approx 6.26\%$$

This exceeds the allowable 5% for socket outlets and 3% for lighting, and could result in:

- Dim or flickering bulbs.
- Relay chatter in electronic ballasts.
- Delayed actuation in contactor-based systems.

#### 2. Heating Due to Excessive Current Density

Undersized conductors increase current density (current per mm<sup>2</sup>), which raises operating temperatures and accelerates insulation breakdown. In long circuits or enclosed conduits, this heat cannot dissipate easily, compounding the problem.

##### Example 2

In a vocational school, a 2.5 mm<sup>2</sup> copper cable was used to feed a 25 A socket ring in the workshop block from a nearby panel located 50 m away:

$$R = 0.00741 \Omega/\text{m}, L = 100 \text{ m}, I = 25 \text{ A}$$

$$V_d = 25 \times 0.00741 \times 100 = 18.525 \text{ V}$$

$$\%V_d = \frac{18.525}{230} \times 100 \approx 8.06\%$$

Besides exceeding voltage drop limits, the conductor would operate near or above its temperature limit, especially when surrounded by other loaded circuits or inside PVC trunking.

#### 3. Overloaded Shared Neutrals

In some multi-circuit setups, a single neutral conductor serves multiple live lines — often of different load magnitudes. If the shared neutral is not upsized

appropriately, it becomes a bottleneck, causing not only voltage drop but neutral displacement as discussed in previous articles.

#### 4. Real-World Case Example

At a peri-urban health clinic, a solar inverter system fed multiple buildings using a single 2.5 mm<sup>2</sup> copper cable over 70 meters. When refrigerators and fans were switched on:

- Measured terminal voltage dropped from 230 V to 208 V.
- The system tripped on under-voltage intermittently.
- The conductor was found to be warm to the touch after 10–15 minutes of peak operation.

Voltage drop calculation:

$$I = 18 \text{ A}, R = 0.00741 \Omega/\text{m}, L = 140 \text{ m}$$

$$V_d = 18 \times 0.00741 \times 140 = 18.7 \text{ V}$$

$$\%V_d = \frac{18.7}{230} \times 100 \approx 8.13\%$$

This confirmed that the selected cable was undersized for both distance and load, leading to recurrent system instability.

These findings show that undersized conductors can cause severe voltage drops, even at modest current levels — especially in longer circuits, enclosed conduits, or during peak usage. Yet, these failures are often misattributed to grid instability or equipment fault, rather than the true root cause: poor conductor sizing.

### Discussion

The findings of this analysis highlight a reality that's far more common than most professionals like to admit: voltage drop caused by undersized conductors isn't just something found in textbooks or exam questions — it's a recurring and often ignored issue on actual sites. From homes and clinics to small commercial buildings, its effects ripple through performance, shorten the lifespan of appliances, confuse end users, and sometimes even put people in danger. It's not theoretical. It's happening — silently, pervasively.

#### 1. The Illusion of Functionality

Walk into most buildings with long, poorly wired circuits and you'll still see the lights on and appliances running — but that functionality is deceptive. Sure, fans may spin and TVs may power up, but behind the scenes, there's a slow burn of deterioration. Motors run hotter and pull more current than they should. Smart devices — chargers, inverters, controllers — behave erratically or shut off at random. Even basic lighting systems lose brightness over time, with bulbs wearing out sooner than expected. What's going on? The real issue — the inadequate size of the conductors — is quietly doing damage, often unnoticed until it's too late.

#### 2. Economic and Behavioral Triggers

One reason this keeps happening is simple: cost. In an effort to save money — or due to limited stock — electricians and technicians often go for 1.0 mm<sup>2</sup> or 1.5 mm<sup>2</sup> cables even on circuits that run long distances or carry significant loads. In informal setups, shortcuts become the norm. Cable lengths are guessed, not measured. Load estimates are assumed, not calculated. Installers rely on cable labels that may be misleading or outright false.

And why does this persist? There's very little enforcement of proper standards, especially in small residential or commercial projects. Voltage drop testing is rarely done. And many installers, honestly, just don't realize how big a deal proper conductor sizing really is.

### 3. Regulatory Blind Spots

It's not just on the ground — the regulatory framework also misses key gaps. Standard inspections usually check for continuity, proper earthing, and breaker or RCD installations. Neat wiring? Passed. But voltage drop under full load? Almost never tested. That means installations with serious performance flaws — and long-term risks — pass inspections and get energized.

Even where standards like the 3%/5% voltage drop limits in BS 7671 exist, they're often treated as guidelines rather than hard rules. And in today's world of voltage-sensitive electronics — LED lighting, inverter-based air conditioners, solar systems, variable speed drives — that mindset is risky. These systems depend on voltage stability, and any significant drop throws off their performance or lifespan.

### 4. Interdependence with Other System Parameters

It's important to understand that voltage drop doesn't operate in a vacuum. It ties into other electrical parameters that, together, shape system behavior. For example, poor power factor in inductive loads can worsen voltage drops. Shared neutrals or unbalanced systems can lead to neutral displacement — another hidden issue. And then there's heat: as undersized conductors heat up, their resistance increases, which then causes even more voltage drop. That drop increases current in some appliances, creating a feedback loop. It's a vicious cycle.

### 5. Awareness and Correction

The good news? Fixing this doesn't require complex tools or advanced diagnostics. It just takes a bit of foresight and commitment to doing things right. Voltage drop calculators — or even good old tables — can help during design. Measuring actual load under peak conditions gives a realistic picture of circuit demand. And anytime circuits stretch beyond 30 meters or serve multiple outlets, it's safer to upsize conductors rather than gamble.

A lot of the faults people blame on "bad power" or "faulty appliances" are really symptoms of voltage drop caused by poor wiring choices. It's time the industry recognized that — from installers to inspectors to policymakers. We need to move from a mindset of "it works" to "it performs reliably and safely."

### Conclusion

This study has demonstrated that undersized conductors are a silent yet persistent threat to voltage stability and safety in low-voltage electrical installations. While often overlooked, the consequences of excessive voltage drop extend beyond flickering lights or poor equipment performance - they include premature equipment failure, increased fire risk, user dissatisfaction, and misdiagnosed electrical faults.

Through simplified technical analysis and field-based observations, the paper showed that even minor under-sizing, particularly in long circuits or shared-load arrangements can result in voltage drops that exceed standard thresholds. These effects are magnified when

installation practices ignore conductor length, operating temperature, or simultaneous load diversity.

The research also highlights several systemic issues including cost-driven decisions and a lack of proper load-distance assessment, poor awareness among installers and end-users regarding the importance of conductor sizing, and regulatory gaps in enforcing voltage drop compliance during inspection and commissioning.

To mitigate the impacts of this often-ignored problem, the following actions are recommended:

1. Adopt proper sizing guides using standard voltage drop tables or calculators during design stages.
2. Perform under-load voltage measurements as part of commissioning, especially for long or high-load circuits.
3. Educate electricians and technicians on the real-world impacts of under-sizing, including safety implications.
4. Enforce corrective measures during inspection when installations show excessive voltage drop, even if all other tests are passed.

Ultimately, resolving the problem of undersized conductors requires a shift from "what works" to "what lasts." Small improvements in cable sizing and voltage drop awareness can significantly enhance electrical reliability, equipment life, and user safety - particularly in the underserved and rapidly electrifying regions where such practices are most critical.

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