Impact of solar PV power cable length on transmission efficiency in multi-building facility: Examining power loss in long-distance cable setups

Ogochukwu Chinedum Chukwunedum[1]*, Chike Pius Nwachukwu[2], Chukwuemeka Obumneme Umobi[2]

[1]Department of Industrial and Production Engineering, Faculty of Engineering, Nnamdi Azikiwe University, PMB 5025, Awka, Anambra State, Nigeria

[2]Department of Agricultural & Bio-resources Engineering, Faculty of Engineering, Nnamdi Azikiwe University, PMB 5025, Awka, Anambra State, Nigeria

*Corresponding author, email: oc.chukwunedum@unizik.edu.ng

Article history
Submitted: 15 October 2025
Revised: 22 November 2025
Accepted: 20 December 2025
Published: 25 December 2025

Keywords
Power loss
Resistance
Solar PV power cable length
Solar PV power cable length transmission efficiency
Voltage drop

Abstract
This study investigates how cable length influences four key output parameters voltage drop, power loss, resistance, and efficiency to determine its overall effect on solar (PV) power transmission efficiency in a multi-building setup. The actual cable length between the PV panel and the building's power system was first measured and used as a baseline for further calculations. From this experimental value, nineteen hypothetical cable lengths were generated one shorter and eighteen longer to enable broader computational analysis based on electric circuit theory. These calculations were used to examine how variations in cable length affect resistance, voltage drop, and power loss, and how these changes ultimately influence transmission efficiency. The results clearly show that cable length plays a critical role in determining PV power transmission performance. Increasing cable length consistently led to higher resistance, which in turn produced greater voltage drop and power loss along the cable. Consequently, overall transmission efficiency decreased as cable length increased. In contrast, shorter cables demonstrated lower resistance and minimized both voltage drop and power loss, resulting in higher transmission efficiency and more reliable delivery of power. Using the experimental cable length of 41 m, the efficiency was calculated at 99.71%. The shortest hypothetical length of 32 m yielded the highest efficiency at 99.78%, while the longest length of 283 m resulted in the lowest efficiency at 98.02%. These findings emphasize the importance of minimizing cable length in PV installations to optimize system performance. The study provides practical guidelines for designing efficient solar power systems in both single-building and multi-building configurations.

1. Introduction

The global shift toward renewable energy has intensified interest in solar power as a sustainable and reliable source of electricity. Solar systems are increasingly being deployed in residential, commercial, and industrial settings to mitigate reliance on fossil fuels and reduce carbon emissions. However, ensuring optimal efficiency in solar power systems involves addressing several critical technical and efficiency challenges, one of which is power loss due to longer cable length. One of the major challenges in solar installations for multi-building facilities is the loss of power due to cable length. When electrical power is transmitted over long distances, resistive losses in cables cause voltage drops, reducing the efficiency of the system. Inadequate cable sizing and improper connection configurations can further exacerbate these losses, leading to suboptimal energy distribution and increased costs. But this project work is limited to the investigation of power loss in long solar power cable length.

Current researches on solar systems focuses hugely on panel efficiency, inverter performance/ efficiency, and battery storage efficiency, but limited attention has been given to the impact of cable length on system efficiency as regards to efficient power transmission, especially in multi-building facilities. There is a need to quantitatively analyze power losses in various solar power cable lengths in order to determine the optimal (efficient) cable length in various single or multi-building facility setups that ensures minimal losses while maintaining efficiency of power transmission. In large-scale solar power distribution, particularly in multi-building facilities in a university environment, industrial complexes, and residential estates, power must often be transmitted over significant distances from solar panels to inverters and load centers. The transmission of electrical power through cables introduces resistance, leading to voltage drops and power losses, which can significantly impact system efficiency. The efficiency of power transfer is affected by various factors; including

© 2025 The Author(s)
This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License
ISSN: 3110-1577

cable material, cable cross-sectional area, ambient temperature, and, most importantly, the length of the cable. In engineering applications, minimizing power loss is critical to ensuring reliable and efficient solar energy distribution. Inefficiencies in power transmission can lead to increased operational costs, reduced system lifespan, and underperformance of electrical loads. In investigating the effect of cable length on power loss in solar installations for multi-building facilities, this study aims to identify efficient solar power cable connection to maximize efficiency in distribution or transmission.

In solar power installations, the type of cables, cable lengths, cable sizes, and layouts are crucial for the safety and efficiency of the system. The efficiency of solar panel systems in multi-building facilities is significantly influenced by the length of cables used for power transmission. As energy travels from solar panels to inverters and load centers, resistance in electrical cables would cause voltage drops and power losses, which impacts the overall performance of the system [1]. Solar photovoltaic (PV) systems are increasingly becoming common, particularly in large-scale and multi-building facilities such as university campuses, residential buildings, and industrial sites. While such facilities gain from distributed solar generation, they also subject to unique infrastructure challenges, particularly the efficiency losses due to long-distance cable runs. One of the most significant yet often underrated factors affecting overall system performance is the length of the cable, which contributes to resistive power losses [2]. The physical mechanisms of power loss, methods of reduction, and the implications for system design, as well as strategies for the improvement of power transmission efficiency are presented in [3]; [4]; [5]. A study by examined the effects of cable length on solar PV efficiency in a university campus setting [6]. The study found that voltage drop increased significantly as the cable length exceeded 50 meters, leading to efficiency losses of up to 5%. The authors recommended the use of step-up converters to mitigate voltage drop. Similarly, another study investigated power losses in off-grid solar systems that supply electricity to remote villages [7]. Their results showed that poor cable sizing led to voltage drops exceeding 10%, resulting in inefficient energy distribution and frequent system failures. Cable sizing plays a crucial role in maintaining system efficiency [8]. The study compared different wire gauges and found that using cables with a cross-sectional area of at least 16 mm^2 significantly reduced voltage drop and power loss in solar installations spanning distances greater than 100 meters. The cost-benefit analysis of cable selection for solar PV installations [9]. Their findings showed that while thicker cables reduce power loss, they also increase installation costs. Therefore, an optimal balance between cable size and cost-effectiveness must be achieved. In the same vein, several methods have been proposed to reduce power loss in solar PV installations.

That step-up DC-DC converters could compensate for voltage drops in long-distance solar power transmission [21]. A hybrid AC-DC distribution network to minimize transmission losses in large-scale solar installations [10]. That placing inverters closer to PV arrays reduced transmission distances and improved system efficiency [11]. The power loss in electrical conductors is primarily governed by Ohm's Law and Joule heating, where the resistance R of the cable causes power dissipation in the form of heat according to the equation P = I2R. The resistance of a cable is directly proportional to its length and inversely related to its cross-sectional area [12]. Several studies have quantified the power losses connected with long cable runs in solar PV systems. Voltage drops of more than 2% occur when cable lengths are over 100 meters under high-load conditions, leading to efficiency losses of 3-5% [13]. Likewise, on distributed solar systems showed that oversizing the solar cable for PV installations are important in reducing energy losses and engenders cost savings [14]. These findings underscore the critical need for careful electrical design in multi-building installations. Some literature clarifies several factors influencing power loss beyond mere cable length. Cable type (copper vs. aluminum), and configuration (cross-sectional area, ambient temperature, and load current) all play significant roles [15]. For example, copper cables have lower resistivity and are generally preferred despite higher costs. The application of higher voltage systems (e.g., 600V or 1000V) is also recommended to reduce current and therefore minimize power losses over long distances [16]. Several design strategies have been proposed to mitigate cable-related efficiency losses. One commonly suggested approach is decentralization using local inverters or micro-inverters at each building rather than a central inverter to reduce the need for long DC cable runs [17]. Alternatively, employing DC-DC optimizers or smart junction boxes with maximum power point tracking (MPPT) capabilities has shown promise in improving voltage regulation and minimizing transmission losses [18].

In addition, the selection of appropriate conductor size is crucial. IEC and NEC standards offer guidelines for acceptable voltage drop thresholds, but studies such as those advocate for customized calculations based on building layout and expected solar yield [19]. Cable trenching routes, weather-proofing, and thermal insulation are also discussed in the literature as contributing factors to energy retention and operational safety. Several empirical studies have quantified the negative impact of extended cable runs on solar PV system efficiency. These losses not only reduce energy yield but also contribute to overheating and potential safety risks in long-term operation. Increasing cable cross-sectional area reduces resistance and consequently power loss. [20], modeled cable runs where doubling cross-sectional area from 2.5 mm^2 to 6 mm^2 cut losses by about 50% over a 50-meter distance, indicating cable sizing as a highly effective loss mitigation technique. However, the complementary rise in material and installation cost demands a balanced approach that considers lifecycle savings versus upfront expenses [9]. That increasing DC voltage in long-distance cables reduced resistive losses and improved system efficiency [22]. Nevertheless, this requires improved insulation and more strict safety

protocols to manage higher voltages safely. Modern power electronics, including optimizers and converters, can help reduce voltage drops by sustaining optimal voltage levels at the module level, as discussed by [23] and [24]. Their research indicates that integrating these devices can compensate for voltage losses caused by extended cable lengths, improving overall system efficiency. Electrical power losses in cables are primarily resistive (I^2R losses), where power is dissipated as heat due to the resistance of conductors. According to [1], these losses increase proportionally with the square of the current and linearly with resistance, which itself is a function of conductor length and cross-sectional area. In multi-building PV systems, where distances between generation points and the load or inverter can span hundreds of meters, this becomes a critical factor. Several studies, highlight that in large campus-style installations, cabling losses can account for up to 5–8% of generated energy if not properly designed [25]; [26]. These losses not only affect energy yield but also reduce the return on investment (ROI) for solar installations. Choosing the correct cable size and material is essential in minimizing transmission losses.

Copper and aluminum are commonly used materials, with copper having better conductivity but higher cost. As per IEEE standards (IEEE Std. 142–2007), increasing the cross-sectional area of cables reduces resistance and thereby power loss, but at a higher upfront cost. Models have been proposed to balance cable size and energy loss cost [27]. Their simulation of solar installations across multiple rooftops showed that oversizing cables by one or two standard sizes can significantly reduce losses and improve lifetime cost-effectiveness. A key decision in solar system architecture is whether to transmit electricity as DC (from panels to central inverter) or convert early to AC using string inverters or micro-inverters. DC transmission over long distances can suffer more from voltage drop due to lower voltage levels and higher currents. A study by [28], compared DC and AC architectures in a university campus in India and found that decentralized AC systems significantly reduced cable losses and increased modularity and reliability. However, with proper voltage regulation and high-voltage DC systems (HVDC), some researchers suggest that centralized DC setups can still be viable, particularly when combined with Maximum Power Point Tracking (MPPT) technologies [29],. Modern solar installations are employing several strategies to counteract the effects of cable losses. One of the most effective is decentralizing power conversion by using string inverters or micro-inverters at the building level. That decentralized systems reduce the need for long DC cable runs and localize energy conversion, significantly improving efficiency and reliability [17]. Another promising solution involves the use of DC-DC optimizers or smart junction boxes, which manage voltage levels and help stabilize power delivery across varying distances [9]. Proper cable sizing also plays a pivotal role in reducing losses. Industry guidelines such as those from the IEC and NEC recommend limiting voltage drop to fewer than 3% for optimal performance, which can be achieved through careful selection of conductor size and routing paths. The importance of dynamic cable sizing based on system load, layout, and climate conditions [19]. Additionally, thermal insulation and appropriate conduit design are vital to managing the effects of ambient temperature and preventing degradation.

The efficiency of solar installations across multiple buildings is significantly influenced by cable length and related transmission losses. While the theoretical foundations of cable losses are well understood, their practical implications in large-scale, multi-building setups demand a more nuanced approach to system design. Advances in decentralized architectures, cable technology, and smart energy management offer promising avenues to mitigate these challenges. As solar adoption continues to grow in complex facilities, incorporating detailed cabling analysis into the design phase will be essential for optimizing energy efficiency and economic returns and also cable length plays a critical role in determining the efficiency of solar installations, especially in multi-building facilities where transmission distances can be substantial. The research review highlights that losses can be significant if not properly mitigated through careful system design, decentralized inverters, smart energy management devices, and optimal cable selection. As solar adoption in large facilities continues to grow, addressing the challenge of cable-induced losses will be essential for achieving cost-effective and energy-efficient operation.

Understanding power loss mechanisms and implementing corrective measures such as appropriate cable length, cable sizing, optimal circuit design, and strategic placement of power equipment can significantly enhance solar system performance. The findings of this study will contribute essentially to: (i) Engineering Advancement: Providing valuable insights into power loss mechanisms in long-distance solar power cable energy transmission, which will contribute to improved system designs. (ii) Cost Reduction: Reducing power losses can lower operational and maintenance costs, making solar installations more economically viable. (iii) Sustainability: Improvement of solar power efficiency which will support/ contribute to global efforts toward renewable energy adoption and sustainability. (iv) Policy and Standards Development: The findings from this study can inform engineering policies, guidelines and standards for solar system design efficiency in single and multi-building facility setups. (v) The findings of this study will also contribute to the best practices in optimizing solar power cable length for efficient solar power electric distribution/ transmission.

The investigation of the impact of solar (PV) power cable length on the efficiency of power transmission in a multi-building set-up, adopting twenty cable length variations within the ranges of 32m to 283m, and using resistance, voltage drop, power loss, and efficiency as the solar (PV) power cable output parameters for analysis is the gap this experimental research study covered.

2. Method

This study employs an experimental and computational approach to investigate the impact of cable length on power distribution efficiency in a solar PV system. The research is divided into three main phases: (A). Experimental Setup and Data Collection: which involves; (i) the experimental measurement of the solar power cable length from the solar panel to the inverter/ battery systems at the building under investigation; (ii) the load/ supply measurements; (iii) the development of nineteen (19) hypothetical values to augment the single experimental value for the computational analysis of the cable length efficiency for twenty different buildings in a multi-building facility setup. (B). Theoretical Analysis: which involves the application of mathematical models of the electric circuit theory to analytically compute the power loss, voltage drop, and resistance and the efficiency of the twenty (20) variations of cable lengths representing the twenty (20) cable length distances from the solar panel to the twenty (20) inverters in the twenty (20) different buildings in a multi-building facility setup. (C). Optimization and Computational Analysis: which involves; (i) the determination of the efficiency of solar power cable transmission using the values of the power loss, voltage drop, and resistance of the twenty (20) different cable lengths; (ii) comparison of the results of the efficiencies of the twenty (20) different cable lengths in order to determine the most optimized/ efficient cable length.

The following materials and equipment would be used for this study: measuring tape (in meters) to measure the experimental solar (PV) power cable length; solar (PV) panels (420W) for the generation of the DC current; inverter (5kVA) to convert DC power to AC for load distribution; power storage battery; circuit breakers (charge controller to regulate voltage levels and prevent systems overcharging/ damage); copper solar (PV) power cable of cross-sectional area of 1.0×10^{-5} m^2 and resistivity of 1.68×10^{-8} Ωm; and finally, a multi-meter for measuring the voltage and current.

2.1. Load Components

Resistive Load: Electric bulbs, refrigerator and heating elements for testing system efficiency and performance.

2.2. Experimental Setup

The experimental setup consists of a solar (PV) panel system transmitting power to a simulated multi-building facility. The system configuration includes: a power source or solar panels (420W) generating DC electricity; 5kVA inverter system converting DC to AC for load distribution; power or energy storage (battery); cable length in the variations of 32m, 41m, 55m, 125m, 138m, 283m etc. cable lengths to assess resistances, voltage drops and the power losses of the varied cable lengths in the multi-facility setup; measurement points where voltage and current are measured, e.g. at the source: solar (PV) panel output, and at each of the load or supply ends to calculate efficiency and losses or drops; electrical loads connected at different points or distances to simulate a multi-building setup.

2.3. Data Collection Process

The following data was collected for the cable lengths of the same cross-sectional area, thickness and resistivity: voltage at the source (Vs) and load (V1); current (I) flowing through the circuit; Power input (Pinput) and power output (Poutput); resistance (R) of each of the cable lengths.

2.4. Mathematical Models of Circuit Theory for Computational Analysis

Voltage drop is calculated using the Ohm's law in Equation (1):

$$V_{drop} = I \text{ X } R \tag{1}$$

Power dissipated due to resistance in the cable is given by Equation (2):

$$Ploss = I2 \times R \tag{2}$$

Efficiency is calculated using the mathematical model in Equation (3):

$$\eta = \left(1 - \frac{Ploss}{Pinput}\right) \times 100\% \tag{3}$$

Computational analysis was performed using Equations 1, Equation 2, and Equation 3, for each of the twenty (20) variations of the cable length for the simulated multi-building facility as shown in Table 1 and Table 2 below.

Table 1. Input Parameter [Standard Copper Solar (PV) Power Cable of Varied Lengths, but of the same Cross-Sectional Area, Resistivity and Thickness]

Cable Length (m)	Resistivity (Ωm)	Cross-Sectional Area(m^2)	Thickness (mm2)
32	1.68×10^{-8}	1.0×10^{-5}	10
41	1.68×10^{-8}	1.0×10^{-5}	10
55	1.68×10^{-8}	1.0×10^{-5}	10
90	1.68×10^{-8}	1.0×10^{-5}	10
102	1.68×10^{-8}	1.0×10^{-5}	10
112	1.68×10^{-8}	1.0×10^{-5}	10
118	1.68×10^{-8}	1.0×10^{-5}	10
125	1.68×10^{-8}	1.0×10^{-5}	10
130	1.68×10^{-8}	1.0×10^{-5}	10
138	1.68×10^{-8}	1.0×10^{-5}	10
141	1.68×10^{-8}	1.0×10^{-5}	10
147	1.68×10^{-8}	1.0×10^{-5}	10
148	1.68×10^{-8}	1.0×10^{-5}	10
160	1.68×10^{-8}	1.0×10^{-5}	10
172	1.68×10^{-8}	1.0×10^{-5}	10
230	1.68×10^{-8}	1.0×10^{-5}	10
250	1.68×10^{-8}	1.0×10^{-5}	10
265	1.68×10^{-8}	1.0×10^{-5}	10
276	1.68×10^{-8}	1.0×10^{-5}	10
283	1.68×10^{-8}	1.0×10^{-5}	10

Table 2. Input Parameter/ Output Parameters

INPUT PARAMETER	OUTPUT PARAMETERS			
Cable Length (m)	Resistance (Ω)	Voltage Drop (V)	Power Loss (W)	Efficiency (η)
32	0.05376	0.5376	5.376	99.78
41	0.06888	0.6888	6.888	99.71
55	0.0924	0.924	9.24	99.615
90	0.1512	1.512	15.12	99.245
102	0.17136	1.7136	17.136	99.286
112	0.18816	1.8816	18.816	99.216
118	0.19824	1.9824	19.824	99.174
125	0.21000	2.1	21	99.125
130	0.2184	2.184	21.84	99.09
138	0.23184	2.3184	23.184	99.034
141	0.23688	2.3688	23.688	99.013
147	0.24696	2.4696	24.696	98.971
148	0.24864	2.4864	24.864	98.964
160	0.2688	2.688	26.88	98.88
172	0.28896	2.8896	28.896	98.796
230	0.3864	3.864	38.64	98.39
250	0.42	4.2	42	98.25
265	0.4452	4.452	44.52	98.145
276	0.46368	4.6368	46.368	98.068
283	0.47544	4.7544	47.544	98.019

The resistance of a cable is given by Equation 4.

$$R = \frac{\rho \times L}{A} \tag{4}$$

Where:
ρ = resistivity of the cable material (Ω. mm^2/ m)
L = cable length (m),
A = cross-sectional area of the cable (mm^2/ m^2)

Total system efficiency is evaluated as Equation 5.

$$\eta = \frac{Poutput}{Pinput} \times 100\% \tag{5}$$

Where P_{output} is the power received at the load, and P_{input} is the power generated by the solar panel.

2.5. Overview of Power Loss Scenarios and Optimization Strategies

In this study power loss scenario is analyzed by investigating the relationship between increasing cable lengths and efficiency reduction. Power loss in solar panel electrical systems can occur due to several factors. Here are some of the key factors and their mathematical representations:

2.5.1. Resistive Losses

The primary cause of power loss in cables is the resistance of the conductors. The power loss due to resistance can be calculated using the Equation 6.

$$\text{Power loss, } P = I2 \times R \tag{6}$$

The resistance of a cable depends on the material properties and its physical dimensions. Specifically, cable resistance is influenced by the electrical resistivity of the conductor material, the length of the cable, and its cross-sectional area. This relationship is expressed in Equation 7.

$$\text{Therefore, } R = \frac{ƒ}{A} \tag{7}$$

Where;
ƒ is resistivity in ohms-meter (Ωm)
A is the cross-sectional area of the cable in meter square (m^2)
L is the length of the conductors in (m)

2.5.2. Voltage Drop

As current flows through a cable, a voltage drop occurs due to the resistance, resulting in a decrease in voltage. The voltage drop can be calculated as Equation 8.

$$V = I \times R \tag{8}$$

Where,
V = voltage drop (V)
I = current (A)
R = resistance (Ω)

This drop can lead to insufficient voltage at the inverter or load, affecting the performance of the solar power system.

2.5.3. Efficiency Losses in Inverters and Converters

Efficiency losses occur due to the conversion of DC power to AC power or vice versa. Mathematical representation is expressed by Equation 9:

$$\eta = \frac{\text{Power output}}{\text{Power input}} \tag{9}$$

Where: η = efficiency (%)
Power output (W)
Power input (W)

2.5.4. Cable Quality and Type

Different types of cables (e.g., copper vs. aluminum) have varying resistivities which can influence power loss. The choice of cable material and quality can significantly impact the overall efficiency of the solar power system, hence, the following are recommended:

a. Using thicker cables to reduce resistance.

b. Employing step-up transformers or DC-DC converters to improve transmission efficiency.

c. Strategic placement of inverters and distribution points to shorten cable runs.

Through a detailed analysis of these factors, the study aims to propose the most efficient connection strategy for ensuring reliable and efficient solar power supply in multi-building facilities.

2.6. Electric Circuit Models for Power Loss Analysis

To quantify power losses, mathematical models have been developed based on Ohm's Law and Joule's Law. The following key Equations 10, Equation 11, and Equation 12 are commonly used in power loss analysis:

Voltage Drop in DC Circuits:

$$V_{drop} = \frac{2 \times I \times L \times \rho}{A} \quad (10)$$

Where:
L is the cable length in meters,
ρ is the resistivity of the cable material,
A is the cross-sectional area of the cable in mm^2.

Voltage Drop in AC Circuits:

$$Vdrop = \frac{I \times (R\cos\theta + X\sin\theta)}{Vsource} \quad (11)$$

Where:
X is the reactance of the cable and θ is the power factor angle.

Efficiency Calculation:

$$\eta = \left(1 - \frac{Ploss}{Pinput}\right) \times 100\% \quad (12)$$

This equation is used to determine the percentage efficiency of the system based on input power and power loss.

2.7. The Mathematical Relationship between Power Loss and Cable Resistance is derived from Ohm's Law and the Power Dissipation Formula.

Power Loss Formula in Equation 13.

$$P_{loss} = I^2 \times R \quad (13)$$

Where:
P_{loss} = Power loss in the cable (watts, W)
I = Current flowing through the cable (amperes, A)
R = Cable resistance (ohms, Ω)

Key Relationships :

Power loss is directly proportional to resistance formulated as an Equation 14:

$$P_{loss} \alpha R \quad (14)$$

This means that as the resistance of the cable increases, power loss increases.

Power loss is proportional to the square of the current formulated as an Equation 15:

$$P_{loss} \alpha I^2 \quad (15)$$

If the current doubles, power loss increases fourfold.

2.8. Relationship with Cable Dimensions:

The resistance R of a cable depends on its length (L), cross-sectional area (A), and material resistivity (ρ) formulated as an equation 16:

$$R = \rho \frac{L}{A} \tag{16}$$

Substituting into the power loss Equation 17:

$$P_{loss} = I^2 \rho \frac{L}{A} \tag{17}$$

Implications:

a. Longer cables increase power loss because R increases with L.
b. Thicker cables reduce power loss because R decreases as A increases.
c. Choosing a low-resistivity material (e.g., copper over aluminum) reduces power loss since R is lower for materials with smallerρ.

This formula is crucial for designing efficient electrical and solar systems, as minimizing resistance reduces energy losses and improves overall efficiency.

2.9. The Mathematical Relationship between Power Loss and Voltage Drop in a Cable can be derived from Ohm's Law and the Power Dissipation Formula.

Key Equations:

Voltage Drop (V_{drop}) using Ohm's Law formulated as an Equation 18:

$$V_{drop} = I R \tag{18}$$

Where:
V_{drop} = Voltage drop across the cable (volts, V)
I = Current flowing through the cable (amperes, A)
R = Cable resistance (ohms, Ω)

Power Loss (P_{loss}) in a Cable formulated as an Equation 19 :

$$P_{loss} = I^2R \tag{19}$$

Deriving the Relationship between Power Loss and Voltage Drop

Substituting $R = \frac{Vdrop}{I}$ into the power loss Equation 20:

$$P_{loss} = I^2 \left(\frac{Vdrop}{I} \right) \tag{20}$$

Simplifying, formulated as an Equation 21:

$$P_{loss} = IV_{drop} \tag{21}$$

Final Relationship formulated as an Equation 22:

$$P_{loss} \alpha V_{drop} \tag{22}$$

Key Insights:

a. Power loss is directly proportional to the voltage drop across the cable.
b. For a given current, reducing voltage drop reduces power loss.
c. Thicker cables (lower resistance) reduce both voltage drop and power loss.
d. Lower current reduces both voltage drop and power loss.

This equation is crucial in electrical system design, especially in solar installations, power distribution, and long-distance transmission, where minimizing voltage drop helps improve efficiency and reduce energy losses.

2.10. Voltage Drop and Power Loss

Voltage drop is a reduction in electrical potential along the length of a conductor due to resistance. It is mathematically expressed as Equation 23:

$$V_{drop} = I \times R \quad (23)$$

Where:
V_{drop} is the voltage drop in volts
I is the current in amperes,
R is the resistance of the cable in ohms

Power loss is directly proportional to the voltage drop across the cable. See Electrical Circuit Theory, Equation 24 above.

$$\text{Power loss} = I^2 \times R \quad (24)$$

This formula shows that power loss is proportional to the square of the current and the resistance of the cable. As cable length increases, resistance increases, resulting in greater power dissipation.

2.11. Factors Affecting Power Loss in Solar Installations

Several factors contribute to power loss in solar PV installations. They include:

a) Cable Length: Longer cables introduce higher resistance, increasing power losses.
b) Cable Material: Copper cables have lower resistance compared to aluminum, making them more efficient for power transmission.
c) Cable Cross-Sectional Area: Thicker cables have lower resistance, reducing power loss.
d) Current Flow: Higher current levels lead to greater power dissipation due to resistive heating.
e) Temperature Effects: Higher ambient temperatures can increase cable resistance, further exacerbating voltage drop.

2.12. Optimal Connection for Efficient Power Supply in Multi-Building Facilities

To achieve optimal efficiency in solar power distribution, several connection strategies must be considered. They include:

a) Minimizing Cable Length:
   a. Locating inverters and distribution panels closer to solar panels.
   b. Using direct connections instead of complex wiring layouts.

b) Using High-Efficiency Conductors:
   a. Employing copper cables instead of aluminum for lower resistance.
   b. Selecting cables with optimal cross-sectional areas based on power demand.

c) Implementing Voltage Regulation Techniques:
   a. Using step-up transformers or boost converters for long-distance transmission.
   b. Employing Maximum Power Point Tracking (MPPT) systems to maintain optimal voltage levels.

d) Hybrid AC-DC Distribution:
   a. Combining AC and DC power distribution to reduce conversion losses.
   b. Using local AC micro-grids for efficient energy distribution across multiple buildings.

2.13. Fundamentals of Power Transmission in Solar Panel Systems

Solar panel systems generate direct current (DC) electricity, which is either used directly or converted to alternating current (AC) using an inverter. The generated power is transmitted through cables to storage units or directly to electrical loads. During this transmission, electrical resistance in cables causes energy dissipation, leading to power losses.

2.14. Relationship between Cable Length, Resistance, Voltage Drop, Power Loss and Efficiency

The results confirm the theoretical principle that resistance is directly proportional to cable length. Longer cables inherently exhibit higher resistance, which in turn causes a greater voltage drop.

Voltage drop in solar direct current (DC) cables can be expressed as Equation 25.

$$Vdrop = I \times R \quad (25)$$

where I is the current and R is the resistance of the cable.

In practice, the resistance of a conductor is calculated as Equation 26

$$R = \rho \times \left(\frac{L}{A}\right) \quad (26)$$

Where:
I is the current and R is the resistance of the cable.
ρ = resistivity of conductor material,
L = length of the cable,
A = cross-sectional area of the cable.

This explains why, as the length increased from 41 m to 283 m, the resistance rose from 0.06888 Ω to 0.47544 Ω, and voltage drop increased proportionally from 0.6888 V to 4.7544 V.

2.15. Power Loss and Efficiency

Power loss due to cable heating is governed by the Equation 27:

$$P_{loss} = I^2 \times R \quad (27)$$

Thus, as resistance rises with length, power loss increases quadratically with current flow. This trend is evident in the results: at 41 m, power loss was only 6.888 W, while at 283 m, power loss surged to 47.544 W.

Although efficiency values above 98% appear acceptable, the absolute energy losses over time can be considerable. For instance, a daily solar production of 20 kWh per building losing just 2% efficiency across 20 buildings could result in a cumulative annual loss exceeding 2,920 kWh, which translates to significant economic implications for large facilities.

2.16. Compliance with Industry Standards

The National Electrical Code (NEC) and International Electro-technical Commission (IEC) recommend limiting voltage drop in photovoltaic (PV) systems to ≤3% for feeders and branch circuits (Go Solar Power, 2025; Azad Tech Hub, 2025). The measured 41 m case produced a voltage drop of 0.6888 V, which is well below 3% for common PV operating voltages (e.g., 48 V or higher), thus demonstrating compliance with industry best practices.

3. Results and Discussion

This study investigated the effect of solar (PV) power cable length on the efficiency of power transmission in a multi-building facility setup, focusing on resistance, voltage drop, power loss, and the overall system power transmission efficiency. The experimental data were obtained by varying cable lengths between the solar panels and inverters and calculating corresponding resistances, voltage drops, power losses, and efficiencies. The system design consideration/ experimental setup focuses on the layout for panel installation, which was on the roof of the experimental building; configuration and connection, which centered on the cable routing from the roof panels to the solar power gadgets (the circuit breakers, the inverter, the power storage battery and the distribution board); the data collections which was based on the load or supply measurements, and the computational analysis for the derivation of the power losses, voltage drops, resistances and the efficiency values using the mathematical models of the electric circuit theory. These formed the ground or foundational technique for the modeling of the solar power transmission efficiency based on partly experimental measurement and computational analytical approach using the electric circuit model theory. This methodology aims to provide a system design approach to evaluating power losses, voltage drops, resistances and efficiency in solar power cable lengths and determining efficient cable lengths for optimal or efficient power transmission in multi-building facility system.

In this research study, the experimental and hypothetical values were obtained and generated. The computational values were obtained using the electric circuit theory for calculating voltage drop, power loss, efficiency, and resistance (Equations 1, 2, 3, and 4 above respectively). These makes up the data for this research study and are presented in Table 2 above.

The experimental cable length was obtained by measuring the cable length from the solar panel installed on the roof of the experimental building to the inverter using a measuring tape. Forty-one meters (41m) was obtained as the experimental value of the experimental cable length. Building on the experimental cable length real value, nineteen (19) hypothetical cable length values were generated. One (1) length would be shorter than the experimental cable length value, and eighteen (18) lengths would be longer than the experimental cable length value. This is to make a realistic comparison and prediction through mathematical computations using electric circuit model theorems, of the effects of cable length (input parameter) on four cable length output parameters, namely: voltage drop, power loss, resistance and efficiency in order to determine the effects of cable length on solar (PV) power transmission efficiency in a multi-building facility setup. The research study shows that all the output parameters (voltage drop, power loss, resistance) increases with an increase in solar power cable length, decreasing the efficiency of the power transmission of the solar power cable whether in a single or multi-facility setup. At a baseline cable length of 41m, which represents the actual cable length distance from the solar panels to the power system (inverter) in the facility under study, the following output parameters were recorded: Cable length - 41m; Resistance - 0.06888Ω; Voltage drop – 0.6888V; Power loss – 6.888W; and Efficiency – 99.71%. Across the range of cable lengths tested (32m – 283m), the efficiency consistently remained high, above 98%, though gradual reductions were observed with increasing length. For instance, at 230m, efficiency dropped to 98.39%, and at 283m, efficiency was further reduced to 98.02%. For the lowest hypothetical cable length of 32m; Resistance – 0.05376Ω; Voltage drop – 0.5376V; Power loss – 5.376W; and Efficiency – 99.78%, while for the highest hypothetical cable length of 283m; Resistance – 0.47544Ω; Voltage drop – 4.7544V; Power loss – 47.544W; and gave a transmission efficiency value of 98.02%. The conventional circuit theorem was used to derive each of the values of each of the output parameters (voltage drop, power loss, resistance and efficiency), from the input parameter (cable length) for the twenty (20) variations of cable length used for this study. The data confirms theoretical expectations; voltage drop and power losses increase with cable length, and even modest incremental length reduces efficiency. In a multi-building context, cumulative losses across 20 buildings, though individual losses could be small, still compounds to meaningfully reduce the total system yield. Design optimization should aim at each cable run to remain below 3% voltage drop. While the 41m baseline satisfies this, longer runs may exceed the recommended thresholds. For instance, at 230m, efficiency is ~98.39%. If the system operates at 48V, this remains acceptable, but in 12 V systems, such losses could be critical. Even at high efficiencies, wasted power (e.g., ~38.64 W lost at 230 m) represents tangible energy loss when multiplied across all the buildings. Industry standards (NEC, IEC) emphasizes ≤3% voltage drop and literature recommends higher system voltages and thicker cables as mitigation strategies. Thus, careful system design is essential for sustainable multi-building solar power installations and efficient transmission.

While this research aims to present a detailed analysis, certain limitations were encountered in the course of executing this research project. They include: (i) Environmental Factors: The study may not account for all external factors, such as climatic and weather conditions that can affect solar power performance. (ii) Financial Constraints: The selection of cable materials and configurations will be subject to budget limitations, which may affect the feasibility of some recommendations. (iii) Data Availability: The accuracy of findings may depend on the availability of real-world data from existing solar installations and literatures. (iv) Scalability: The study focuses on specific multi-building facilities and may require further research for applicability to larger or smaller-scale setups.

4. Conclusion

This study successfully achieved its objectives by demonstrating the clear and consistent impact of solar power cable length on transmission efficiency in a multi-building facility setup. By combining one experimentally measured cable length with nineteen hypothetical variations, the research established how cable length affects resistance, voltage drop, power loss, and overall system efficiency. Mathematical models of electric circuit theory confirmed that increases in cable length lead to higher resistance, greater voltage drops, and increased power loss, which collectively reduce the efficiency of power transmission.

The findings conclusively show that shorter solar power cables result in better transmission efficiency, with lower voltage drop, reduced power loss, and decreased resistancen key factors for optimizing solar PV system performance. Conversely, longer cables consistently produced diminished efficiency and higher losses. These outcomes underscore the importance of minimizing or optimizing cable lengths in solar installations, particularly in multi-building environments. Overall, the study validates the central premise that cable length is a critical determinant of solar PV transmission performance, and optimizing cable design is essential for enhancing the reliability, efficiency, and sustainability of solar energy systems.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

Funding

No funding support was received.

Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

References

[1] G. M. Masters, *Renewable and Efficient Electric Power Systems*. Wiley, 2013.

[2] S. Ekici and M. A. Kopru, "Investigation of PV system cable losses," *International Journal of Renewable Energy Research*, vol. 7, no. 2, pp. 807–815, 2017

[3] Shen, Z. Li, and T. Ma, "Analysis of the power loss and quantification of the energy distribution in PV module," *Applied Energy, vol. 260*, p. 114333, 2020, doi: 10.1016/j.apenergy.2019.114333.

[4] Jamil, H. A. Rahman, S. Shaari, and Z. Salam, "Performance degradation of photovoltaic power system: Review on mitigation methods," *Renewable and Sustainable Energy Reviews, vol. 67*, pp. 876–891, 2017, doi: 10.1016/j.rser.2016.09.072.

[5] B. Aboagye, S. Gyamfi, E. A. Ofosu, and S. Djordjevic, "Investigation into the impacts of design, installation, operation and maintenance issues on performance and degradation of installed solar photovoltaic (PV) systems," *Energy for Sustainable Development, vol. 66*, pp. 165–176, 2022, doi: 10.1016/j.esd.2021.12.003.

[6] W. S. Ebhota and P. Tabakov, "Influence of cabling on photovoltaic system performance: Wire length, diameter, and material," *Kurdistan Journal of Applied Research, vol. 10,* no. 1, pp. 50–65, 2025, doi: 10.24017/science.2025.14.

[7] J. Ehnberg, M. A. Gelchu, and P. D. Uwitije, "Assessing cable sizing for PV micro-grids: Economic and environmental factors," in Proc. IEEE PES/IAS PowerAfrica, 2024, doi: 10.1109/PowerAfrica61624.2024.10759427.

[8] L. A. I. Carrera et al., "Efficiency and sustainability in solar photovoltaic systems: A review of key factors and innovative technologies*," Engineering, vol. 6,* no. 3, p. 50, 2025, doi: 10.3390/eng6030050.

[9] A. Narasimhan, "Qualitative assessment of PV system cable loss and practical cost optimization," in Proc. *IEEE CONECCT*, 2020, doi: 10.1109/CONECCT50063.2020.9198671.

[10] A. Rajkumar and S. Gangatharan, "A novel solar PV equipped flexible AC/DC micro-grid energy management for residential power distribution," *IEEE Canadian Journal of Electrical and Computer Engineering, vol. 45*, no. 3, 2022, doi: 10.1109/ICJECE.2022.3189687.

[11] S. Rathee et al., "Assessment of two 20 kW PV solar energy plants in homogenous environments," in Proc. *IEEE PEEIC*, 2023, doi: 10.1109/PEEIC59336.2023.10451686

[12] M. P. Nair and K. Nithiyananthan, "Effective cable sizing model for building electrical services," *Bulletin of Electrical Engineering and Informatics, vol. 5,* no. 1, 2016, doi: 10.11591/eei.v5i1.516.

[13] A. Chouder and S. Silvestre, "Automatic supervision and fault detection of PV systems based on power losses analysis," *Energy Conversion and Management, vol. 51*, no. 10, pp. 1929–1937, 2010, doi: 10.1016/j.enconman.2010.02.025.

[14] A. D. Mosheer and C. K. Gan, "Optimal solar cable selection for photovoltaic systems," *International Journal of Renewable Energy Resources, vol. 5*, pp. 28–37, 2015.

[15] L. S. Y. Ting, S. S. L. Ngu, Y. L. Then, and A. C. Azhar, "Resistive loss in PV array configurations: Impact of cable length and cross-section on power performance," *in Proc. IEEE ICPEA,* 2025, doi: 10.1109/ICPEA65539.2025.11198188.

[16] M. Abujubbeh, M. Fahrioglu, and F. Al-Turjman, "Power loss reduction and voltage enhancement via distributed photovoltaic generation: Case study in North Cyprus," *Computers and Electrical Engineering, vol. 95*, p. 107432, 2021, doi: 10.1016/j.compeleceng.2021.107432.

[17] D. Bondarenko and S. Matyakh, "Using micro-inverters for photovoltaic cluster," *Vidnovluvana Energetika, vol. 1*, no. 76, 2024, doi: 10.36296/1819-8058.2024.1(76).51-56.

[18] K. H. Tajaldin and H. J. Motlak, "Enhancement of DC–DC Luo converter using adaptive PI MPPT and P&O MPPT for photovoltaic system," *Journal Européen des Systèmes Automatisés, vol. 57,* no. 3, pp. 921–933, 2024, doi: 10.18280/jesa.570330.

[19] S. R. Madeti and S. N. Singh, "Modeling of PV system based on experimental data for fault detection using KNN method," *Solar Energy, vol. 173*, pp. 139–151, 2018, doi: 10.1016/j.solener.2018.07.038.

[20] A. Agha and K. Alzaareer, "Optimized economic cross-sectional area of low-voltage power cables using minimum energy loss computing," *Journal of Electrical and Computer Engineering*, vol. 2025, no. 1, 2025, doi: 10.1155/jece/9983157.

[21] V. Marzang et al., "A high step-up non-isolated DC–DC converter with flexible voltage gain," *IEEE Transactions on Power Electronics, vol. 35*, no. 10, 2020, doi: 10.1109/TPEL.2020.2976829.

[22] R. Liu, "Progress of long-distance DC electrical power transmission," *in Proc. ICEMPE*, 2017, doi: 10.1109/ICEMPE.2017.7982153.

[23] D. Guo et al., "Series bipolar hybrid voltage optimizer based on switching-cell-inserted direct AC–AC converter and multi-windings transformer," *IEEE Transactions on Power Electronics, vol. 41,* no. 1, 2025, doi: 10.1109/TPEL.2025.3604579

[24] Y. Chen, X. Zhang, J. Li, H. Wang, and P. Zhou, "Role of power optimizers in reducing cable losses," *IEEE Journal of Photovoltaics*, 2021.

[25] R. Patel, D. Shah, and K. Sharma, "Power loss analysis in solar PV installations: Case study on multi-building campus," *International Journal of Renewable Energy Research, vol. 8,* no. 3, pp. 1241–1249, 2018.

[26] R. Sharma and S. Singal, "Energy loss due to long cable transmission in rooftop solar systems," *Energy Reports, vol. 6*, pp. 183–192, 2020.

[27] M. Ali and F. Khan, "Economic optimization of cable sizing in PV systems," *Solar Energy, vol. 187,* pp. 102–109, 2019

[28] P. Nema, R. Nema, and S. Rangnekar, "Comparative analysis of DC and AC distributed solar systems," *Renewable Energy Focus, vol. 39*, pp. 34–42, 2021.

[29] Y. Wang, T. Li, and J. Qiu, "High voltage DC solar micro-grid: An efficient design for large campus networks," *Energy Conversion and Management, vol. 148,* pp. 945–955, 2017