VOLTAGE DROP COMPENSATORS FOR LONG CABLE RUNS

WHITE PAPER

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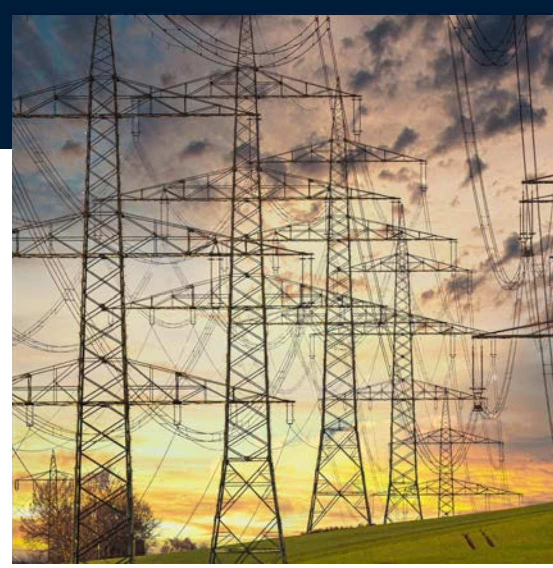
OVERVIEW

Voltage drop results in the irregular operation of loads and can cause significant damage to electrical equipment. If not addressed, the drop, which is common in long cable runs – often leads to operational interruptions, instabilities, and substantial financial losses. The goal of a good electrical design process is to ensure the voltage drop levels are within the allowable range, regardless of the size of the load.

While there are several methods or practices of reducing voltage drop and their effects, using the conventional methods is costly and may not deliver significant savings. However, there are effective technologies such as the use of voltage drop compensators and others that help to maintain the levels within acceptable limits, hence delivering huge cost and operational benefits.

This paper will outline the causes of voltage drops, allowable limits, how to calculate the voltage drops, and finally, examine possible cost-effective solutions.



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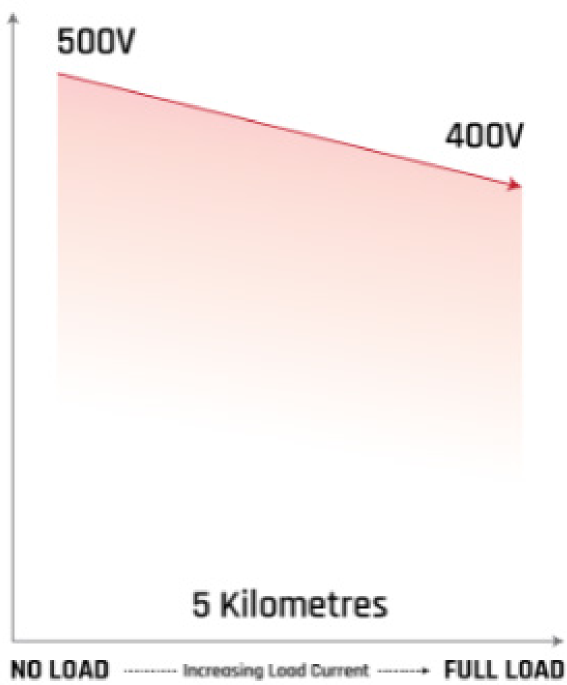
WHAT ARE VOLTAGE DROPS?



Voltage drop is the decrease of electrical voltage as current flows within an electrical circuit. The drop leads to a lower voltage at the endpoint. When current passes through an electrical circuit, a voltage drop occurs due to the resistance or impedance to the flow of the current.

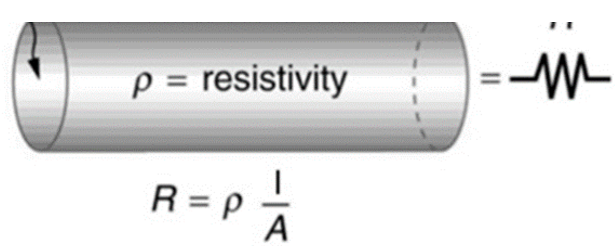
The resistance or impedance is usually due to the passive elements such as the transmission cables, connection points, contacts, and other factors. Generally, the amount of resistance or impedance in the circuits determines the level of the voltage drop. A common analogy to illustrate a voltage drop is water flowing along a hose pipe. The further away from the connection tap, the stream of water becomes weaker as it flows out.

This is also true for electricity, the longer the distance from the electric source, the weaker the voltage will be due to the losses along with the transmission and distribution networks. In practice, the longer the transmission cables, the more the voltage drop

What Factors Affect Voltage Drop?

The voltage drop in an electrical circuit increases with the resistance of the various components along the current path. As such, any issues that affect the resistance or impedance such as temperature will also have an influence on the voltage. For example, during hot weather, the high temperature increases the resistance of the conductors and consequently the voltage drop.

One property that influences the voltage drop is resistivity, ρ, which is the measure of how a material or conductor opposes the flow of current. The resistance of a material is directly proportional to the resistivity, expressed in ohms meter (Ωm), as shown below.



Resistance of a conductor Image: Elprocus

Besides the resistivity which is constant, below is a list of some of the factors that lead to voltage drop.

As can be seen, resistivity has a great impact on resistance and voltage drop.

Factors That Lead To Voltage Drop

Factor	Effect
Long-Distance Cable Runs	The resistivity of a conductor is directly proportional to the length of the conductor or circuit. As such, shorter conductors will experience lower voltage drops compared to longer cables since the resistivity of the conductor is smaller.
Size Or Gauge Of Conductors	Resistivity is inversely proportional to the cross-sectional area of a conductor. Under a constant current, conductors with small diameters experience higher voltage drops than those with larger diameters and the same length.
Type Of Conductor Material	The resistivity value of each material is different. Some materials have lower resistivity than others. Copper has a lower resistivity compared to Aluminum, hence a more efficient conductor. Conductors with higher resistivity, the higher the voltage drops.
The Temperature Of The Conductor	The resistivity of conductors is affected by temperature. An increase in temperature results in an increase in resistance within a conductor. This is due to increased oscillation of the electrons due to the gain of energy, which results in more collisions, hence increased resistance.
Current Carried By The Conductor (Ampere Load)	With the resistance held constant, an increase in current flowing through the circuit will result in more voltage drop. This is due to Ohms Law where Voltage (V) = Current (I) x Resistance (R)
Connections In The Circuit	The connections of loads and connection points in a power supply system or circuit introduce impedances and resistances. If the connections are done poorly, resistance and impedance increases hence increasing voltage drop within the circuit

HOW DO YOU CALCULATE VOLTAGE DROPS

Energy companies should consider the potential voltage drops and effects when designing long transmission lines. When calculating voltage drops, one needs to find and use the corresponding coefficient value from Table 4E4B - Voltage drop per ampere, per meter 70°C conductor operating temperature.

VOLTAGE DROP PER AMPERE PER METER (mV). Conductor operating temperature: 70°C

Conductor Cross Sectional Area mm	Two Core Cable D.C. mV	Two Core Cable Single Phase A.C. mV			Three or Four Core Cable Three phase A.C. mV		
1.5	29	29			25		
2.5	18	18			15		
4	11	11			9.05		
6	7.3	7.3			6.04		
10	4.4	4.4			3.08		
16	2.8	2.8			2.04		
		r	x	z	r	x	z
25	1.75	1.75	0.170	1.75	1.50	0.145	1.50
35	1.25	1.25	0.165	1.25	1.10	0.145	1.10
50	0.93	0.93	0.165	0.94	0.80	0.140	0.81
70	0.63	0.63	0.160	0.65	0.55	0.140	0.57
95	0.46	0.47	0.155	0.50	0.41	0.135	0.43
120	0.36	0.38	0.155	0.41	0.33	0.135	0.35
150	0.29	0.30	0.155	0.34	0.26	0.130	0.29
185	0.23	0.28	0.150	0.29	0.21	0.130	0.25
240	0.180	0.190	0.150	0.24	0.165	0.130	0.21
300	0.145	0.155	0.145	0.21	0.136	0.130	0.185
400	0.105	0.115	0.145	0.185	0.100	0.125	0.160

Extract from the IEE Wiring Regulations, 17th Edition

Calculating Voltage Drop for a 3-Phase Circuit

To calculate the voltage drop for a 3-Phase circuit, use the formula

$$VD = \frac{mV/A/m * I * L}{1000}$$

Where,
VD is the voltage Drop
mV/A/m is a constant value from Table **4E4B** above
I is the actual current
L is the length in meters

Procedure

Step 1: Take the value from the volt drop table 4E4B (mV/A/m) for the cable cross-section area you want to use.
Step 2: Multiply the actual current the cable will deliver (do not use the cable rating).
Step 3: Multiply by the length of cable run in meters.
Step 4: Divide results by 1,000 (to convert millivolts to volts)

$$VD = \frac{0.33 * 100 * 200}{1000}$$

For example, if you are using a 4 core, three-phase cable 200 meters, current of 100A, with a cross-section area of 120mm2, you will go to the table and pick the coefficient relating to r. In our case, this value will be 0.33. As such, the voltage drop will be: The Voltage drop for our case will be 6.6V for the cable. The percentage voltage drop will be (6.6/400)*100 which gives us 1.65% which is within the allowable limits.

ALLOWABLE VOLTAGE DROP LIMITS IN SELECTED REGIONS

Maximum allowable voltage drop limits vary from one country/region to the other. IEC60364-5-52 standard is widely used in most countries.

Voltage Drop limits in the USA

The NEC recommends a maximum combined voltage drop of 5% for both feeder and branch circuits. According to the NEC 210.19(A)(1) Informational Note No. 4, the voltage drop for branched circuits is limited to 3% of the applied voltage. This allows a 2% drop in the feeder. [1]

Voltage Drop limits in Europe

In Europe, the maximum permitted voltage drop is 3% for lighting or 5% for other uses. This is for low voltage installations supplied directly from a public LV distribution system. For low voltage installations supplied from private LV Supply, the limits are 6% for lighting and 8% for other uses.

Voltage Drop limits in the U.K.

For Consumer's Installations, the maximum permitted voltage drop is 3% for lighting or 5% for other uses. This is for low voltage installations supplied directly from a public LV distribution system. For low voltage installations supplied from private LV Supply, the limits are 6% for lighting and 8% for other uses. [2]

For Commercial and Industrial Installations, the supply voltage can vary between statutory limits of +10% to −6%. [3]

Voltage Drop limits in Australia

The maximum permissible voltage drop between the point of supply and any point of the installation is as follows: Any low voltage Electrical installation must not exceed 5% voltage drop and where a substation is located on-premises, must not exceed 7% voltage drop. [4]

Voltage Drop limits in Singapore

Voltage drop at consumer final sub-circuit should be kept at below 4% – Under normal conditions, the voltage drop at the terminals of any fixed current-using equipment such as switch socket outlet should not exceed 4% of the nominal voltage of the supply. [5]

WHAT HAPPENS WHEN VOLTAGE DROPS OCCURS?

Voltage drops lead to unstable and unreliable power supply power which can cause, various operational, financial, and environmental problems and losses. Usually, operating below recommended limits can cause sensitive or critical electrical and electronic systems to malfunction or fail in addition to reduced operational efficiency. On the extreme, the persistent voltage drop may result in a complete shutdown of equipment or plants hence causing huge financial losses to the consumer. The utility company will also suffer due to the lost opportunity to sell power to the consumer during the shutdown.

Most of the electrical equipment can operate effectively with supply voltages variations of up to 10%. However, some sensitive equipment such as those in telecommunication, computing, medical, and similar applications require a more constant and stable supply for normal operation.

Persistent Voltage Drops may cause a complete shutdown of facility operation in the end, which may lead to huge financial losses.

Also, the effects of voltage drop on some machinery and equipment operations may be too huge to ignore. Persistent voltage drops may cause a complete shutdown of facility operation in the end, which may lead to huge financial losses.

Some of the consequences of voltage drop include;

Consequences of Voltage Drops include:

1. Reduced/Inconsistent lighting levels – a 10% voltage drop decreases the output of lamps by over 25% for incandescent lights, 15% for fluorescent tubes, and 20% for IR lamps.

2. Flickering of lights – Voltage drops may cause flickering of lights which may eventually lead to damage of the lights as well as a human health issue.

3. Reduced heating element efficiency – A 10% voltage drop causes a reduction of more than 20% heat output or induction heaters.

4. Reduced motor torque and efficiency – A 10% voltage drop reduces torque by about 18%. Increased heating also occurs due to increased current drawn to supplement the voltage drop.

5. Failed motor startup: - Motor startup requires higher in-rush current levels, which will be limited if the voltage drop is significant.

6. Intermittent and erratic equipment operations due to persistent voltage drops. The equipment may be required to work harder which with time will lead to poor performance and efficiency.

7. Increased damage of fault protection equipment such as circuit breakers. This is associated with the increased current drawn by the circuit to satisfy the load power requirements. This will lead to damage to circuit breakers and protection equipment.

8. Where the Voltage drop is persistent over long periods, the low voltage and increased resistance will pose a fire risk due to increased heating and heat dissipation.

9. Computer errors and downtime – An 8% voltage drop is enough to cause damage and errors to computers.

10. Increased Welding cycle – A 10% voltage drop to welding equipment supply will lead to a 20% increased welding cycle to maintain the weld quality.

11. A 10% voltage drop will cause abnormal operation of magnetic machines, sluggish solenoids, and overheating.

12. A reduced transmission quality and coverage range for radio and TV transmission systems.

13. A 5% volt drop in the supply of photographic processing machines will increase exposure time by 30% with a significant reduction in the print quality.

14. In cases where the long cable runs are used for communication transmission systems and security systems, unplanned interruptions of these critical services may have a negative ripple effect.

HOW DO YOU SOLVE VOLTAGE DROP ISSUES?

There are a few proven solutions for reducing voltage drops and their effects on long cable runs and installation. The choice of a suitable solution may vary according to the specific situation and there is a need to consider some critical factors.

Generally, the main factors include length and cross-section area of the conductor, type of conductor used, the load current, connections, and temperature.

In most instances, the length of the cable will remain constant and there is little to do on this unless changing the route or design, which may not be possible. Load is something that requires proper consideration if there is going to be a long cable run.

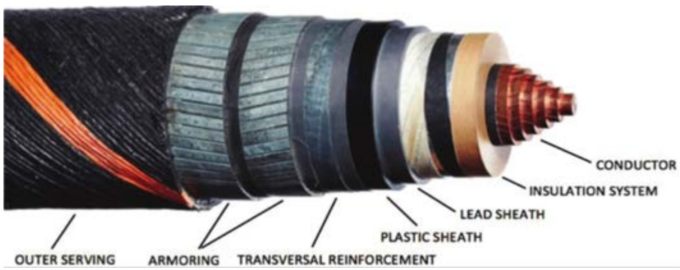
If the load is relatively non-essential such as lighting and pumps, the solution to voltage drop issues should be one that does not strain the available finances. However, for critical loads, it is important to deploy a cost-effective and reliable solution that prevents the negative effects of the voltage drop at a reasonable budget.

Based on the issues that result in voltage drops, there are conventional methods that work by limiting the contributing factors hence preventing the occurrence. At the same time, there are adaptive methods that help to reduce voltage drops and are therefore suitable when it is impossible to stop them.

Conventional Methods

The conventional methods include:

1. Using Larger Cross-sectional Sized Cables



As seen, larger cross-sectional areas conductors offer less resistance to the flow of current. Therefore, increasing the cross-sectional area reduces the voltage drop in the long cable run.

An illustration would be a 3 – core, XPLE copper long cable run of about 1500 meters, carrying a load current of 100 Amperes at 400V power being transmitted = 40kVA. A cable of 35mm2 can handle the current capacity ignoring the Voltage drop issue.

$$\textbf{VD} = \frac{1.10 * 100 * 1500}{1000} = \textbf{165V}$$

Using the Voltage drop calculation formula above, with the (**mV/A/m**) constant for the cable as 1.10, the Voltage drop for this setup will be 165V which is equal to 41% Voltage Drop.

To find out the cable size that will reduce this voltage drop to less than 4%, which is 16V, we will make the (**mV/A/m**) constant the subject of the formula, and it will then become:

From the calculations, the (mV/A/m) constant needed to have less than 4% Voltage drop should be equal to or less than 0.1066. Checking this value in the tables for 3 and 4 core conductors, the value corresponds to a cross-sectional area of 400mm2. The cross-sectional area of the cable run has been increased from 35mm2 to 400mm2 to ensure the voltage drop remains within allowable limits.

$$(\textbf{mV/A/m}) = \frac{1000 * 16}{1 * L} = \frac{1000 * 16}{100 * 1500} = \textbf{0.1066}$$

2. Increasing the Number of Transmission Cables

The more the number of cables, the lower the resistance of transmission lines since they will share the current, hence reducing IR losses and voltage drop.

An illustration would be a 3-core, XPLE copper long cable run of about 1500 meters, carrying a load current of 100 Amperes at 400V power being transmitted = 40kVA. A cable of 35mm2 can handle the current capacity ignoring the voltage drop issue. If we increase the number of conductors to 12 conductors, the current will be shared hence each

$$\textbf{VD} = \frac{1.10 * 8.33 * 1500}{1000} = \textbf{13.74V}$$

conductor will have a current of 8.333 Amperes. Using the Voltage Drop Calculation formula,
Therefore, you can reduce the voltage drop to allowable limits by using 12 conductors of a cross-sectional area of 35mm2.

3. Increasing Transmission Voltage

Increased transmission current leads to an increase in voltage drop. Using higher transmission voltages can also reduce voltage drops for a given amount of power transmitted.
Power (**P**) = Voltage (**V**) * Current (**I**).

For the same power being transmitted, an increase in voltage leads to a reduction in the current to transmit.

However, delivering higher voltages is costly since it requires a step-up transformer at the sending end. It will also require another step-down transformer at the destination end to lower the voltage to the standard level. Unfortunately, adding the transformers may increase the cost of transmission significantly when dealing with the much higher voltages.

Adoptive Method of Reducing Voltage Drops

Voltage Drop Compensators

An adaptive solution provides a means to regulate and maintain the voltage within acceptable levels while offering cost savings on cable costs for the overall project. This is where voltage drop compensators come in. A voltage drop compensator (also referred to as a Constant Voltage Compensator) is an electrical device designed to compensate for voltage drops. Voltage drop compensators are installed at the end of a long electrical cable run, compensating for the voltage drop where it is highest. The cable selected for use together with a voltage drop compensator need not be oversized to cater for the drop.

In practice, the compensator continuously monitors and adjusts the voltage to maintain it constantly and within stipulated levels. It can as well compensate for any fluctuations in the utility mains supply.

Benefits of a Voltage Drop Compensator at the End Transmission Line

- Addressed the voltage drop issue – It compensates for the losses hence ensuring that the voltage level is in compliance with regulations.
- Automatically stabilizes the end voltage from no-load to full-load.
- Ensures that the load variations and power factor does not affect voltage- the compensator will automatically ensure a constant voltage supply
- Reduces the need for extensive cable sizing that would have been required to compensate for voltage drop regulation in the conventional method, hence saving on cable costs and cable installation requirements.

While there is s number of voltage drop compensators in the market, not all are made equal. Since this is a long-term investment it is important to install a reliable and cost-effective solution with a short response time and high efficiency such as Ashley Edison's products.

Ashley-Edison's range of Voltage Drop Compensators have a response time of less than 1.5ms and an output voltage accuracy of ± 1%. Efficiency levels are more than 98%. They come in High Voltage (380/220V; 400/230V or 415/240V) and Low Voltage (200/115V; 208/120V or 220/127V) models.

Standard protection features include an input circuit breaker with overcurrent protection, transient voltage surge suppressors, and lightning surge arrestors.

COMPARISON OF CONVENTIONAL AND VOLTAGE DROP COMPENSATOR VOLTAGE REGULATION METHODS

As a project electrical consultant at the design stage, value for money is important. And if you are bidding for a project, ideally you will seek to reduce the overall budget costs to remain competitive. The above-mentioned conventional methods may make a significant debt to your long cable transmission budget. Safety of the system is key, and hence ensuring the supply of a regulated and stabilized voltage to your loads should always be a priority.

While the conventional methods will solve the voltage drop issue, the main disadvantage of using these methods especially for long cable runs, are the huge financial costs needed for their implementation.

If only non-essential loads are being powered, the justification for the extra costs required for the oversizing of the cables, or the use of extra conductors may not be realistic. Extra design considerations also need to be put in place for the cable installations

For the Voltage Drop Compensator solution, the cable will be sized and selected without the need to overrate the cable for a volt drop. The combined cable and compensator cost should show a substantial overall cost saving compared to the cost of needing an oversized cable. Additionally, the smaller-sized cables to be used will be easier and less expensive to install.

CONCLUSION

Voltage drops are very common where long transmission cables are used. As an engineer or electrical consultant, this is one factor you have to consider while designing and implementing projects with long cable runs. As highlighted, there are several solutions one can employ to reduce the voltage drop issues in your projects.

The use of Voltage Drop Compensators in your project is one of the most reliable and cost-effective approaches, especially when powering up non-essential loads. This way you will reduce financial expenses on extra electrical cables required to compensate for the high voltage drops. The smaller cable size used becomes also advantageous in the cable installation process.

Voltage Drop Regulators also come with additional protection features that ensure the protection of your loads and power system. These include input circuit breaker overcurrent protection, inbuilt high overload capability, transient voltage surge suppression as well as lightning surge arrestors. This way loads are guaranteed to receive the recommended and stable voltage, hence improving the overall efficiency and performance while minimizing unforeseen downtime.

To ensure safety and avoid financial loss, voltage drop regulation is key, particularly for facilities that use long transmission cable lines. Is your facility or electrical system in need of an effective voltage drop solution?

Get in touch with us at **sales@ashleyedison.com** and our consultants will be happy to speak to you.

Speak to us today on protecting your facility from the harmful effects of voltage fluctuations – our consultants respond within 24 hours.

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