NAVIGATING POWER IMBALANCES

Consequences and Complacency in Power Quality and the Unfazed Attitude

Abstract

The notion of “power quality” might seem abstract, particularly when dealing with an intangible resource like electricity. However, for facility managers in commercial and industrial settings, it carries substantial significance. Ensuring stable and reliable electrical supply is crucial for maintaining efficient operations and minimizing disruptions.

Bertie Bezuidenhout

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Introduction

The concept of “power quality” may appear abstract, especially when dealing with an intangible commodity like electricity. However, for commercial and industrial facility managers, it holds significant importance. Good power quality directly impacts productivity and employee safety. Conversely, poor power quality can lead to financial losses due to equipment damage, reduced productivity, and product spoilage. Recognizing and maintaining optimal power quality is essential for efficient operations and overall business success.

Power quality, often overlooked but crucial, has significant economic implications. The Leonardo Power Quality Initiative estimates that poor power quality costs the European economy up to €150 billion annually, while in the U.S., losses range from $119 billion to $188 billion, as reported by the Electric Power Research Institute (EPRI). However, a pivotal finding by EPRI highlights that a staggering **80 percent of power-quality disturbances originate within a facility itself**.

The data, although dated, suggests that the economy has experienced substantial growth. Additionally, network operators now heavily rely on renewable energy sources. However, this shift may have unintended consequences, potentially impacting power quality.

In the context of increased competitiveness, companies are increasingly concerned about sustainable development. Inadequate power quality (PQ) can lead to significant financial losses and impact on a company’s sustainability.

Utility companies charge commercial and industrial consumers based on both active power (kW) and reactive power (kVAR). Imbalances affect both. Reactive power (associated with voltage and current phase differences) increases due to imbalances, leading to additional charges. Moreover, higher losses from imbalances result in increased energy consumption, indirectly affecting consumer bills.

While energy providers and users worldwide recognize the urgency of addressing power quality issues, South Africa faces unique challenges. Despite an aging infrastructure, load fluctuations, and insufficient maintenance, power quality issues are not addressed adequately. Articles calling out Eskom, City Power, and NERSA have gone unanswered. Questions arise about NERSA’s role—does it merely issue licenses and approve tariff increases, or does it also manage safety and reliability compliance? It is time to raise awareness and demand accountability. End-users must advocate for higher-quality power, and utilities should prioritize improved power quality.

In this document, I delve into the principles of balanced and unbalanced power networks, using real-world data to highlight the differences between these scenarios. Specifically, I address Eskom and other power distributors’ awareness of unbalanced network conditions and their actions to rectify them.

Importantly, I explore how customers, who experience unbalanced networks, shoulder a substantial financial burden through their electricity bills.

Meanwhile, electricity generators—whether from coal-fired power stations, nuclear sources, or renewable energy—may remain apathetic. The inefficiencies arising from unbalanced networks could inadvertently enhance their profits.

Unbalanced Networks Conditions

While I had the option to replicate the full explanation of Symmetrical Component Analysis from the Agulhascorp website into this text, I chose a different approach.

To understand the rationale behind this analysis and gain insights into Negative Phase Sequencing, I encourage you to explore these topics further. This will equip you with the necessary background to comprehend the forthcoming discussion.

Detecting Power Network Imbalances

The inquiry often arises: Are power network imbalances localized to specific regions? Is their presence easily discernible? Can anyone identify such incidents? In this study, I delve into the complexities of detecting power network imbalances. Without the appropriate instrumentation and analytical expertise, pinpointing these imbalances remains elusive. For instance, merely measuring phase-to-phase and phase-to-neutral voltages falls short of revealing the full extent and severity of power network imbalances.

To address this, I present two real-life scenarios that illustrate this phenomenon. Accompanying online videos on our website enhance comprehension, allowing viewers to grasp the underlying concepts more effectively.

Causes of Voltage Unbalance

Voltage unbalance occurs when the magnitudes of the three-phase voltages in an electrical system are unequal. Some of the reasons behind this phenomenon are:

1. **Variation in Line Characteristics**: Differences in properties, such as resistance or impedance, among the electrical lines used for transmitting and distributing electricity can lead to voltage unbalance.
2. **Uneven Distribution of Electrical Loads**: If one phase carries a heavier load than the others, it results in unbalanced voltages. Unequal power drawn from electrical devices can cause this imbalance.
3. **Faulty Operation of Power Factor Correction Equipment**: Malfunctioning power factor correction equipment can contribute to voltage unbalance.
4. **Unbalanced Utility Supply**: Variations in the utility supply can impact the voltages across the phases.

Consequences of Unbalanced Voltage in Electrical Systems

In an electrical system, the **voltage vector** represents the voltages across the three phases (Phase 1, Phase 2, and Phase 3). When visualized, this vector resembles an ellipse due to the varying magnitudes and phase angles of the voltages.

An **off-center ellipse** occurs when the voltages in the three phases are not balanced or symmetrical. This situation indicates that the system is experiencing unbalanced voltages. Specifically, when the ellipse is off-center:

1. **Bearing Stress**: Electric motors connected to such an unbalanced network face challenge. The off-center ellipse causes uneven magnetic forces within the motor windings.

Consequently, the motor bearings experience **uneven stress** due to the varying magnetic fields.

2. **Vibration**: The uneven magnetic forces lead to vibration in the motor. This vibration can significantly impact the motor's performance and longevity.
3. **Uneven Motor Performance**: Motors connected to unbalanced voltages may operate inefficiently or experience overheating. The torque produced by the motor becomes uneven, leading to mechanical stress and potential failure.
4. **Increased Current**: Unbalanced voltages cause unequal current distribution among the phases. This can overload conductors, transformers, and other equipment, leading to premature wear and potential damage.
5. **Voltage Drop**: Voltage unbalance results in voltage drops across the system. Sensitive equipment may malfunction or fail due to inadequate voltage supply.
6. **Negative Impact on Power Factor**: Unbalanced voltages affect the power factor, reducing system efficiency and increasing reactive power consumption.
7. **Harmonic Generation**: Voltage unbalance contributes to harmonic distortion, affecting the quality of power supply and potentially damaging sensitive electronics.

Negative Sequence Currents in Power Systems

In a power system, when one phase is "**missing**," the system becomes unbalanced, leading to negative sequence currents. These currents can have significant effects on power system equipment and operation. Here are some potential consequences:

1. **Increased Heating**: The absence of a phase can cause motors, generators, and transformers to heat up excessively. Elevated temperatures may lead to component damage or reduce their lifespan.
2. **Mechanical Stresses**: Rotating machinery, such as motors and generators, experiences mechanical stresses due to unbalanced currents. Vibrations and torque fluctuations can impact overall system stability.
3. **Voltage Dips and Unbalanced Voltages**: Negative sequence currents contribute to voltage dips and unbalanced voltages. These fluctuations affect the performance of connected loads and sensitive equipment.
4. **Increased Power Losses**: An unbalanced system results in higher power losses due to uneven current distribution. This inefficiency affects overall system efficiency.

Additionally, the concept of the **Ideal Voltage Vector** plays a crucial role in power engineering. Represented by a vector with a power factor of 0.9 and at the rated circuit voltage (e.g., 6.6 kV), it defines the ideal voltage magnitude and phase angle for a balanced system. Understanding this concept helps analyze system behavior under various conditions.

Perfectly Balanced Network Condition

In an ideally balanced power network, the magnitudes of currents and voltages are identical, with phase displacements precisely at 120 degrees. Additionally, this balanced system **exclusively consists of a Positive-Sequence Component, without any Negative- or Zero-Sequence Components**.

In Figure 1, the positive-sequence voltage component within a 6.6kV network signifies a perfectly balanced system. The only vector present corresponds to this positive-sequence component.

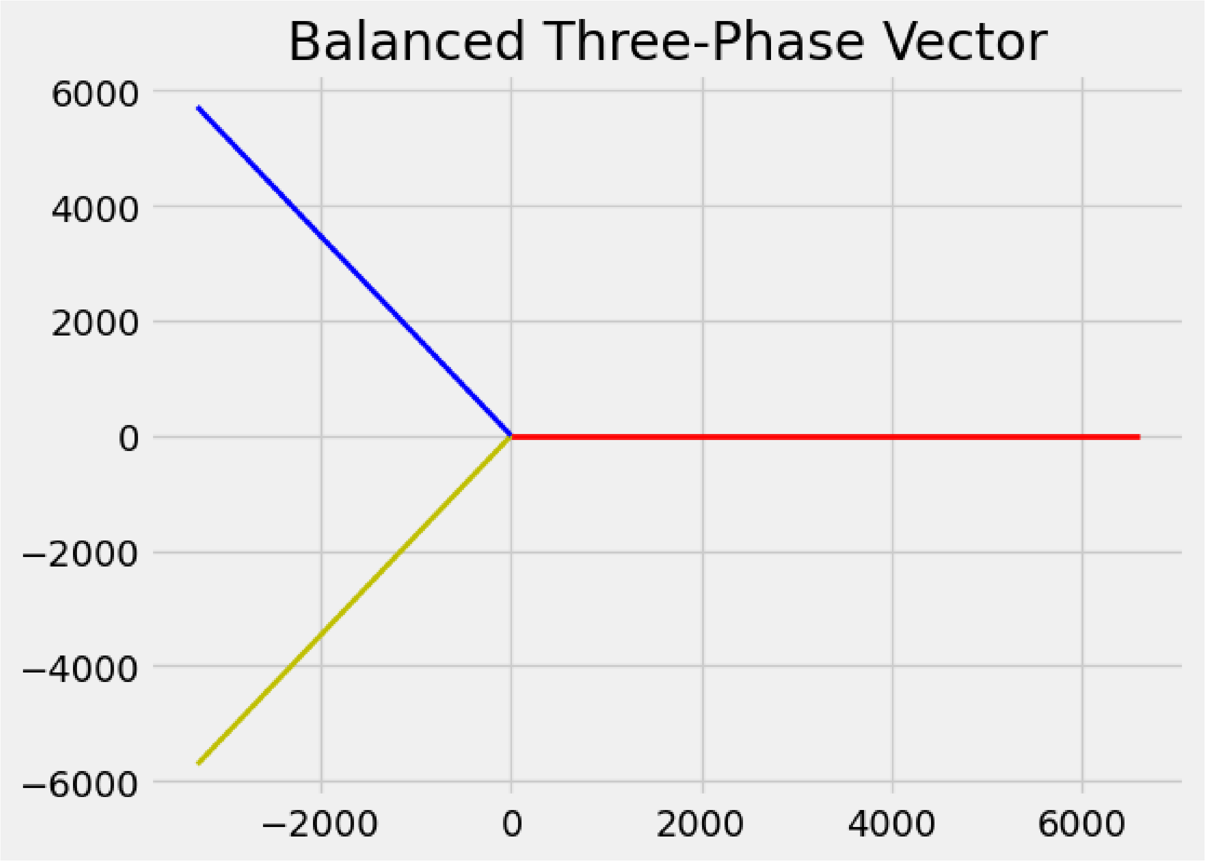

Figure 1: Modderbee Balanced Voltage Vector

If you would like to visualize this concept, I recommend watching this online video. Visual context often enhances understanding and provides a clearer picture of the topic.

Figure 2 depicts the positive-sequence voltage component within a **240-volt network**. This component represents a **perfectly balanced system**, which is the ideal supply for domestic consumers in South Africa. The sole vector present corresponds precisely to this positive-sequence component. For a visual demonstration, I recommend watching the online video, which provides further context and illustrates the concept.

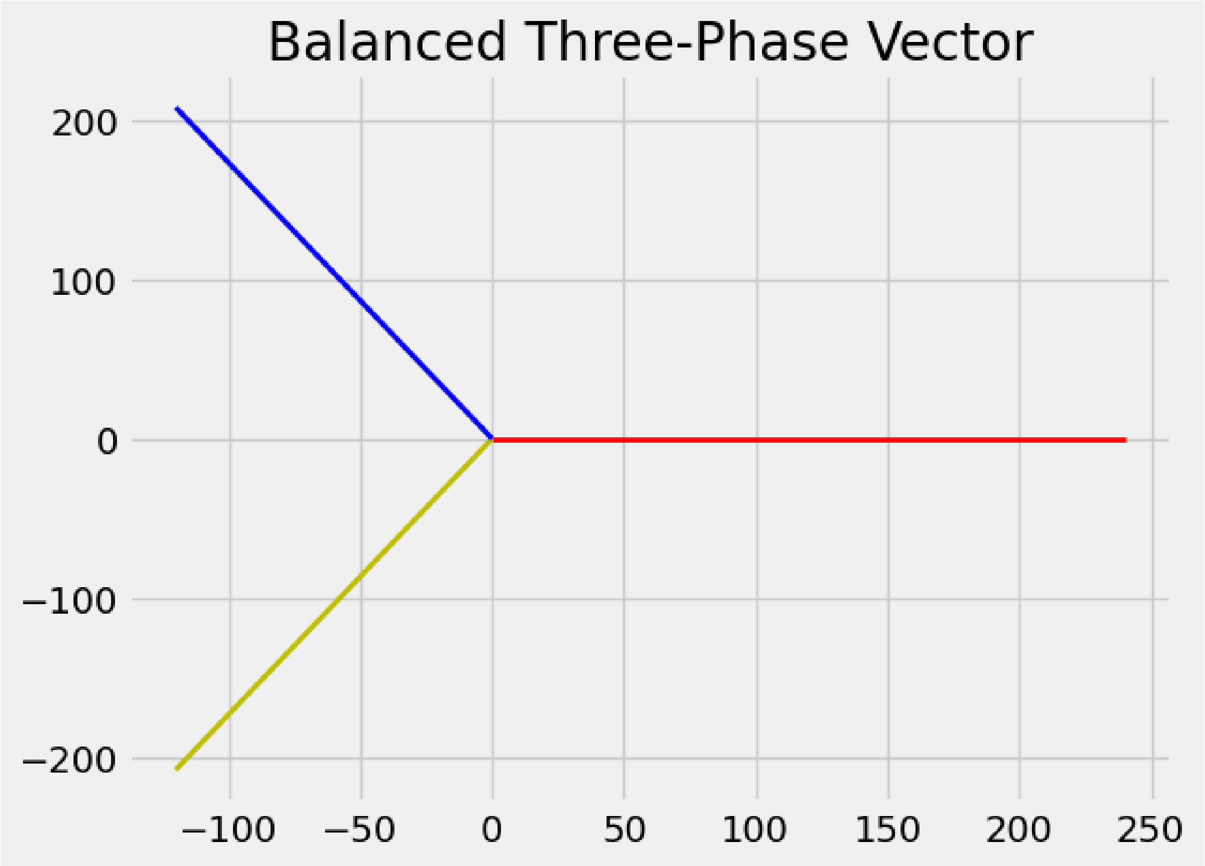

Figure 2: Linden Balanced Network Vector

True Stories of Network Imbalances

I have learned that an Eskom representative was informed about potential imbalances in network conditions at the Modderbee municipal substation, but this information was possibly dismissed. I am frustrated by the lack of response to my emails seeking collaboration on examining the issue of unbalanced currents and voltages. Despite successful delivery, my first email remained unanswered, and the second was inexplicably erased without being read. The lack of acknowledgment from the recipient is perplexing, especially considering the urgency of the matter. As a result, I am calling out Eskom, City Power, and NERSA in this article to highlight these issues.

Modderbee Municipal Substation

Data Recordings

In August 2023, I was tasked of monitoring the load on a municipal feeder at the Modderbee substation in Springs, Gauteng. The consulting engineer assigned this task to determine the additional load that the specific 6.6kV feeder could accommodate.

During the installation of the Power Quality Monitor on August 30, 2023, we noticed the absence of one phase-to-neutral voltage. To verify this, I used a secondary device and confirmed that the voltage was indeed less than 2 volts. We speculated that a blown fuse on the secondary side of the busbar-VT might be the cause, but we proceeded with the installation, prioritizing current measurements.

The Modderbee municipal substation receives its supply via two 6.6kV cables from the nearby Eskom substation. Equipped with two 6.6kV busbars and an open bus-section breaker, the substation's busbar-VTs measure incoming voltages from these cables.

To obtain reliable minimum, average, and maximum load measurements, I allowed the instrument to operate for approximately a week, recording data from August 30, 2023, to September 5, 2023.

Data Analyses

Initially, my focus was primarily on examining the measurements of **real (P)**, **reactive (Q)**, and **apparent power (S)**. However, when the consulting engineer raised concerns about the elevated neutral currents, I began to scrutinize the data more thoroughly. It was during this detailed analysis that I uncovered the unusually high levels of unbalanced currents and voltages.

In the upcoming sections, I will delve into the symmetrical component analyses of the unbalanced three-phase system at the Modderbee substation. Our discussion is based in the data collected via the Power Quality Monitor during the period from August 30, 2023, to September 5, 2023.

Positive-Sequence Component

Figure 3 illustrates the positive-sequence component of the voltages, documented at 03:40:00 on September 5, 2023.

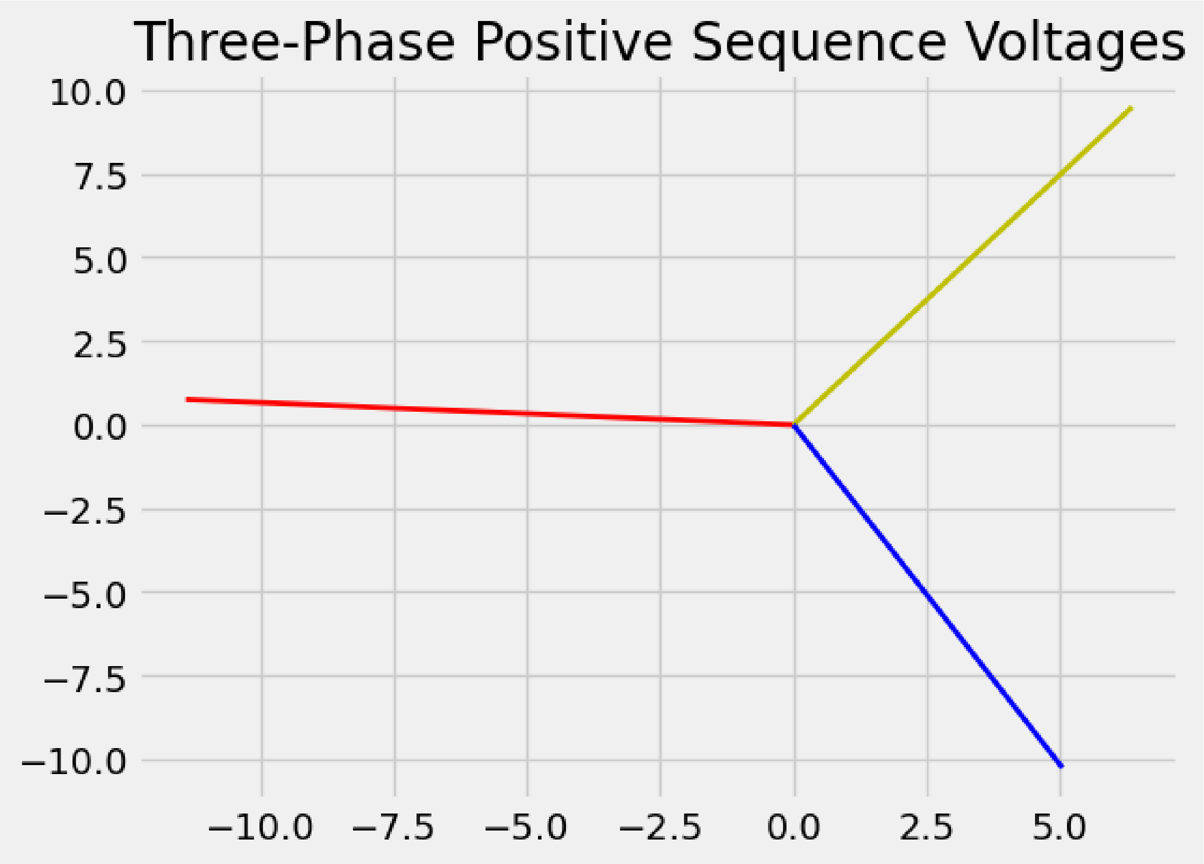

Figure 3: Modderbee Positive Sequence Voltage Vector

The initial observation to make is that the complete vector has undergone a rotation close to 180-degrees, given that the red line is expected to align with the X-axis, pointing to the right.

The second crucial observation pertains to the unusually low values of the three phases. Ideally, they should be closer to 6.6 kV, but they deviate significantly. Consequently, the positive sequence voltage component exhibits no pronounced characteristics within this network.

To see what this looks like, you can watch this online video. It provides visual context and further illustrates the concept.

Negative-Sequence Component

Figure 4 illustrates the negative-sequence component of the voltages, captured at the timestamp of 03:40:00 on September 5, 2023.

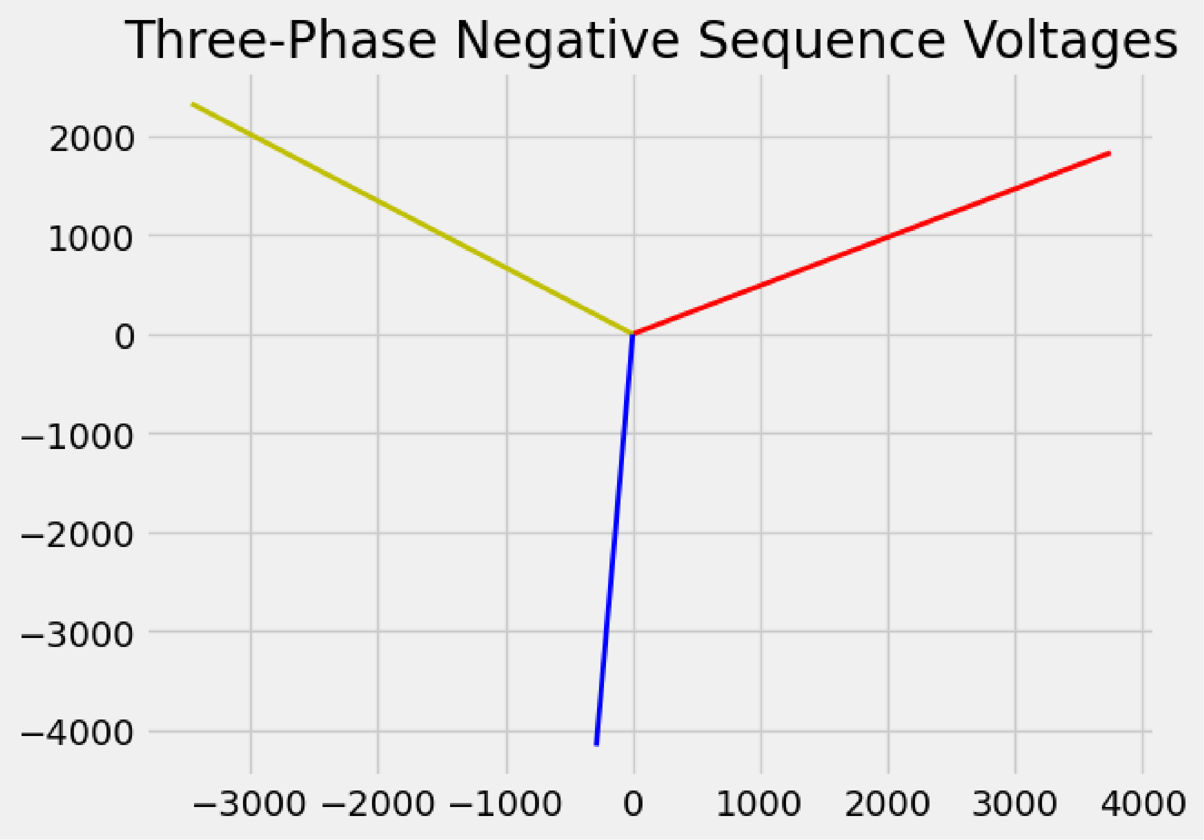

Figure 4: Modderbee Negative Sequence Voltage Vector

Observe the elevated magnitudes of the three negative sequence components. **Ideally, these should be non-existent, resulting in no lines at all.**

Additionally, pay attention to the color order of the three phases. It is not the conventional red, yellow, and blue sequence—keep in mind that the vectors rotate in an anticlockwise direction. In this instance, the sequence is red, blue, and then yellow, which is why it is referred to as the Negative Phase Sequence.

You can watch this brief online video for visual context and a clearer illustration of the concept.

Zero-Sequence Component

Figure 5, depicted below, illustrates the zero-sequence component of the voltages, documented at 03:40:00 on September 5, 2023.

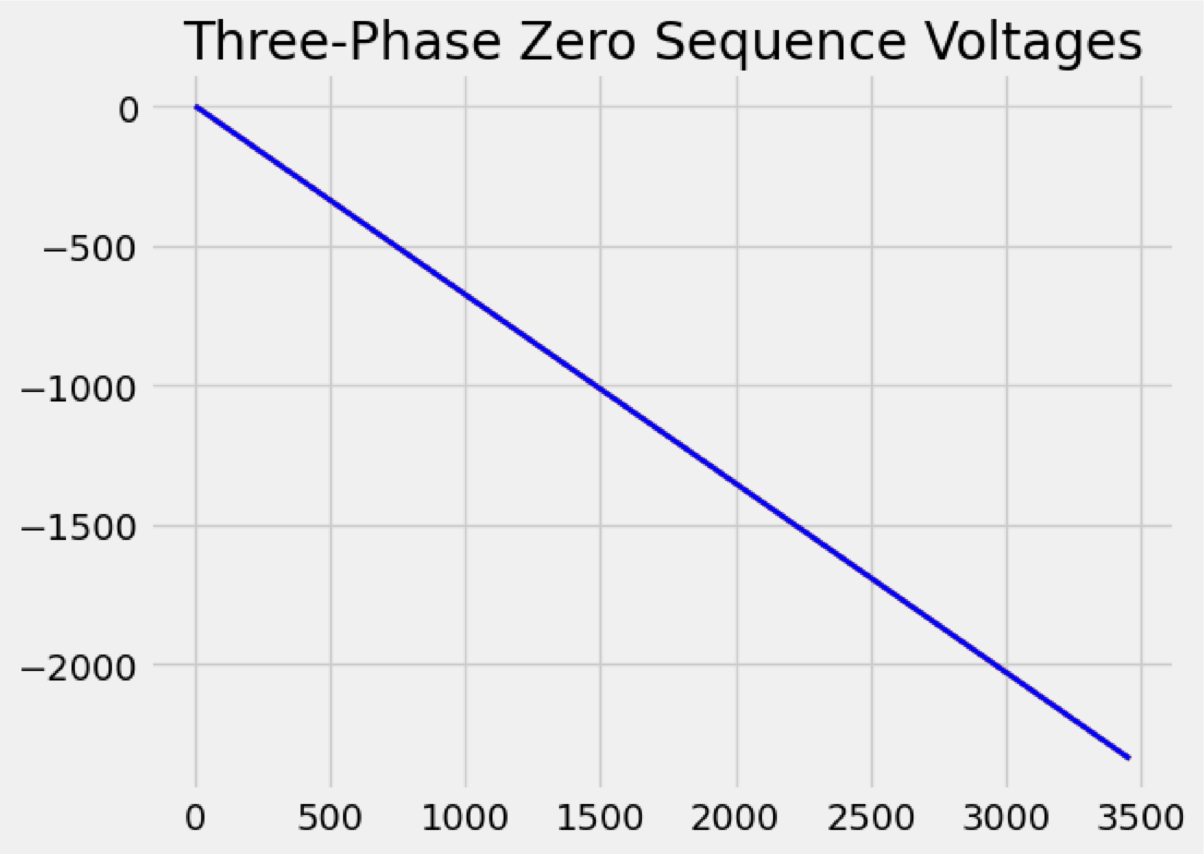

Figure 5: Modderbee Zero Sequence Voltage Vector

The blue line is the only visible one because the red and yellow lines are concealed beneath it. All three lines share the same magnitude and direction.

Observe the elevated magnitudes of the three zero-sequence components. **Ideally, these should be non-existent, implying there should be no lines at all.**

You can watch this brief online video for visual context and a clearer illustration of the concept.

Modderbee Cartesian Coordinate System Analysis

Figure 6 illustrates the three symmetrical components constituting the voltages, as documented at 03:40:00 on September 5, 2023.

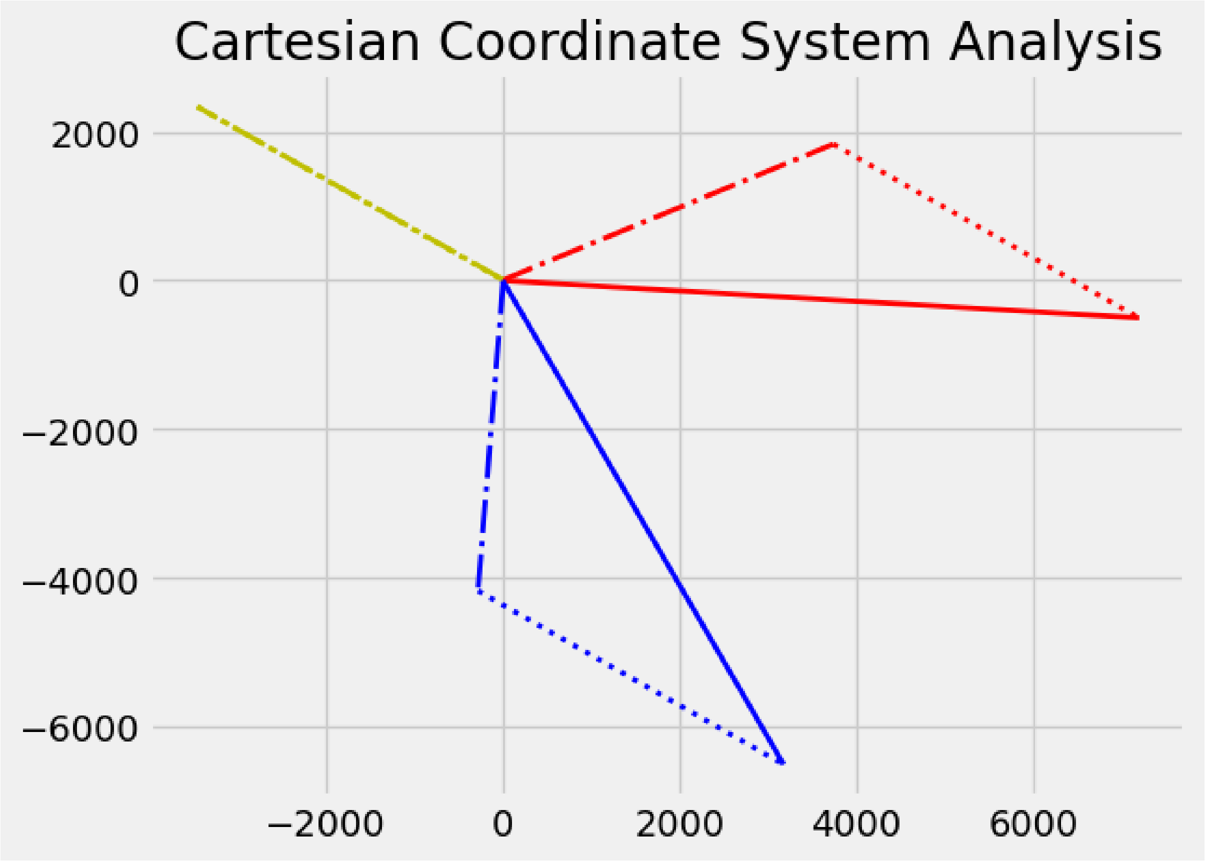

Figure 6: Modderbee Cartesian Coordinate System Analysis

The visibility of the solid yellow line, which represents the recorded voltage, is compromised because it is overlaid by the three lines symbolizing the positive, negative, and zero-sequence components. Additionally, the brevity of the solid yellow line contributes to its lack of clarity.

Please observe the proximity between the solid red and blue lines. Additionally, pay attention to the order of the “phases”.

To see what this looks like, you can watch this short online video. It provides visual context and further illustrates the concept. In the video, I have included a vector representation of the balanced system. Specifically, I have used Brown to represent Phase 1, Black for Phase 2, and Grey for Phase 3.

Phase-To-Phase Voltages

Figure 7 illustrates the phase-to-phase voltages of an ideally balanced network juxtaposed with the unbalanced phase-to-phase voltages of a network. These were recorded at the Modderbee municipal substation at 03:40:00 on September 5, 2023.

The red triangle symbolizes the recorded phase-to-phase voltages, while the green triangle signifies an ideally balanced network.

It is crucial to observe that the center point of the ideally balanced network aligns with the intersection of the X- and Y-axes. However, the center point for the recorded voltage (depicted by the red triangle) is noticeably off-center.

You can watch this brief online video for visual context and a clearer illustration of the concept. Pay close attention to the rotation of the two triangles and consider the implications for a large three-phase electric motor.

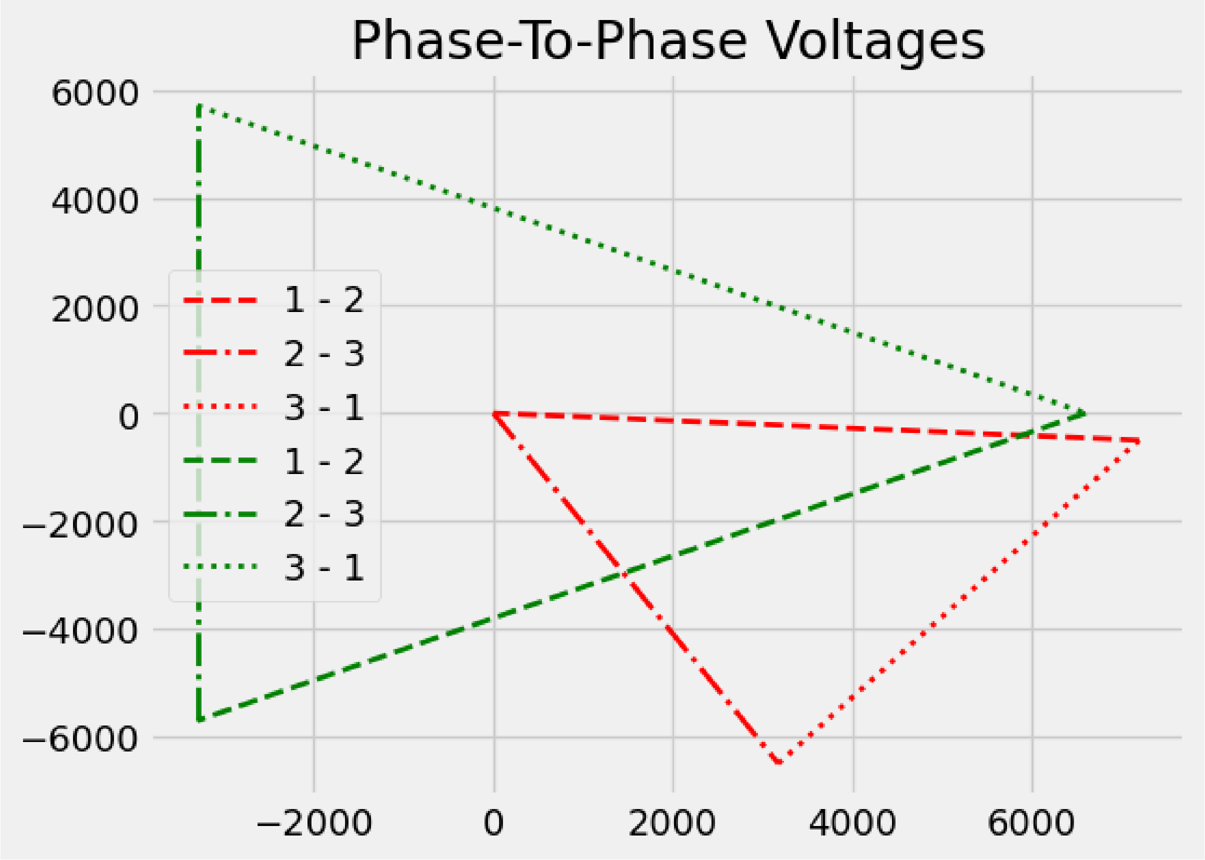

Figure 7: Modderbee Phase-To-Phase Voltages

In the Consequences of Unbalanced Voltage in Electrical Systems, several aspects related to three-phase motors are explored. When the voltages in the three phases are not balanced or symmetrical, an off-center ellipse forms. This occurrence signifies that the system is experiencing unbalanced voltages. Specifically, electric motors connected to such an unbalanced network face challenge.

The off-center ellipse results in uneven magnetic forces within the motor windings. Consequently, the motor bearings experience varying stress due to magnetic field fluctuations. These uneven magnetic forces lead to motor vibration, significantly impacting both performance and longevity.

Motors operating with unbalanced voltages may run inefficiently or even overheat. The torque produced by the motor becomes irregular, causing mechanical stress and potential failure. To better grasp the impact of voltage unbalance on motor performance and longevity, consider visualizing the rotation through this online video. The dots represent the magnetic fields rotating around the origin which is essentially the center of the motor.

In the video, vector values have been intentionally reduced to enhance the visualization of magnetic fields. This adjustment allows for clearer observation and understanding of the magnetic phenomena depicted. Now consider the stresses caused by unbalanced voltage supply on a three-phase, 4-pole electric motor supplied by a 50Hz frequency, which then rotates at 1800 rpm.

The individual who previously stated that the network at Modderbee substation being unbalanced was “highly unlikely” might find the above explanation enlightening.

Modderbee Sine Wave

For a clearer understanding, I recommend you watch an online video that illustrates the three-phase sine wave. Pay close attention to how closely the red and blue sine waves align with each other and observe how the yellow sine wave remains near the zero line throughout.

City Power Area—Linden

Despite numerous appeals to City Power to investigate potential imbalances in the network at the Roosevelt Park substation in Johannesburg, and even volunteering my services to help pinpoint if this issue was localized, I took the initiative to set up my own Power Quality Monitor at a nearby three-phase installation. I had suspicions that our area was experiencing unbalanced network conditions, and I was keen to confirm this.

City Power Recordings

On the 12th of April 2024, I set up my Power Quality Monitor at a residence in my neighborhood for a duration of roughly 20 hours.

Upon retrieving the device and briefly examining the data, I observed a significant dip in two out of the three phases at 04:23:55. Initially, I was unsure why only two phases were impacted while the third remained stable. However, a meticulous review of the data revealed that our residential area is indeed prone to unbalanced network conditions.

Despite my efforts to have City Power conduct a parallel assessment for unbalanced network conditions, I have yet to receive the requested results. However, I have already provided them with my data.

Data Analyses

As previously mentioned, in an ideally balanced system, the voltage magnitudes should be identical, and the phase shifts should be precisely 120 degrees. Furthermore, such a balanced system should exclusively **exhibit a Positive-Sequence Component, with the absence of any Negative- or Zero-Sequence Components**.

Hence, the sole vector for this region should resemble the one depicted in the subsequent image, Figure 8.

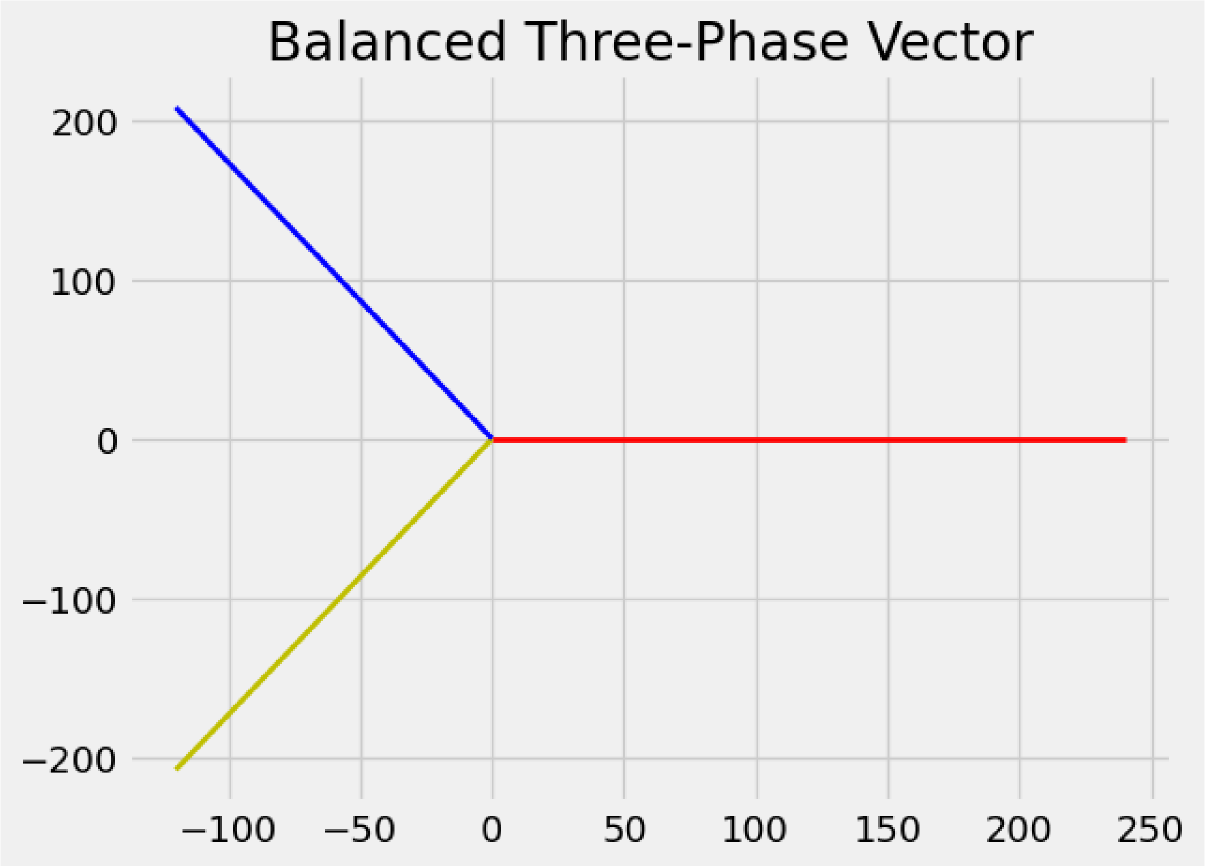

Figure 8: Linden Balanced Network Condition—Voltage Vector

Observe that the three phases have the same length and are separated by an exact displacement of 120 degrees. Pay attention to the position of phase 1, depicted by a red line. It lies on the X-axis and is situated to the right of the Y-axis.

The direction of the phase rotation, whether it is clockwise or anti-clockwise, is irrelevant. The line will consistently be located on the X-axis and to the right side of the Y-axis.

You can watch this brief online video for visual context and a clearer illustration of the concept.

Positive-Sequence Component

The positive-sequence component depicted in the Figure 9 below is derived from the recording taken at 21:20:00 on April 12, 2024.

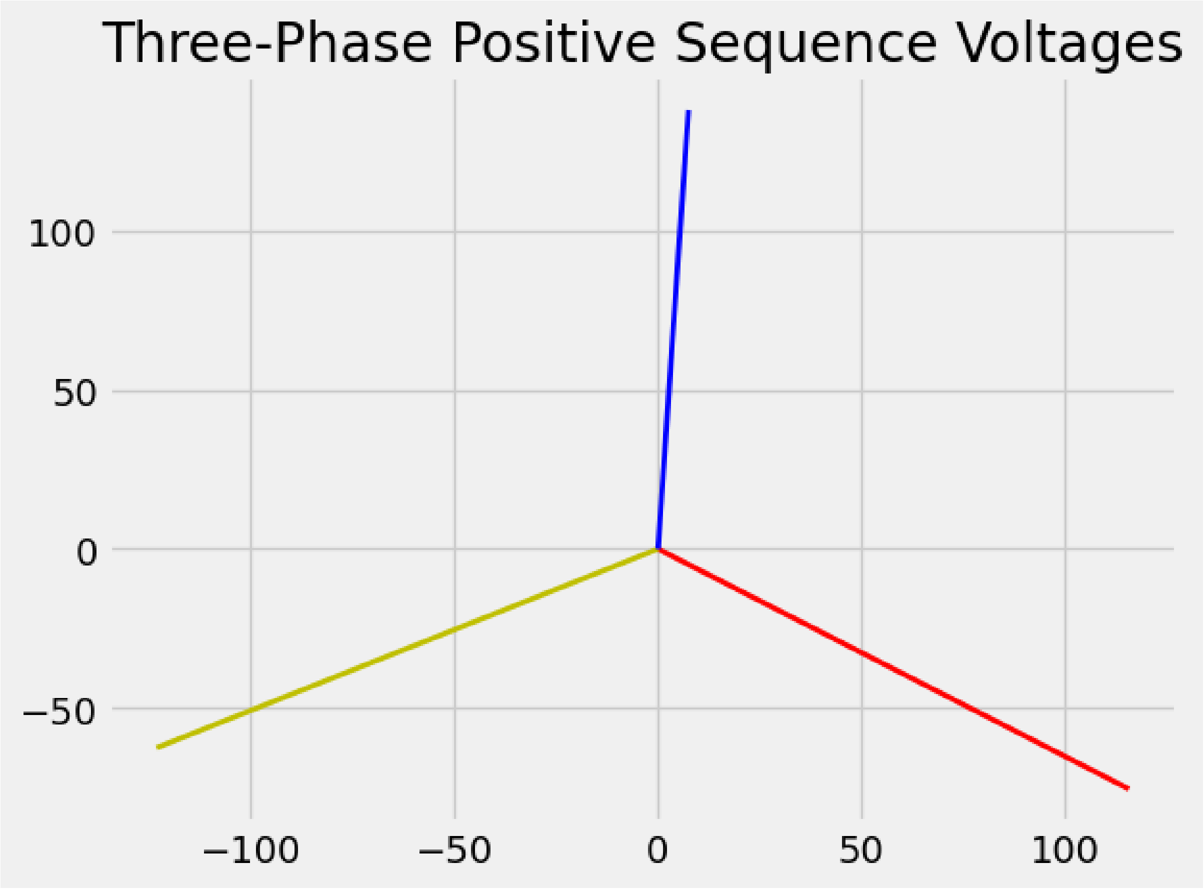

Figure 9: Linden Positive-Sequence Component

Observe the location of phase 1, indicated by the red line. The whole positive-sequence component has moved in a clockwise direction. Additionally, pay attention to the length of the lines. They are expected to match the length as is in **Error! Reference source not found.**. This e vident discrepancy signals an issue.

You can watch this brief online video for visual context and a clearer illustration of the concept.

Negative-Sequence Component

The negative-sequence component of the voltages, as documented at 21:20:00 on April 12, 2024, is depicted in the following Figure 10.

Recall the previous discussion: in an ideally balanced system, a Negative-Sequence Component should not exist. **Therefore, the canvas area of** Figure 10 **should appear empty.**

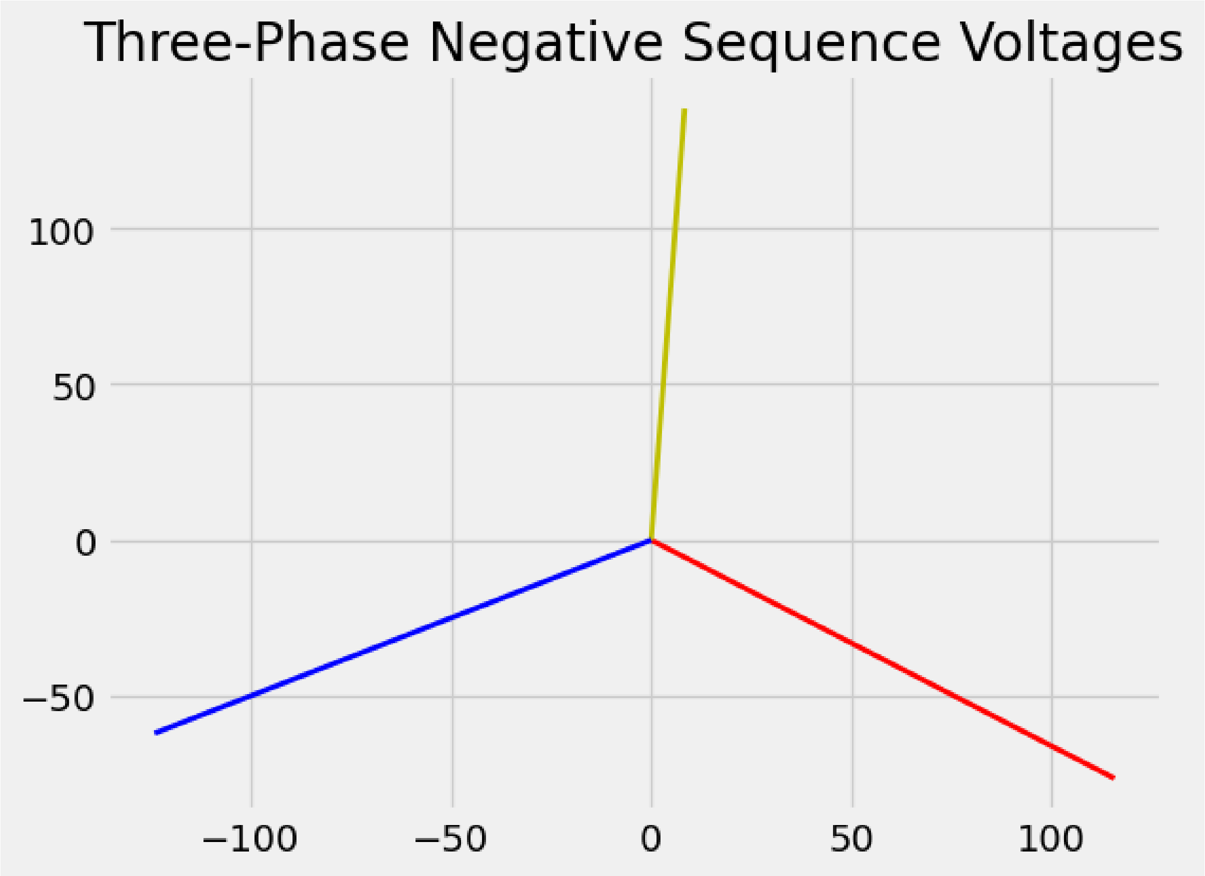

Figure 10: Linden Three-Phase Negative Sequence Voltages

I would like to highlight that the phase 1, indicated by the red line, has the same angle and magnitude as the red line in Figure 9 above, which symbolizes the positive-sequence voltage component.

To see what this looks like, you can watch this short online video. It provides visual context and further illustrates the concept.

Zero-Sequence Component

The zero-sequence voltage components, as documented at 21:20:00 on April 12, 2024, are depicted in the following Figure 11. You can watch this brief online video for visual context and a clearer illustration of the concept.

Recall the previous statement: a perfectly balanced system should not contain a Zero-Sequence Component. **Therefore, the canvas area of the subsequent image should have been empty.**

The blue line is the only visible one because the red and yellow lines are concealed beneath it. All three lines share the same magnitude and angle.

Observe the elevated magnitudes of the three zero-sequence components. **These should be non-existent, implying there should be no lines whatsoever, or as previously mentioned, it should be presented as an empty canvas.**

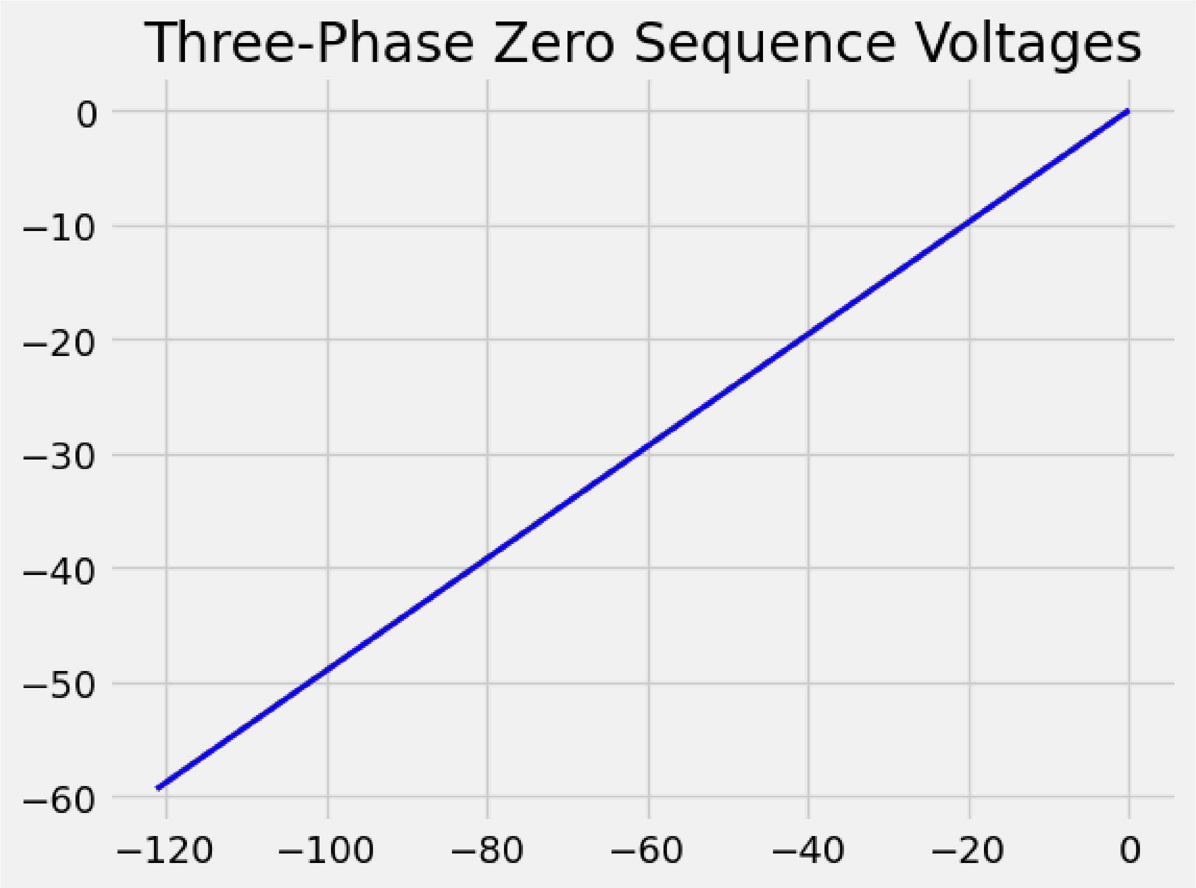

Figure 11: Linden Three-Phase Zero Sequence Voltages

Linden Cartesian Coordinate System Analysis

The illustration below, Figure 12, depicts the three symmetrical components constituting the voltages, as documented in Linden at 21:20:00 on April 12, 2024.

A crucial observation is the apparent absence of a solid yellow line.

Before you assume a phase is absent, I can confirm that this is not the case. The phase-displacement between two of the phase-to-neutral voltages is nearly identical. What has occurred is that phases 2 and 3 are almost equal in magnitude and share a similar phase-displacement angle.

You can watch this brief online video for visual context and a clearer illustration of the concept. It provides visual context and further illustrates the concept. In the video, I have included a vector representation of the balanced system. Specifically, I have used Brown to represent Phase 1, Black for Phase 2, and Grey for Phase 3.

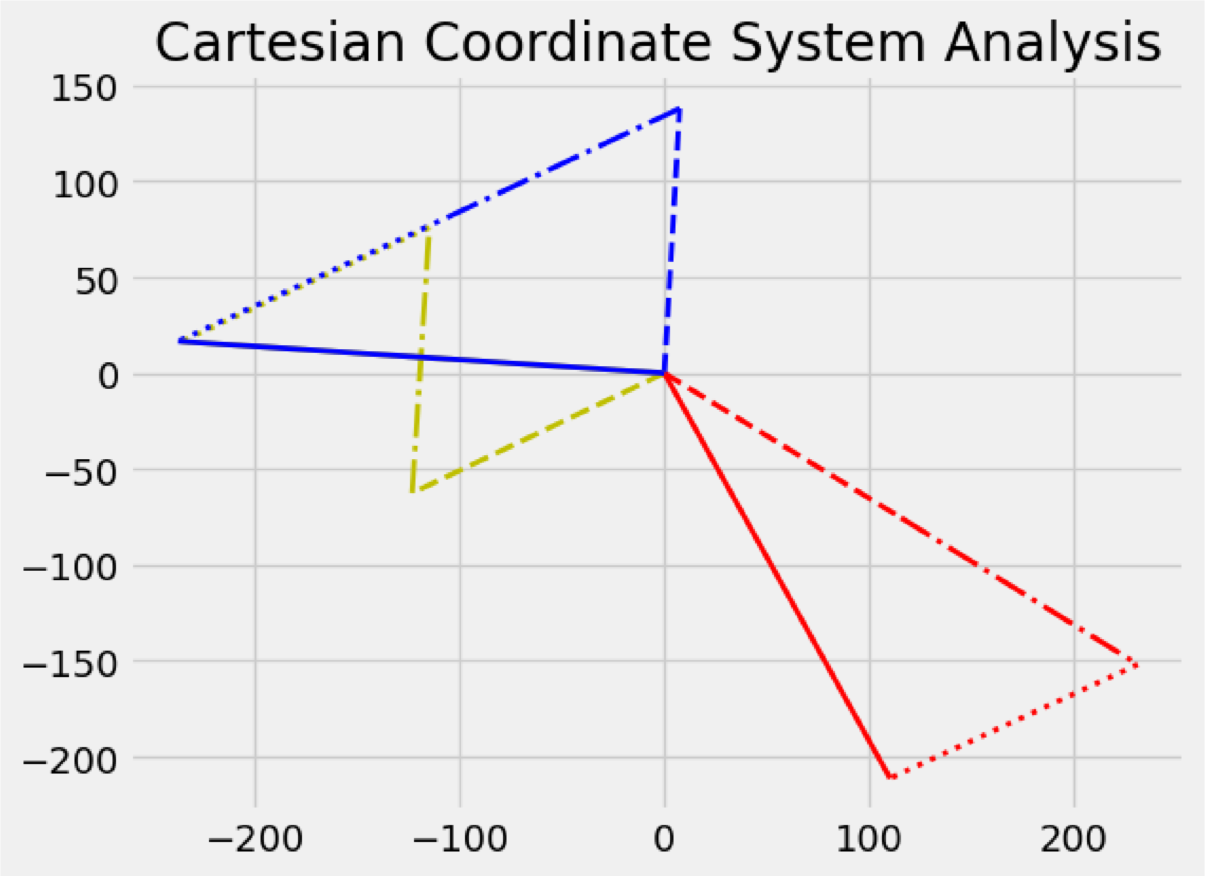

Figure 12: Linden Cartesian Coordinate System Analysis

Phase-To-Phase Voltages

The diagram depicted in Figure 13 illustrates the phase-to-phase voltages of an ideally balanced network, contrasted with the unbalanced phase-to-phase voltages of a network. These measurements were recorded in Linden at 21:20:00 on April 12, 2024.

The red “triangle” in the diagram symbolizes the measured phase-to-phase voltages, whereas the green dashed-line triangle signifies an ideally balanced network. However, in this instance, the red “triangle” is absent. Instead, the phase-to-phase voltages seem to be depicted as a “straight line”, deviating from the expected triangular representation. This anomaly is due to the phase-to-phase voltage between phase 2 and 3 being only 0.33 volts.

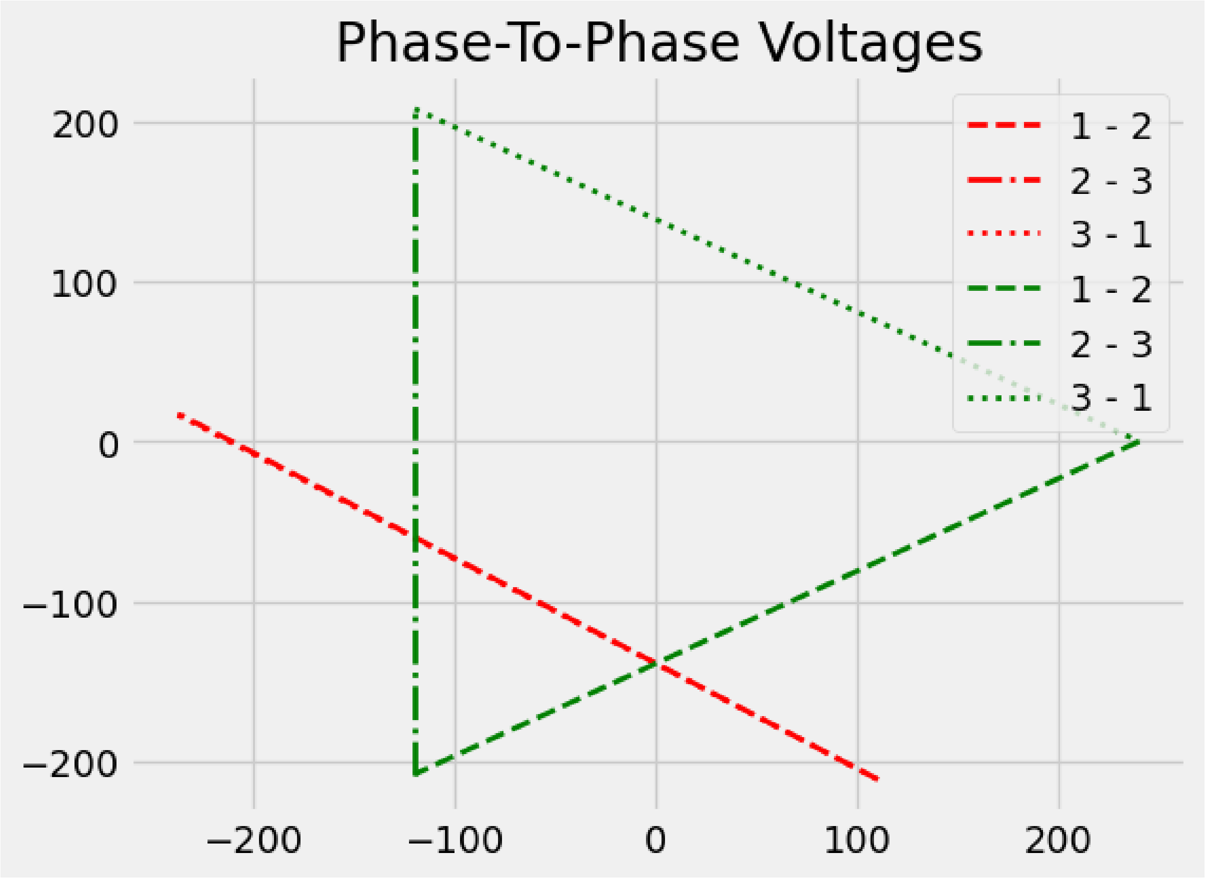

Figure 13: Linden Phase-To-Phase Voltages

To gain a clearer understanding, I recommend watching an online video that illustrates phase-to-phase voltages. Pay close attention to the rotation of the green triangle representing the balanced power network. Additionally, observe the “red line,” which should form a triangle but does not due to the yellow and blue phases coinciding with each other.

In the Consequences of Unbalanced Voltage in Electrical Systems, several aspects related to three-phase motors are explored. When the voltages in the three phases are not balanced or symmetrical, an off-center ellipse forms. This occurrence signifies that the system is experiencing unbalanced voltages. Specifically, electric motors connected to such an unbalanced network face challenge.

The off-center ellipse results in uneven magnetic forces within the motor windings. Consequently, the motor bearings experience varying stress due to the magnetic field fluctuations. These uneven magnetic forces lead to motor vibration, significantly impacting both performance and longevity.

Motors operating with unbalanced voltages may run inefficiently or even overheat. The torque produced by the motor becomes irregular, causing mechanical stress and potential failure. To better grasp the impact of voltage unbalance on motor performance and longevity, consider visualizing the rotation through this online video. The dots represent the magnetic fields rotating around the origin which is essentially the center of the motor. Now consider the stresses caused by unbalanced voltage supply on a three-phase, 4-pole electric motor supplied by a 50Hz frequency, which then rotates at 1800 rpm.

Linden Sine Wave

To gain a clearer understanding, I recommend you watching this online video that illustrates the three-phase sine wave. Pay close attention to how the yellow wave may appear to be missing, but it is aligned with the yellow sine wave and hidden behind the blue one. Additionally, observe the spacing between the red sine wave and the yellow/blue sine waves—it is evident that they are not equally spaced.

Effect on Electricity Bill

A question of equal significance might be: does the imbalance in voltages and currents impact the consumer's electricity charges? The concise response is, indeed, it does!

Within the power triangle of an AC circuit, three components exist.

The **real power**, denoted as (**P**), also referred to as true or active power, is responsible for executing the actual work within an electrical circuit. The unit of measurement for real power is watts (W).

The power triangle's second component is the **reactive power** (**Q**), also referred to as wattless power. It does not contribute to any productive work but significantly influences the phase shift between voltage and current waveforms. Reactive power is absent in DC circuits. In contrast to **real power** (**P**) that performs all the work, **reactive power** (**Q**) detracts power from a circuit. This happens due to the generation and diminution of both inductive magnetic fields and capacitive electrostatic fields, making it more challenging for the true power to directly supply power to a circuit or load. The units of measurement for reactive power are volt ampere reactive (VAR).

The power triangle's third element is the **apparent power** (**S**), which is the product of Volts and Amps (VI). The unit of measurement for apparent power is volt-ampere (VA).

The billing for single-phase customers is determined by the product of the apparent power and the tariff. On the other hand, many, but not all, three-phase customers have an extra charge on their bills that is calculated based on the reactive power (kVAR) component.

Envision that your rate is R2.41 per kWh, but it is R2.41 per kVAh. It is important to note that standard meters do not log kWh.

Kempton Park

Initially, we must examine the load characteristics of a "nearly perfectly balanced network". To do this, I will utilize data gathered from a residential complex in Kempton Park.

The loads are significantly increased, yet the crucial factor is the ratio between apparent and real power. In this instance, the highest recorded total apparent power (**SΣ**) was 59.554 kVA, while the highest total real power reached 57.160 kW. Consequently, the ratio of total apparent power to total real power is 1.04:1 – $({}^{59.554}/{}_{57.160})$.

In Figure 14, the horizontal green line symbolizes the real power, the angled red line denotes the apparent power, and the vertical grey line stands for the reactive power. The angle it forms with the X-axis is 16.30 degrees – $\cos^{-1}\left({}^{57.160}/{}_{59.554}\right)$

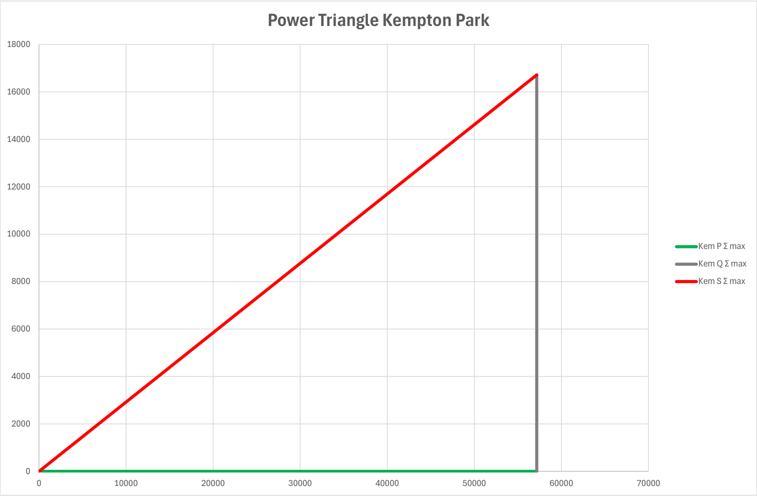

Figure 14: Kempton Park Power Triangle

Linden

Just like the scenario in Kempton Park, the values in this instance are derived from real data collected in Linden.

The highest recorded total apparent power (**SΣ**) was 3.666 kVA, and the peak total real power reached 1.549 kW. These measurements were taken at 21:20, a time when it is probable that all the "high power-consuming appliances" were turned off.

In Figure 15, the upward slope of the apparent power is noticeable. The angle it forms with the X-axis measures 65.01 degrees – $\cos^{-1}\left({}^{1.549}/_{3.666}\right)$.

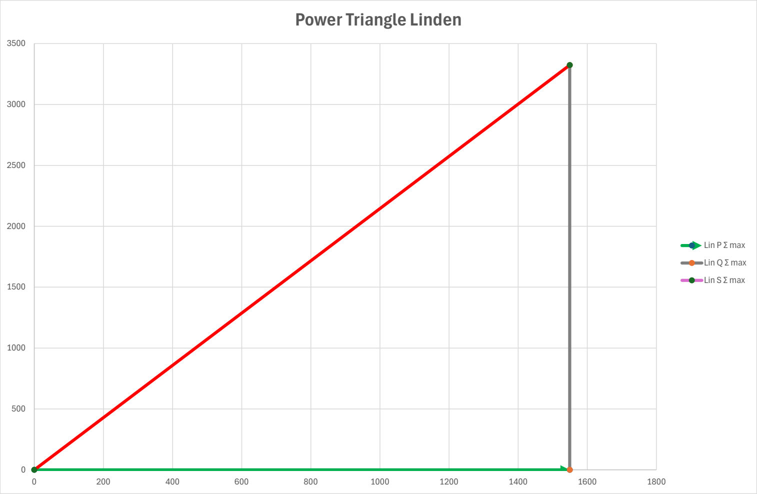

Figure 15: Linden Power Triangle

An important yet often overlooked fact is that unbalanced network conditions cause the apparent power to rise significantly due to other inefficient powers. The customer, unfortunately, has no control over this. Despite this, they are required to pay a premium for something they cannot influence.

Given that most customers use prepaid services, it becomes challenging to confirm their consumption habits. Consequently, the ratio of total apparent power to total real power stands at 2.37:1 – $({}^{3.666}/{}_{1.549})$.

The customer reports that their average monthly bill amounts to R1,000.00, which corresponds to an estimated monthly consumption of around 414.94kVAh – $(\frac{R1000}{R2.41})$.

Analogical Reasoning

Initially, to make an accurate comparison, both the maximum total apparent power (**SΣ**) and the maximum total real power (**PΣ**) need to be normalized to a common base.

The maximum total real power (**PΣ**) for Kempton Park is being scaled by a factor of 0.0.3 – $({}^{1.549}/{}_{57.160})$ – The maximum total real power (**PΣ**) is given as 1.549 kW. This value is then scaled by a factor of 1.04 to calculate the maximum total apparent power (**SΣ**), which results in 1614.14 kVA. This calculated value is subsequently divided by the maximum total apparent power (**SΣ**) that was recorded in Linden (Kempton Park) scaled by a factor of 1,000, resulting in a "new bill" amounting to R440.21. Hence, it is likely that a customer in Linden is overpaying by approximately R559.79 each month.

While it may be challenging to discern the angles in the following image, the line that signifies the apparent power for a house in Kempton Park with a comparable load pattern has a slope of 16.30 degrees. Conversely, the line indicating the apparent power for a house in Linden has a slope of 65.01 degrees, making it **3.99 times steeper**.

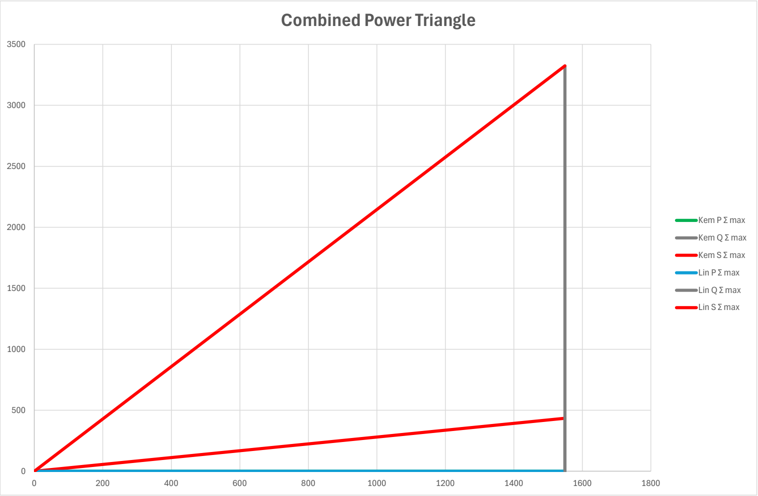

Figure 16: Combined Linden / Kempton Power Triangle

Effects of Unbalanced Networks in Linden

As previously mentioned, the component known as the zero-sequence is responsible for generating heat in transformers and cables.

In a previous statement, I mentioned that there would be an exceptionally high neutral current and intense circulating currents in the delta windings of transformers. This can lead to the overheating of transformers and cables, potentially causing unexpected shutdowns or even more serious failures like cables igniting or the insulation within the transformer catching fire.

Reflect on the frequency of cable and transformer malfunctions in the northern suburbs, particularly in Linden, over the previous years, and form your own conclusions.

All are free to peruse the Analogical Reasoning and perform the calculations independently. However, it is likely that residents in specific areas of Johannesburg's northern suburbs are bearing a substantial cost due to imbalanced network conditions, reflected in their electricity bills. Considering the percentage difference between the "new bill" amounting to R440.21 and the current electricity payment, there is a surge of 127.16%.

Customers might be able to contribute to balancing the currents if they all utilize three-phase power. However, they have no influence over the unbalanced voltages that are being delivered.

Cost of Complacency—Unbalanced Voltages and Economic Losses

In my newsletter published on November 14, 2023, I aim to capture the attention of accountants and financial officers. The focus? Explaining how unbalanced voltages, phase-shift variations, and harmonics disturbances can lead to significant economic losses.

But let us rewind to a previous blog post from September 24, 2023. In that piece, I stumbled upon unbalanced voltages and currents while analyzing measurements for a consulting engineer. The engineer sought information on the maximum loading capacity of a 6.6kV cable feeder.

On our website, two pages stand out as particularly relevant for understanding the consequences of unbalanced voltages:

1. **Decomposing Unbalanced Quantities**: Our most recent page delves into how unbalanced three-phase quantities can be broken down into their symmetrical components. These seemingly subtle imbalances can have a massive impact on the power system, often going unnoticed.
2. **Negative Phase Sequences**: An earlier publication highlighted the harmful effects of negative phase sequences on power system equipment and operation.

Now, let us explore the financial implications. In another newsletter titled "**Financial Losses Resulting from an Unbalanced Network**," also published on November 14, 2023, I discuss a critical issue: large power users—industrial, commercial and domestic—are paying for **Apparent Power (kVA)** while effectively utilizing only **Real Power (kW)**.

Consider the incident mentioned in the September 24, 2023, blog. Customers connected to that feeder are likely to pay a staggering **237.27% more** than they should. The kVA-to-kW ratio stands at 3.37:1.

But does this issue affect only large power users? The answer is nuanced. Both single-phase and three-phase power users face similar challenges. Everyone pays per unit, but here is the catch: the unit is **kVAh**, not **kWh**. Consequently, those fed from the unbalanced feeder end up paying approximately **3.37 times more** than their actual usage warrants.

Now, what happens when you raise a complaint with the power utility company? Brace yourself. They will insist on testing your electricity meter, and I can predict the outcome:

nothing wrong with the meter. Next, they will dispatch someone to check voltages and currents at the substation. Unfortunately, even this won't resolve the issue. Why? Because they measure voltages between phases using a panel meter that is grossly inaccurate. And so, the cycle continues, reinforcing the illusion that "**nothing is wrong**."

And do not assume this problem is isolated. I recently spoke with someone from Middelburg, Mpumalanga, South Africa, who reported mysteriously doubled utility bills. The cost of complacency in managing unbalanced voltages reverberates far beyond a single area.

Unfazed Attitude Towards Power Quality Issues

In a September 2023 article, I highlighted the impact of poorly maintained switchgear on long-lasting power quality issues. Based on an actual incident in Springs, Gauteng, South Africa, I noted that two of the three phases experienced voltage increases exceeding 51%, while the third phase dropped to nearly zero. Despite my efforts to raise awareness through media and newsletters, further investigation remains elusive. It appears that municipalities and Eskom remain indifferent to these power quality concerns.

Another critical issue is phase imbalance in distribution networks. Operators and maintenance crews often underestimate the negative consequences of such imbalances on low-voltage (LV) networks and electrical equipment. Current imbalances reduce the serviceable loading capacity of LV cables and distribution transformers. These imbalances can lead to additional heat losses, affecting both phase and neutral conductors. End users supplied by unbalanced voltages face efficiency reductions, increased losses, overheating risks, and potential equipment failures. Severe voltage or current imbalances may even cause protection relay malfunctions.

Notably, these issues extend beyond individual substations; they can impact entire regions. For instance, in the Magaliesburg area, frequent replacements of electric motors and electronic equipment suggest an ongoing unbalanced network problem.

Highlighting the cost of complacency, a November 2023 article emphasized that unbalanced voltages, phase-shift variations, and harmonic disturbances result in significant economic losses. Businesses, particularly accountants and financial officers, should take notice. Customers on certain feeders, like the one in Springs, may be paying up to **237.27% more than necessary** due to power quality issues.

In summary, the lack of action suggests an unfazed attitude towards power quality issues, despite their far-reaching impact.

Conclusion

Primarily, it is crucial to understand that the zero-sequence component is responsible for generating heat in transformers and cables, hence the need for its elimination. Secondly, imbalanced network conditions lead to an **extremely high neutral current** and **elevated circulating currents in the delta windings of transformers**. These conditions can cause

transformers and cables to overheat, potentially leading to unexpected shutdowns or even more serious failures like cables being burnt off or transformer insulation ignition.

Reflect on the recent surge in reported cable and transformer malfunctions, and then form your own opinion: Are Eskom and other power distributors cognizant of the imbalanced network conditions? Furthermore, do they take adequate measures to inspect the networks for this issue? Based on my observations, it seems unlikely. They appear to disregard any notifications concerning imbalanced network conditions.

A recurring query is: who reaps the benefits from the additional charges customers pay due to unbalanced network conditions? Let us delve into this. Customers require a certain amount of electrical power, or **real power**, to carry out specific tasks. However, these unbalanced network conditions lead to a substantial rise in inefficient powers, causing an increase in **apparent power**. Since customers' bills are primarily based on this apparent power, they end up paying more for these inefficient powers. On the generation side, power must be produced to offset the losses. Each unit generated includes a profit margin. Therefore, the more units produced, the greater the profits. It is important to note that none of the power plants, whether coal-fired, nuclear, or renewable, operate as non-profit entities.

It might be beneficial for individuals like the Eskom executive to peruse this article, along with other articles I have shared on my blog. Additionally, web pages such as Symmetrical Component Analysis and Negative Phase Sequencing could provide further understanding of this concept.

Those who have comprehended the aforementioned information can independently determine the validity of the claim that Modderbee and Linden are not experiencing unbalanced network conditions.

What is crucial is that consumers need to determine if they are willing to pay a significantly higher price for electricity, considering that the issues should be resolved by the power supply distributors, including Eskom.

Equally significant is the fact that imbalances in networks are not readily apparent in power supplies. For instance, in Linden, individuals might assume the power supply is functioning normally by checking the phase-to-neutral voltages. Similarly, in Modderbee, Eskom and electricity department officials might perceive the network as problem-free when they observe that the phase-to-phase voltages are consistent.

If you are under the impression that residing in a different part of the globe shields you from unbalanced network conditions, it might be worth verifying that assumption. As outlined in this document, you might be totally unaware of such occurrences.