Unbalanced Networks

I could have copied the entire Symmetrical Component Analysis explanation from the Agulhascorp website and then post it into this document, but I have decided not to do that.

You can also read what is being said about Negative Phase Sequencing so that you as a reader can get a good grasp of what I am about to explain below.

I also wish to point out that I have a vast amount of experience in this field dating back to the early 1980s. There are several articles that I have already posted on the blog to read and perhaps one I can specifically point out is the one about Untransposed Transmission Lines. There are a lot more to read.

Modderbee Municipal Substation

Introduction

I recently learnt that, when an Eskom official was briefed about a possible unbalanced network condition at a municipal substation fed directly from the Eskom substation, which is about 20-metres away, he said that it is highly unlikely. Since I was not present, I cannot vouch for the authenticity of the message I have received through another party.

The second reason for this posting is that I have reached out to someone who profess to be on top of power quality at Eskom with not one, but two emails. Both these emails were successfully delivered with no response to the first email while the second was “deleted without being read”, as per the notification I received on my email account.

In my first email I said that “if you are the right person to cooperate with to investigate this apparent issue of unbalanced currents and voltages, as explained below, kindly let me know”. In the same email I said, “I would really welcome it if you can include me in such an investigation”. Whether he read the email, I cannot say but I cannot understand that he would not have noticed the email dated April 2, 2024, by now.

Since September 2023, I have made several postings on the Agulhas Utilities Corporation website, blog, LinkedIn, and Facebook. I sincerely counted on him perhaps seeing what I have posted and react to my findings, or for other Eskom personnel to see the postings and perhaps make those who deal with power quality to take aware of the postings. This has not happened up until now. Furthermore, my emails to senior people in the electricity department of the City of Ekurhuleni Metropolitan Municipality have also not evoked any reaction. The emails were sent to the senior officials as per their website.

I have therefore decided that it is time to post this new article.

Modderbee Municipal Substation Recordings

August 2023, I was commissioned to record the loading on a municipal feeder Modderbee substation in the Springs, Gauteng, area for a consulting engineer who wanted to determine how much extra load can be added to a specific 6.6kV feeder.

On August 30, 2023, when we installed the Power Quality Monitor, we noticed that one of the phase-to-neutral voltages was “missing”. I then used a second instrument to check our findings. When the voltage was indeed below 2-volts, we thought that it could be a blown fuse on the secondary side of the busbar-VT. We continued to install the instrument since the measurement of the currents ware probably more important.

The Modderbee municipal substation is supplied by two 6.6kV cables from the Eskom substation which is approximately 2-metres away. The municipal substation has two 6.6kV busbars with a bus-section breaker which remains open. Essentially, the busbar-VTs thus measures the incoming voltages.

To get a good indication of the load, I usually leave the instrument running for a week or so. The recording was therefore done for the period from August 30, 2023, and removed on September 5, 2023.

Data Analyses

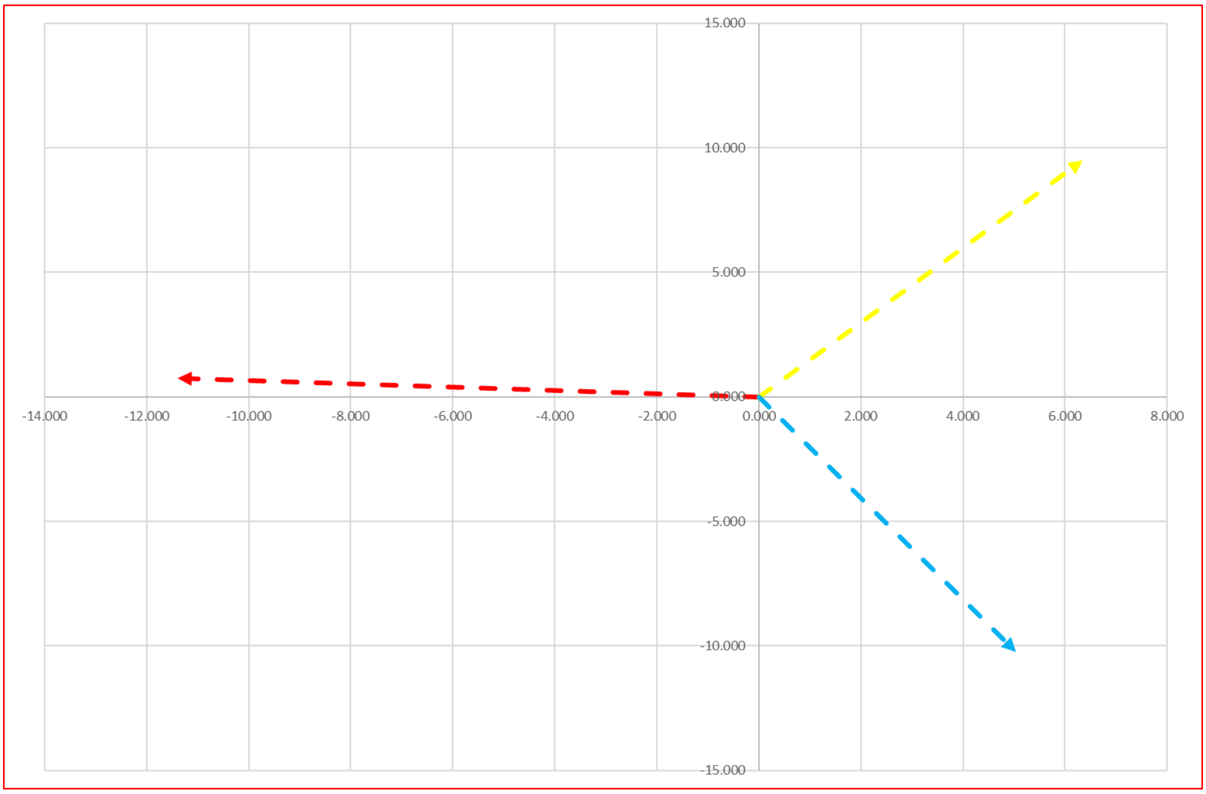
At first, I did not pay attention to anything else but to check the real-, reactive- and apparent-power results, but when the consulting engineer asked why the neutral current was so high, I started to analyze the data and it was then I discovered the unbalanced currents and voltages.

With a perfectly balanced system, the magnitudes of the voltages should be the same and the phase-displacements should be 120-degrees exactly. Secondly, with a perfectly balanced system, there should ONLY be a Positive Sequence Component and NO Negative or Zero Sequence Components.

The following are images representing the symmetrical components of the unbalanced three-phase system as recorded at Modderbee substation between August 30, 2023, and September 5, 2023.

Positive-Sequence Component

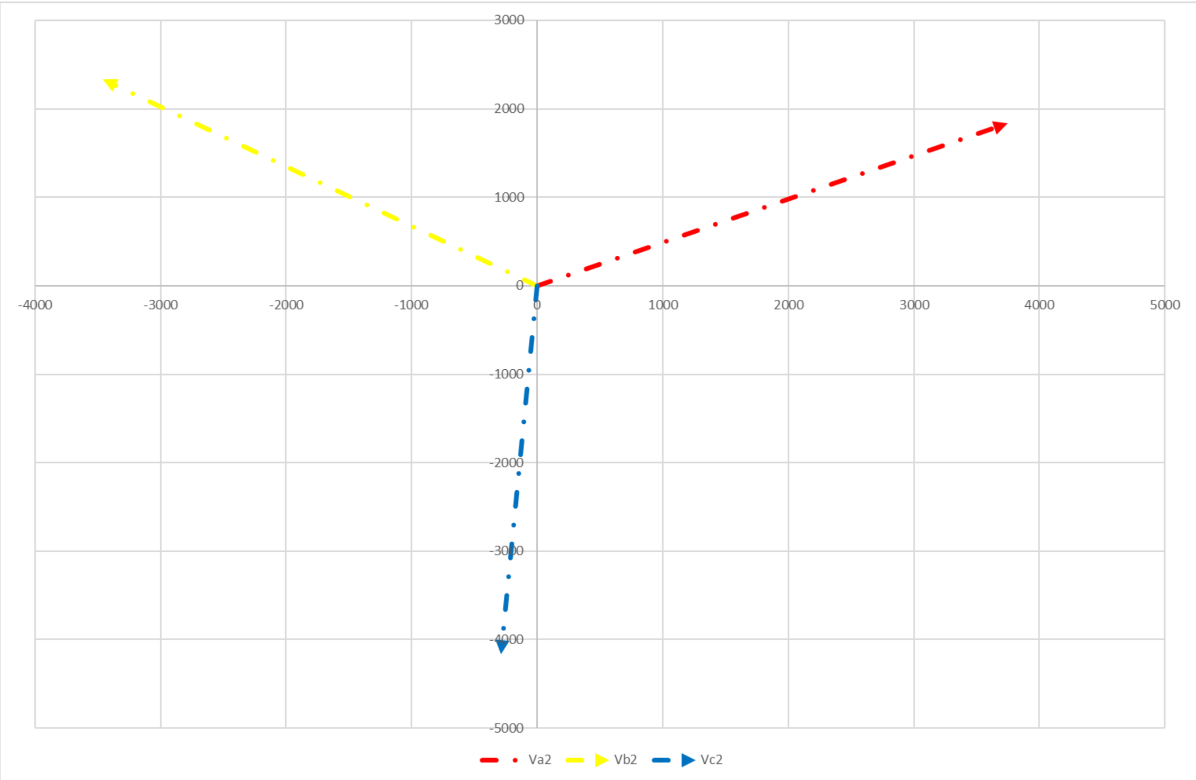
The first image is the positive-sequence component of the voltages as recorded at 03:40:00 on September 5, 2023.



The first thing to notice is that the entire vector is rotated by nearly 180-degrees since the red line should essentially be on the X-axis towards the right.

Negative-Sequence Component

The image below is the negative-sequence component of the voltages as recorded at 03:40:00 on September 5, 2023.

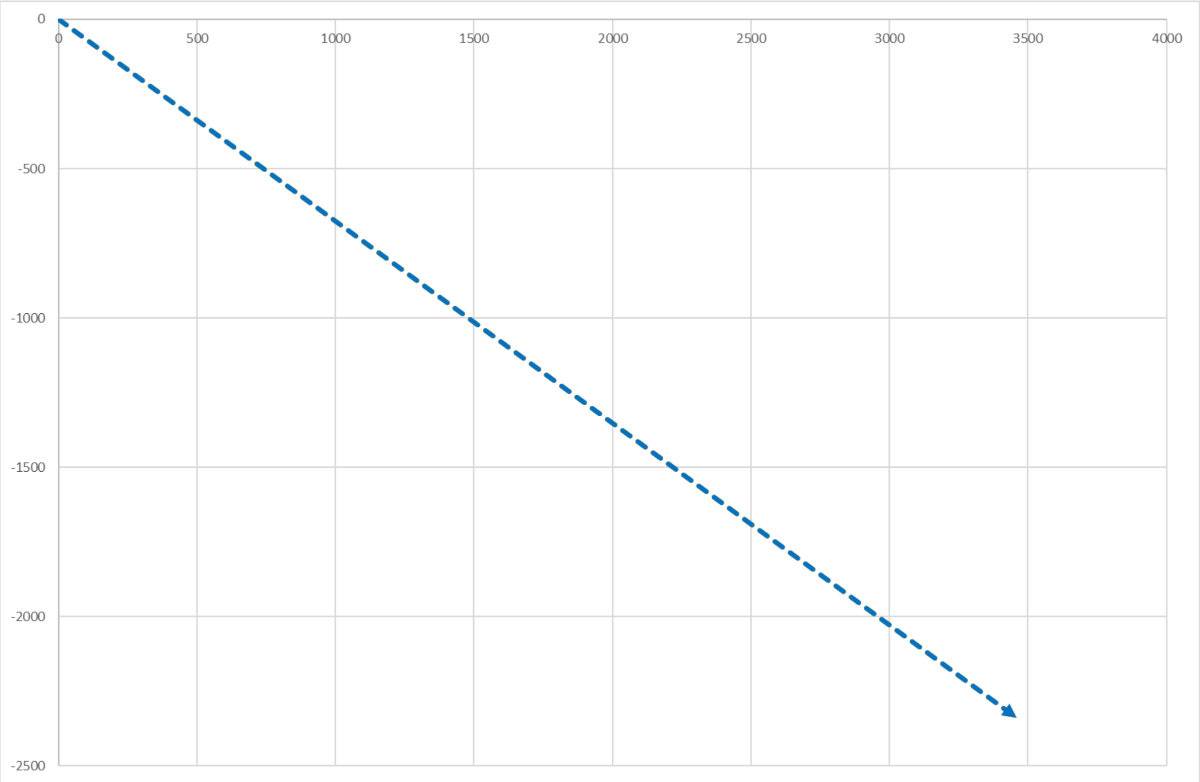


Now look at the high magnitudes of the three negative sequence components. **This should be NIL and therefore absolutely NO lines at ALL.**

Also look at the colors of the three phases. It is not Red, Yellow, and then Blue – remember the vectors are turning anticlockwise. In this case, it is Red, Blue, and then Yellow and that is why it is called Negative Phase Sequence.

Zero-Sequence Component

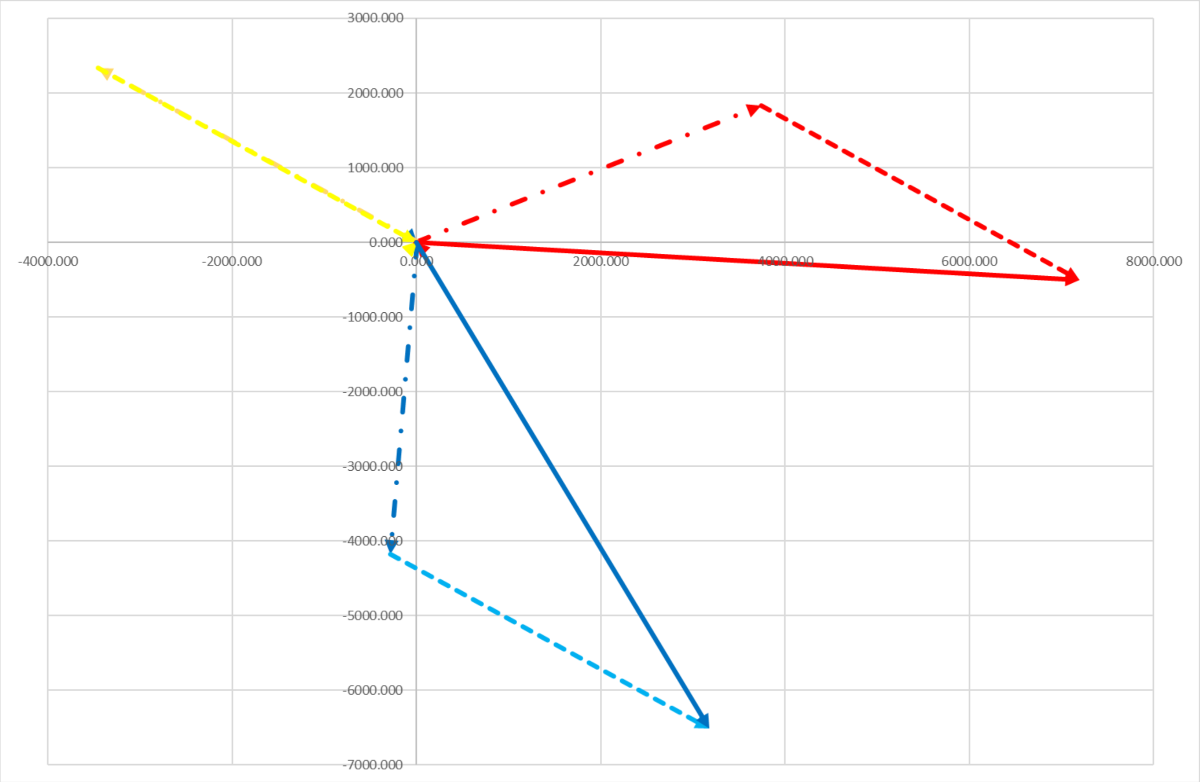
The image below is the zero-sequence component of the voltages as recorded at 03:40:00 on September 5, 2023.



The reason why you only see the blue dashed line is that the red and yellow are hidden underneath the blue. All three are of the same magnitude and angle.

Now look at the high magnitudes of the three zero-sequence components. **This should be NIL and therefore absolutely NO lines at ALL.**

Cartesian Coordinates of Recorded Voltages



The image above shows the how the three symmetrical components that make up the voltages as recorded at 03:40:00 on September 5, 2023.

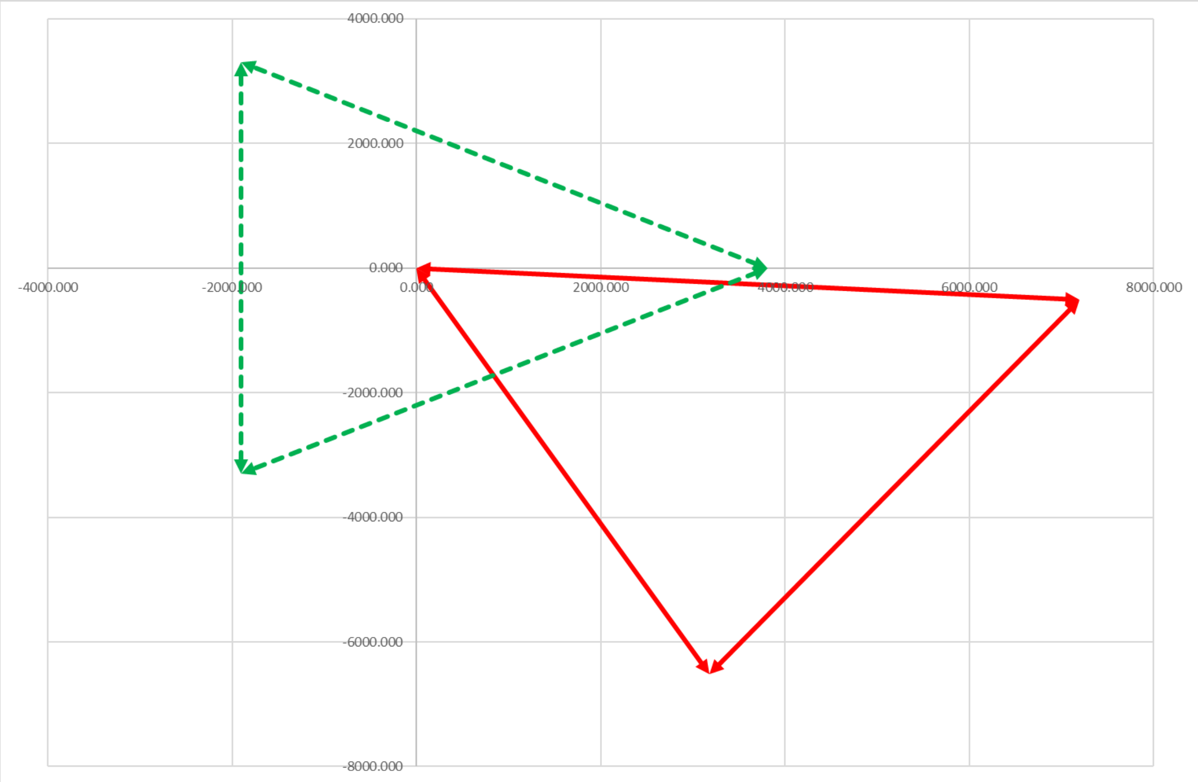
The reason why the yellow solid line (recorded voltage) is not clearly showing is that all three lines representing the positive-, negative-, and zero-sequence components are on top of each other.

Phase-To-Phase Voltages

The image below shows the phase-to-phase voltages of a perfectly network with the unbalanced phase-to-phase voltages of network as recorded at 03:40:00 on September 5, 2023, at Modderbee municipal substation.

The red triangle represents the recorded phase-to-phase voltages while the green dashed-line triangle represents a perfectly balanced network.

It is important to note that the center point for the perfectly balanced network is at the crossing point of the X- and Y-axis. The center point for the recorded voltage is completely off-center.



Perhaps the person who said that it "highly unlikely" that the network at Modderbee substation in unbalanced will benefit from this explanation.

City Power Area – Linden

Introduction

After repeated request to City Power to check for possible unbalanced network conditions at Roosevelt Park substation in Roosevelt Park, Johannesburg, offering my service and participation to determine whether this may be restricted to one area, I decided to install my own Power Quality Monitor at a three-phase installation near me. I already suspected that our area is being subjected to unbalanced network conditions and I wanted to find out whether that is so.

City Power Recordings

On April 12, 2024, I installed my Power Quality Monitor at a neighbor's house for approximately 20-hours.

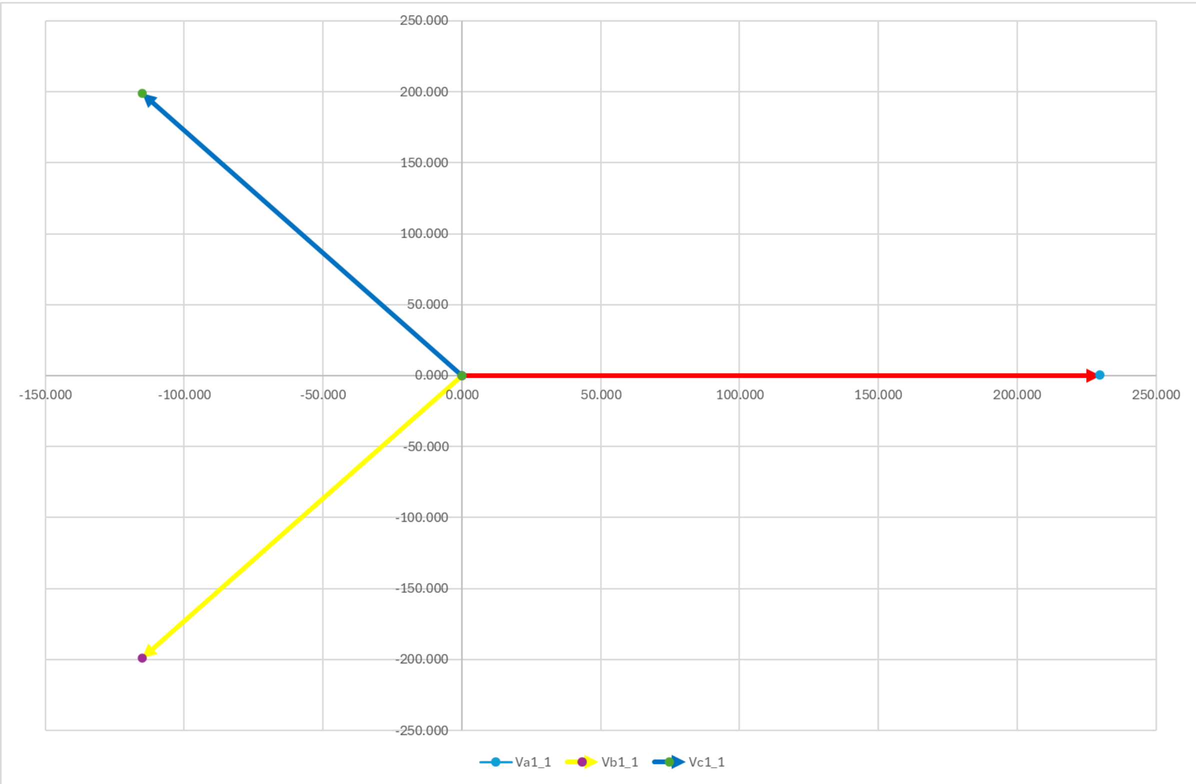
When I removed the instrument and took a quick look at the results, I noticed a sever sag on two of the three-phases at 04:23:55. At that time, I did not know why it only happened in two phases while the third one remained unaffected. After careful analysis of the results, I discovered that the area we live in is indeed subjected to unbalanced network conditions.

My attempts to get City Power to do a similar check for unbalanced network conditions did not materialize since I have not yet received their results, which I have requested. I shared my data with them.

Data Analyses

As I have said above, with a perfectly balanced system, the magnitudes of the voltages should be the same and the phase-displacements should be 120-degrees exactly. Secondly, with a perfectly balanced system, there should ONLY be a Positive Sequence Component and NO Negative or Zero Sequence Components.

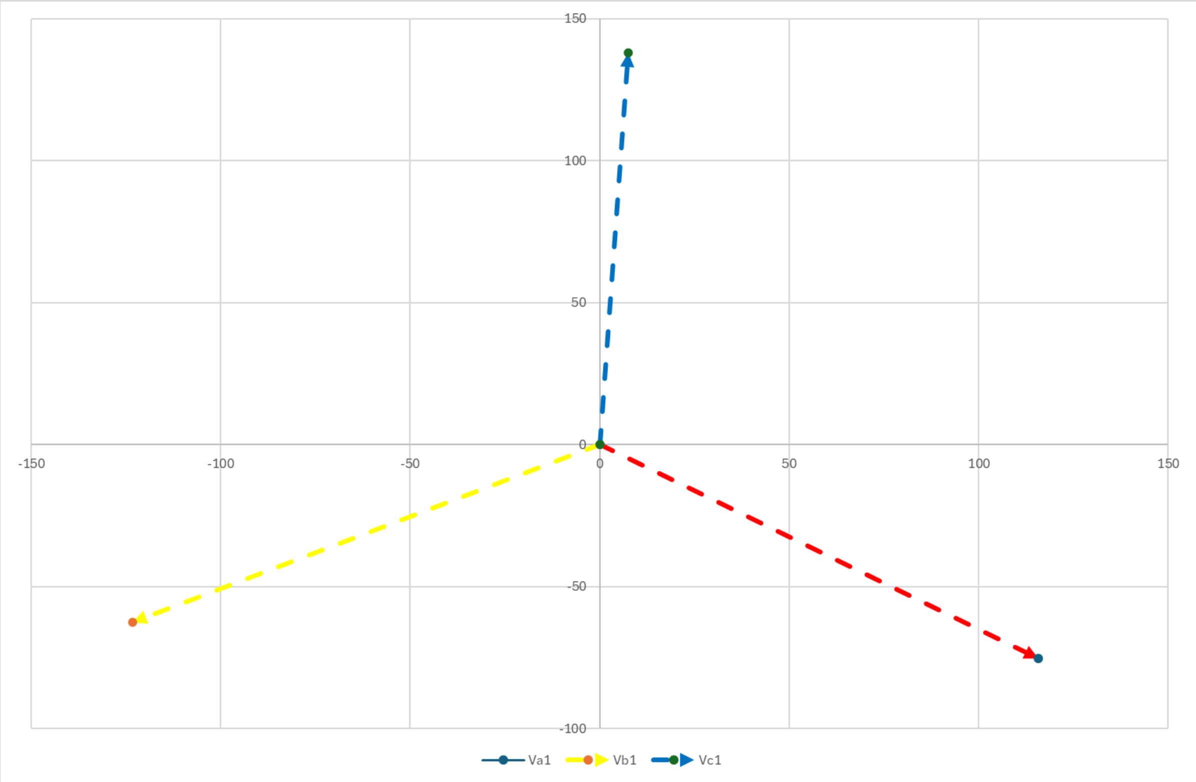
Therefore, the only vector for this area should look like in the image below.



Notice that the three phases are equal in length and displaced by exactly 120-degrees. Also notice the placement of phase 1 which is represented by a red line. It really does not matter whether the phase rotation is clockwise or anti-clockwise. That line will always be on the X-axis.

Positive-Sequence Component

The image below represents the positive-sequence component based on the recording done at 21:20:00 on April 12, 2024.

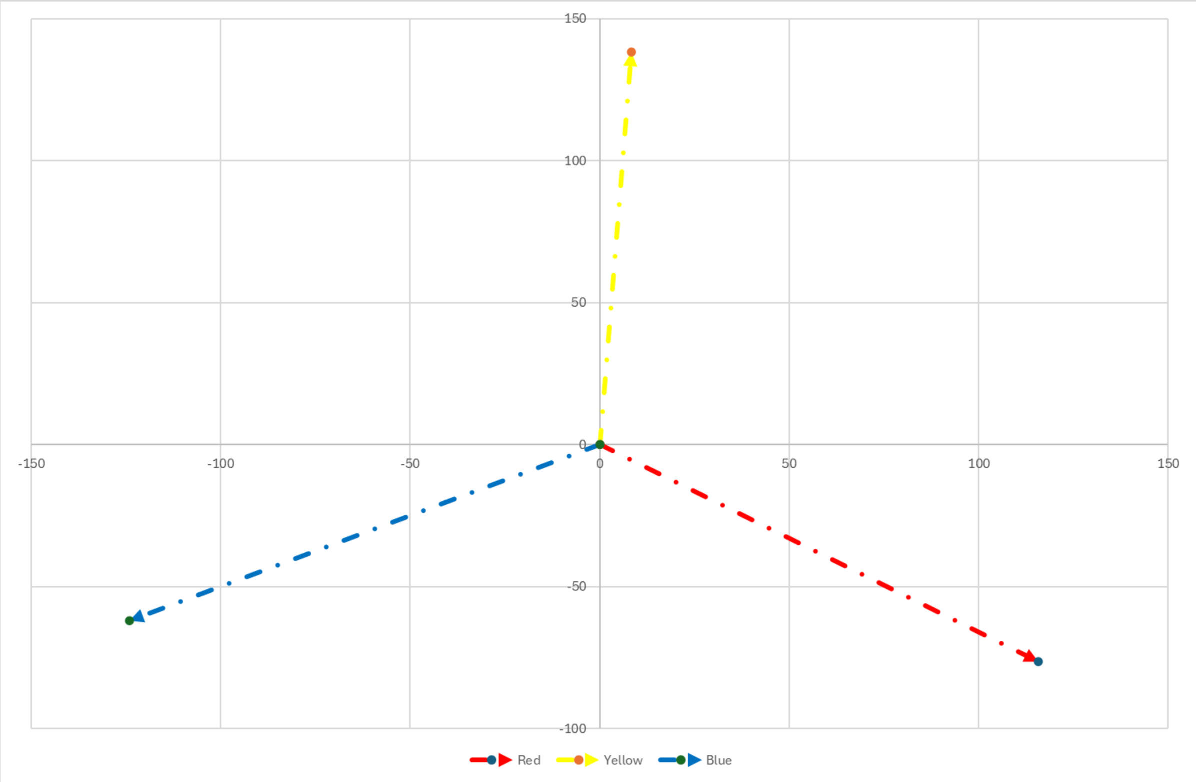


Now look at the position of phase 1 represented by the dashed red line. The entire positive-sequence component has shifted in a clockwise direction. Secondly, look at the length of the dashed lines. They should be of the same length as in the previous image. This clearly that there is a problem.

Negative-Sequence Component

The image below represents the negative-sequence component of the voltages as recorded at 21:20:00 on April 12, 2024.

Remember what I said above, with a perfectly balanced system, there should NOT be a Negative-Sequence Component present. So, the canvas area of the image below should be blank.



I want to point out that phase 1 represented by the red dashed line is at the same angle and magnitude as the red dashed line in the image above, the positive-sequence component.

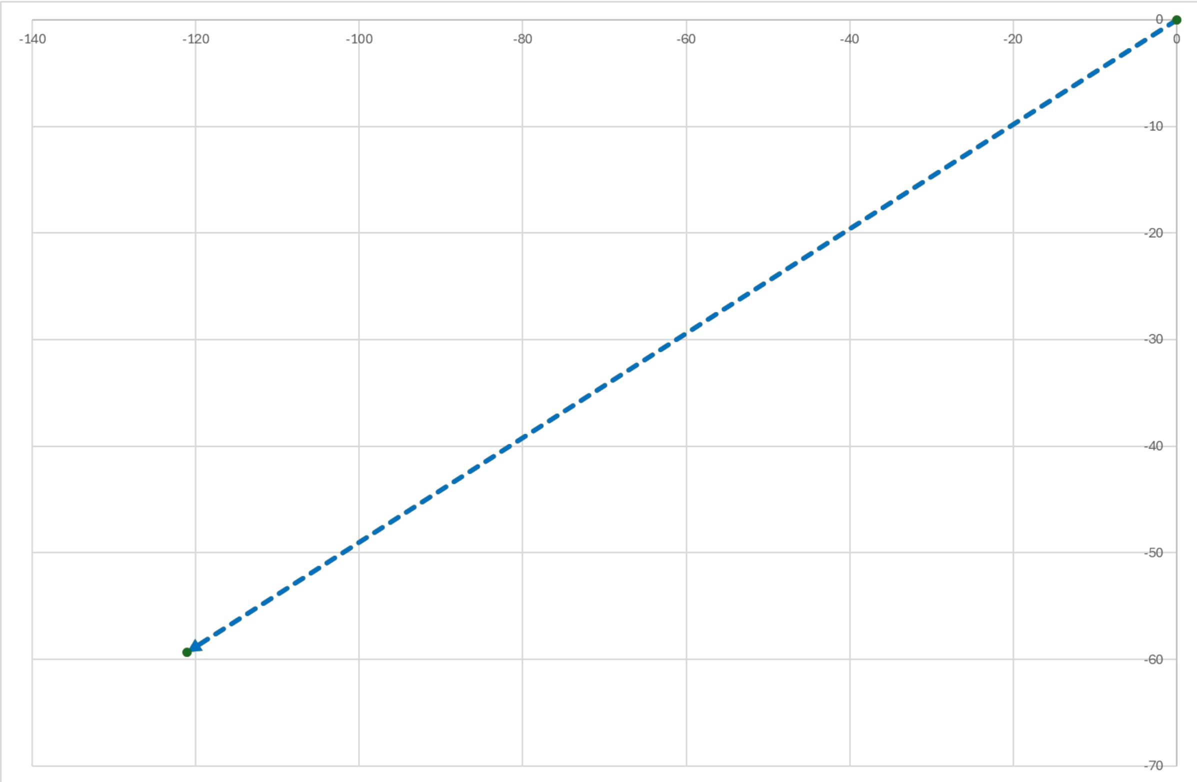
Zero-Sequence Component

The image below represents the zero-sequence component of the voltages as recorded at 21:20:00 on April 12, 2024.

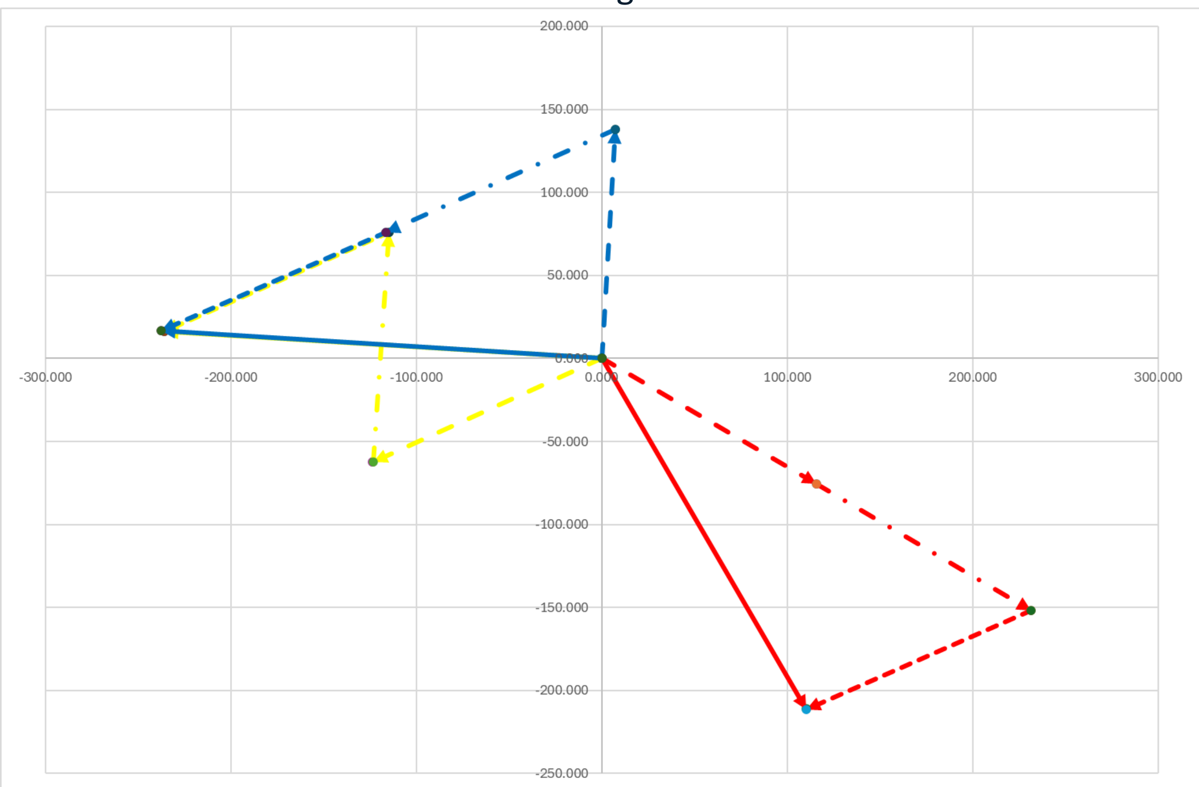
Remember what I said above, with a perfectly balanced system, there should NOT be a Zero-Sequence Component present. So, once again, the canvas area of the image below should be blank.

The reason why you only see the blue dashed line is that the red and yellow are hidden underneath the blue. All three are of the same magnitude and angle.

Now look at the high magnitudes of the three zero-sequence components. **This should be NIL and therefore absolutely NO lines at ALL**, or, as I have said above, it should be a blank canvas.



Cartesian Coordinates of Recorded Voltages



The image above shows the how the three symmetrical components that make up the voltages as recorded at my neighbor's house at 21:20:00 on April 12, 2024.

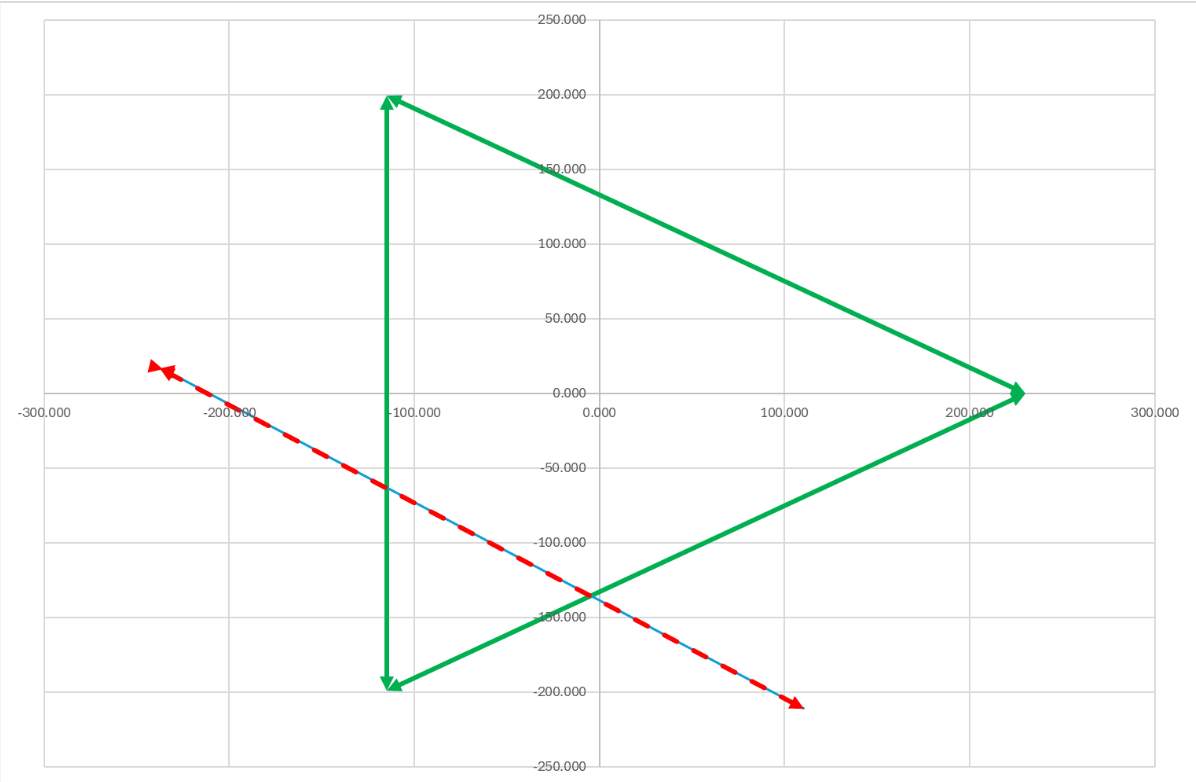
The important thing to notice is that that there appears to be no yellow solid line.

Before thinking that there is a phase missing, let me assure you that it is not so. The phase-to-neutral voltages are very close to each other. However, what has happened is that the 2 and 3 is almost of the same magnitude and at the same angle.

Phase-To-Phase Voltages

The image below shows the phase-to-phase voltages of a perfectly network with the unbalanced phase-to-phase voltages of network as recorded at my neighbor's house at 21:20:00 on April 12, 2024.

The red "triangle" represents the recorded phase-to-phase voltages while the green dashed-line triangle represents a perfectly balanced network. Well, in this case there is no red "triangle". It appears that the phase-to-phase voltages are represented by a "straight line" rather than a triangle, which it should be. The reason is that the phase-to-phase voltage between phase 1 and 3 is 0.33-volts.



Conclusion

First and very important to note is that the zero-sequence component produces **heat in transformer and cables**. So, it is important to eliminate the zero-sequence component. Secondly, unbalanced network conditions result in very high neutral current and very high circulating currents in the delta windings of transformers. This also causes overheating in transformers and cables and can eventually result in spurious trips or even more severe failures such as cables burning off or the insulation inside the transformer catching fire.

Now consider the number of cable and transformer faults reported lately and then you can make up your own mind whether Eskom and the power distributors are aware of unbalanced network conditions, and do they do enough to check the networks for this phenomenon, or do they simply ignore it when a member of the public, such as I, report it to them.

Perhaps, they should read the posting on the blog as well as the web pages such as Symmetrical Component Analysis and Negative Phase Sequencing to understand this concept.

Everyone who has read and understood what I have said above can judge for themselves whether it is true that Modderbee and Linden are not subjected to unbalanced network conditions.

What is equally important is how unbalanced networks are not easily manifested in power supplies. In the case of Linden, people may think that the power supply is normal by measuring the phase-to-neutral voltages. In the case of Modderbee, Eskom and officials from the electricity department may think that there in nothing wrong with network when they select the phase-to-phase voltages and notice that it is almost the same.

Effect on Electricity Bill

Perhaps an even more important question is: do the unbalanced networks affect the customer's electricity bill? The short and simple answer is yes, it does!

In the power triangle of an AC circuit there are three parts.

The **real power (P)** is also known as **true** or **active power**, and it performs the "**real work**" within an electrical circuit. **Real power** is measured in **watts (W)**, **kilowatts (kW)**, or **megawatts (MW)**.

The second part of the power triangle is the **reactive power (Q)** which is sometimes called wattless power and it does not perform any useful work but has a big effect on the phase shift between the voltage and current waveforms. Reactive power does not exist in DC circuits. Unlike real power (P) which does all the work, reactive power (Q) takes power away from a circuit due to the creation and reduction of both inductive magnetic fields and capacitive electrostatic fields, thereby making it harder for the true power to supply power directly to a circuit or load. **Reactive power** is measured in **volt ampere reactive (VAR)**, **kilovolt-ampere-reactive (kVAR)**, or **megavolt-ampere-reactive (MVAR)**.

The third part of the power triangle is the **apparent power (S)**. This is Volts multiplied by Amps (VI). **Apparent power** is measured in **volt-ampere (VA)**, **kilo-volt-ampere (kVA)**, or **mega-volt-ampere (MVA)**.

Single-phase customers' bills are based on the **apparent power** multiplied by the **tariff**.

Not all but a great number of three-phase customers' bills have an additional item which is based on the **reactive power (kVAR)** component.

Imagine you are being charged at R2.41 / kWh – it is R2.41 / kVAh. Ordinary meters do not record kWh.

Linden

The values used in the following example are based on actual recorded data.

The **maximum summated apparent power (SΣ)** recorded was 3.666 kVA. Say the load remains constant for the entire month, 30-days, then the customer would be paying R8.84 per hour or R6 361.24 per month. However, the customer effectively only has 1.549 kW of useful or **real power, summated (PΣ)**, for which he should have been paying closer to R1 115.28 per month.

This was recorded at 21:20 when the “heavier power consuming appliances” were likely all switched off. **<u>The summated apparent to summated real power ratio is thus 5.7:1</u>**.

Since most customers are on prepaid, it becomes very difficult to verify such consumption patterns.

Kempton Park

For a comparison, I will use load data from another installation. This is from a housing complex, so the loads are substantially higher. In this comparison I will use the same tariffs.

The **maximum summated apparent power (SΣ)** recorded was 59.554 kVA and the load remains constant for the entire month, 30-days, the housing complex would thus have been paying R143.53 per hour or R103 339.07 per month. However, they effectively only has 57.160 kW of useful or **real power, summated (PΣ)**, for which they should have been paying closer to R99 185.68 per month. **<u>The summated apparent to summated real power ratio is thus 1.04: 1</u>**.

Again, you as reader can do your own sums and then decide whether unbalanced network condition is something to be ignored.