Unbalanced Network Conditions

I could have copied the entire <u>Symmetrical Component Analysis</u> explanation from the Agulhascorp website and then post it into this document, but I have decided not to do that. You can <u>read more</u> about the reason for this type of analysis and also read what is being said about <u>Negative Phase Sequencing</u> so that you as a reader can get a good grasp of what I am about to explain below.

For quite some time, I have been suspecting that the power distribution is in a state of unbalance. From 12 March 2024, I have persistently tried to get City Power to investigate my suspicions. My impression is that my warnings are treated in a way that I got the impression that it is being stopped or simply ignored without taking a careful look of what I said or initiating an investigation.

Since this is not the first time I have dealt with this type of situation, I can construe the signs into the true realities. Consequently, I decided to expand my own investigation since I was not getting any support from those who are responsible to do this kind of investigation for the power distributor.

With data recorded at two sites, I am going to explain the effect of unbalanced currents and voltages in the real-world scenarios.

The first is the current situation in Linden and second is from a location in Kempton Park which I have done a few years ago.

The data recently recorded in Linden shows that the area is currently subjected to unbalanced currents and voltages while the data recorded in Kempton Park shows that the unbalance is well withing limits set by the relevant standards and norms to be expected from the electricity distributor.

In both cases, the data that was recorded on three-phase networks since it is completely impossible to do a <u>Symmetrical Component Analysis</u> with data recorded on a single-phase supply.

Linden

In this chapter, I am going to explain the data I previously sent to City Power in an Excel workbook and particularly the data in the spreadsheet called "Power Quality Data Linden".

Based on the apparent lack of urgency on the part of City Power officials, I concluded that those who received the emails dated 15 and 17 April 2024 clearly did not understand the data nor my messages.

In my email of 15 April 2024, I said: "The second and far more important aspect is that the summated negative sequence voltage went up to 139.37-volts with the summated zero-sequence voltages went up as high as 137.46-volts. **Both these values should effectively be zero (nil).** Furthermore, the highest zero-sequence as a percentage of positive sequence voltage is 100.62% and so is the negative sequence as a percentage of the positive sequence voltage. **Again, these percentages should be zero or very close to zero.**"

In my email of 17 April 2024, I said: "Three days later, I have not had any response to my email from anyone at City Power and decided to send you another Excel workbook with a lot of data

"redacted" so that I can point out the dangers. When you look at column H (U L31 avg. 10 min [V]) you will notice that the phase-to-phase voltage between phases 1 & 3 is less than 1 volt. The reason for that is the severity of the unbalanced voltages. That means a large three-phase delta connected electric motor would not start, or if it is running, it would be destroyed in a very short period. Your transformers and cables would also overheat and perhaps catch fire as has been happening lately." Again, there was no apparent urgency on the part of the City Power officials.

Since I do this kind of work for an income, I have nevertheless decided to prepare this document to explain why I specifically said, "you will notice that the phase-to-phase voltage between phases 1 & 3 is less than 1 volt".

Perfectly Balanced System

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 image below is the positive-sequence voltage component of a perfectly balanced system.



There is only one vector and that is the positive-sequence component.

Unbalanced System

The following are images representing the symmetrical components of the unbalanced threephase system such as currently exist in Linden.

Before anyone says that City Power uses a different phase rotation, simply swap the blue and red in your mind when you look at the vectors below.

Positive-Sequence Component Vector

The image below is the positive-sequence component of the voltages as recorded at 21:20:00 on 2024-04-12.



In the image below, the positive-sequence components of the voltages of both the perfectly balanced network and the unbalanced network as recorded in Linden are shown.



The solid-lines represent the positive-sequence components of the voltages of the perfectly balanced network while the dashed-lines represent unbalanced network.

First notice the lengths of the solid- versus the dashed-lines. Secondly, notice the shift in two vectors.

Negative-Sequence Component Vector

The image below is the negative-sequence component of the voltages as recorded at 21:20:00 on 2024-04-12.



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 Sequence.

Zero-Sequence Component Vector

The image below is the zero-sequence component of the voltages as recorded at 21:20:00 on 2024-04-12.



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 question that should have been asked based on my statement "you will notice that the phase-to-phase voltage between phases 1 & 3 is less than 1 volt", is "why"?

The voltages as recorded at 21:20:00 on 2024-04-12 between phases 1 & 2 was 414.9-volts and between phases 1 & 3 was 414.82-volts. Now look at the image below and you will see that if you measure between the ends of the line 1 & 2 and 1 & 3, will get those values since the red and yellow phases are very close to in-line with each other. That is why the phase-to-phase voltage between phases 2 & 3 is less than 1 volt.

Before anyone thinks that the one phase is missing, let me make it clear, it is not. In simple terms, it the one phase "is hiding behind" the other phase. I have heard stories of City Power officials wanting to join two conductors on a cable together and then join the two sets of conductors to the "live phases". It may work for "only single-phase supplies" but would be disastrous for three-phase networks.



The subject line of my email dated 17 April 2024 read "Possible Reason for Cable and Transformer Failures in Northern Suburbs". I did not use that as the subject in my email for no reason.

A question that should have been raised immediately after looking at the data in the spreadsheet called "Power Quality Data Linden" is: how does the voltage unbalance affect electric motors, generators, transformers, and power supply cables?

The performance of the motor depends on the voltage. A voltage unbalance of 1 percent at the terminals of a fully loaded motor can result in phase current unbalance of 6 to 10 percent, which raises the operating temperature of the motor, reduces its energy efficiency, and shortens its life. Secondly, the speed and torque characteristics change if the voltage is unbalanced. The unbalanced voltage causes an unbalanced stator current, increasing the losses and the net torque. The negative sequence current produces the backward-rotating magnetic field and produces the opposite torque to the positive sequence component. Thus, the torque produced by the negative sequence current tries to retard the motor by exerting opposite torque.

In my Excel workbook attached to my email dated 17 March 2024, I remove the data about the currents since it would present a distorted image and make people confused. The recording was done at a house with all the appliances being single-phase with currents that can hardly be balanced. However, at the substations, it would be a completely different situation. The currents should be balanced.

With voltages represented by the solid lines of the vector as displayed in the last image, you will get a very high neutral current and very high circulating currents in the delta windings of transformers. This is what causes heat generation. The zero-sequence component is the one that produces heat in transformer and cables.

Effect on Electricity Bill

Perhaps an equally important question is: do the unbalanced voltages and currents 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, the customer would thus 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.

Since most customers are on prepaid, it becomes very difficult to verify such consumption patterns. The summated apparent to summated real power ratio is thus 5.7:1.

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 have 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:</u> <u>1</u>.

Conclusion

As stated before, the zero-sequence component is the one that produces **heat in transformer and cables**."

Up above I also said "you will get a very high neutral current and very high circulating currents in the delta windings of transformers. Overheating in transformers and cables 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 in the northern suburbs and specially Linden in the past, and then you can make up your own mind.

Everyone can read the Effect on Electricity Bill to do the sums for themselves, but the conclusion is that customers in certain parts of the northern suburbs of Johannesburg are probably paying a very hefty price for the unbalanced currents and voltages through their electricity bills. If one considers the percentage change between the two ratios, it is an increase of 448%.

Customers can perhaps help balance the currents if they are all on three-phase, but they have absolutely no control over the unbalanced voltages being supplied.