# IMPACT OF FLOATING NEUTRAL IN DISTRIBUTION SYSTEMS

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## *ABSTRACT*

*Eskom Distribution losses lot of money annually in investigation and settlement of public claims that arise due to loss of neutral conductors in our networks. This paper discuss the impact that loss of neutral have on distribution systems, the causes, systems affected by loss of neutral as well as remedial actions that can be taken to mitigate the risk.*

## INTRODUCTION

As part of the universal access, Eskom has committed to supply electricity to all people living in South Africa by 2012. A substantial amount of money is spent to make this dream a reality and the return in these investments is very low especially on electrification customers.

Instead of Eskom making profit from the sales of electricity that we are supplying to customers, Eskom is paying millions of Rands for public liability claims caused by floating neutral in distribution networks [1].

A broken or loose neutral conductor in the network will have different impacts depending on the type of supply, type of installation and load balancing at the particular installation. The worse case scenario would include both damage to connected loads or creation of hazardous touch voltages on exposed conductive parts [2].

## LOSS OF NEUTRAL IMPACT TO CUSTOMERS

The impact of floating neutral is dependent on the position in the system where the neutral is broken.

### Loss of neutral at the transformer

**Single Phase Transformer**
For installations supplied from a single phase transformer, the impact of broken neutral is not very severe. Customers connected to that particular transformer will not have supply as the return path will have been broken. Hazardous touch voltages might also be experienced on exposed conductive parts.

**Dual Phase Transformer**
A loss of neutral on a dual phase transformer will cause the voltage to float up to the line voltages depending on the load balancing on the system. This type of fault condition may damage the customers equipment connected to the supply.

Hazardous touch voltages might also be experienced on exposed conductive parts [2].

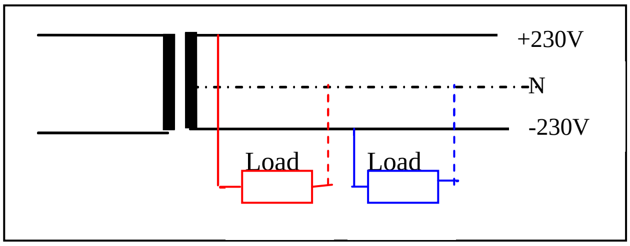


Figure 1: Dual Phase Transformer under healthy condition

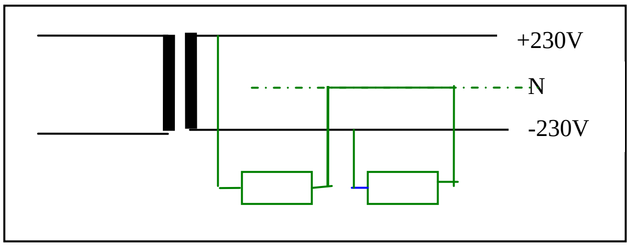


Figure 2: Dual Phase Transformer with broken neutral

From figure 2 above, it can be seen that when the neutral is broken, the two loads will be connected in series with line to line across them. The voltage will float between +240V and -240V resulting in voltages that can reach up to 460V.

**Three Phase Transformer**
A broken neutral on a three phase transformer will cause the voltage to float up to the line voltages depending on the load balancing on the system. This type of fault condition may damage the customers equipment connected to the supply.

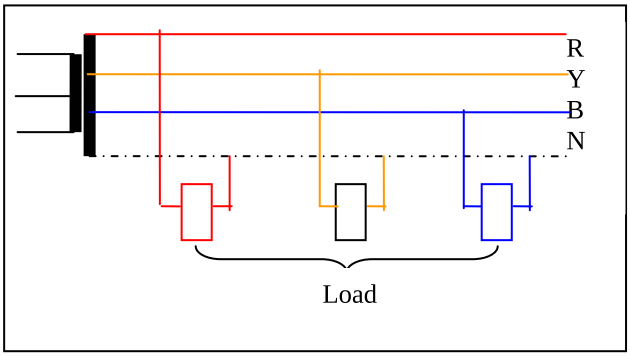


Figure 3: Three Phase Transformer under normal condition

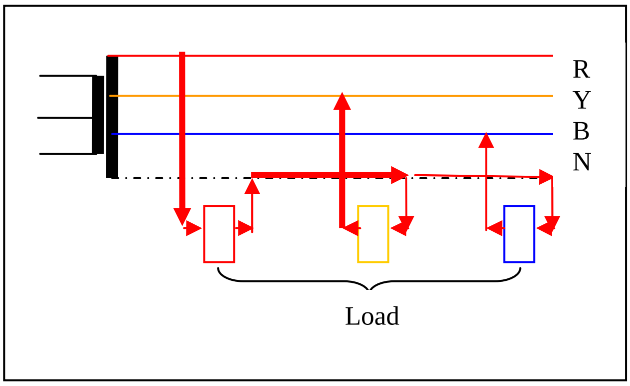


Figure 4: Three Phase Transformer with broken neutral

From figure 3 and 4, it can be seen that under normal conditions, the current flow from the phases to the load and back to the source though the neutral. When the neutral is broken the current from the red phase will go back to the yellow or blue phase resulting in line to line voltage between the loads. Similarly the same will applies for the other phases.
Some customers will experience over voltage and others will experience under voltage.

## Loss of neutral at the Conductors

**LV Conductors – ABC or Bare LV Conductors**
The impact of broken neutral at the low voltage conductors will be similar to when the conductor is broken at the transformer.
For single phase Aerial bundled conductors (ABC), a broken neutral will just result in loss of power to the customers. No damage will occur to the connected loads.

For dual phase and three phase low voltage conductor will result in supply voltage floating up to line voltages instead of phase voltage. This type of fault condition may damage the customers equipment connected to the supply.

**Services Conductor**
A broken service conductor will only result in loss of supply at the customer point; there will be no damage to customer equipment.

## Loss of neutral at the Pole Top Box

If the neutral conductor is broken neutral at the Pole Top Box, there impact on the customer is that there will be no supply. The fault condition will not damage the customer's equipment.

## TYPES OF NEUTRAL FAILURES AND CAUSES

From the studies that were conducted, there are several factors that were identified as the causes of floating neutral in the system.

## Transformer Bushing

A lot of neutral failures on the transformers were on the transformer bushings.

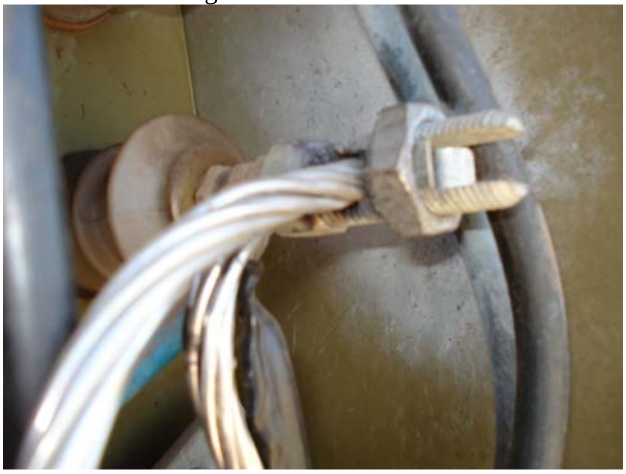

Figure 5: Neutral Failure on transformer bushing

The use of line taps on transformer bushings was identified as the main cause of neutral conductor failures on the transformer bushings. It was found that the nut on the line tap get loose with time due to vibration and temperature differences resulting in a hot connection. The conductor starts melting and ultimately broke off as seen on the picture above.
Poor workmanship by the technical personnel doing the installation also contributes to hot connections on transformer bushings.

## Low voltage conductors

The loss of neutral on Low voltage conductors is very common. Investigations reveal that the causes of neutral failures on LV conductors are the following:

**Incorrect applications of Insulation Piercing Connectors**
IPC's are connectors that are used to connect insulated conductors without removing the insulation. It is important that the connection must be very tight to ensure that the connector is able to go trough the insulation and make contact wit the conductors. If that is not done, a hot connection will develop resulting in conductor failure.

Two IPC's per connection are used to ensure that the integrity of the connection is maintained at all times as the consequence of loss of neutral is detrimental to our end users.

Figure 6: IPC connection

Figure 6 above shows an IPC connected on bare and insulated neutral conductors. The IPC head is not shared off which means that the connection between the connector and conductor is not very good. One has been used instead of two and that increases the risk of failure.

Figure 7: IPC removed from the conductor

Once an IPC is installed on the conductor, it cannot be removed for any reason. Punctured holes will remain on the conductor if the IPC is removed, resulting in short circuit between the phase and neutral conductors especially when it is raining. That will cause the neutral to burn off and break.

## Overloading and Load Balancing

Network overloading combined with poor load balancing are some of the main causes of neutral failures in our networks.
Eskom specified a reduced neutral conductor size for low voltage Aerial Bundled Conductors (ABC). This is based on the fact that if the network is properly designed, there must be minimum current flowing on the neutral conductor.
Theoretically, the current flow on the neutral conductor was supposed to be zero because of the cancellation due to $120^o$ phase displacement on the phase currents.

$$I_N = I_R \angle 0^o + I_Y \angle 120^o + I_B \angle -120^o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

When you have an overloading problem combined with load unbalance, you end up having a lot of current flowing through the neutral conductor resulting in conductor failure at the weakest spot. Mostly the failures occur at the joints, terminations and where the conductor has kinks.

## Other causes of neutral conductor failures

Other factors that were found to be contributing to neutral conductor failures are the following:

**Bad workmanship**
Bad workmanship on installations was found to be one of the causes of neutral conductor failures in our networks.

**Poor maintenance Practices**
Low voltage networks are mostly not given the attention that they deserve and as a result they are mostly in bad condition. Utilities tends to concentrate more on High voltage networks, substations and medium voltage networks and ignores the low voltage network where millions of our end users are connected to.

**Conductor Theft**
There is an increase in number of failures that result due to conductor theft for resale as scrap metal. This leaves customers without power and poses a safety risk to the community.

# PROPOSED SOLUTIONS

There are number of studies that are in progress, in collaboration with low voltage protection equipment suppliers and academic institutions, to come up with proposed solutions for eliminating or minimising the impact of floating neutral to Eskom and our end users.

## Improved Installation techniques

The root cause of the problem is the loss of neutral in the system. Enforcing quality of workmanship and adherence to standards and installation techniques can minimise the risk of having broken neutral conductors.
The problem can be greatly reduced by ensuring discipline during network design and construction. Doubling of IPC's per neutral connection will ensure that integrity of the neutral connection as the chances of simultaneous failure of both are IPC's is very low.
Good maintenance practices on low voltage networks can also help to identify and correct potential problems before they arise.

## Improved Load balancing techniques

It has been proved that load balancing contribute to number of neutral failures, if the problem of load balancing can be addressed the impact will be reduced. Even if we can loose a neutral connection, under balanced load condition the voltages will still be within their normal limits hence the impact to the customers will be minimised.

There is a study in progress in collaboration with Tswhane University of Technology that looks at developing a load switch selector to ensure that the load is always balanced at all times.

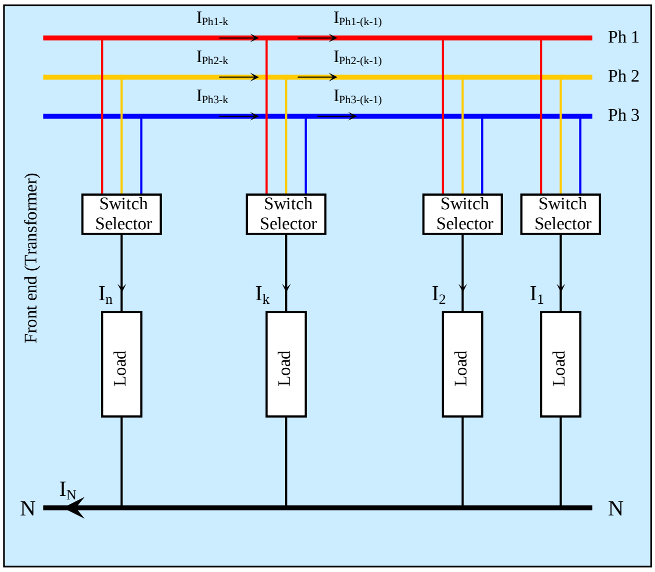


Figure 7: Three phase feeder with Switch Selector

The proposed functionality of the unit in figure 7 is such that each single phase load is connected to the three phase feeder via a switch selector. Only one phase can supply the load at a given period depending on the load balancing on the three phases. [3]

The mathematical model can be expressed as:

$$\boldsymbol{I}_{ph1k} = \sum_{i=1}^{3} sw_{k1i}\boldsymbol{I}_k + \boldsymbol{I}_{ph1(k-1)} \quad (1)$$

$$\boldsymbol{I}_{ph2k} = \sum_{i=1}^{3} sw_{k2i}\boldsymbol{I}_k + \boldsymbol{I}_{ph2(k-1)} \quad (2)$$

$$\boldsymbol{I}_{ph3k} = \sum_{i=1}^{3} sw_{k3i}\boldsymbol{I}_k + \boldsymbol{I}_{ph3(k-1)} \quad (3)$$

The constraints of only allowing one breaker in each of equations (1) to (3) to be closed can be written as following:

$$\sum_{i=1}^{3} sw_{k1i} - 1 = 0 \quad (4)$$

$$\sum_{i=1}^{3} sw_{k2i} - 1 = 0 \quad (5)$$

$$\sum_{i=1}^{3} sw_{k3i} - 1 = 0 \quad (6)$$

To minimize the neutral current, the objective of this new algorithm is to minimize the difference of the rms value of the phase currents ( $I_{phik(i=1,2,3)}$ ):

$$\text{Minimize}\left[ I_{ph1k} - I_{ph2k} \;\; I_{ph1k} - I_{ph3k} \;\; I_{ph2k} - I_{ph3k} \right] \quad (7)$$

## Protection

Eskom has engaged low voltage protection equipment suppliers to come up with units that can be able to protect end users against loss of neutral.
The technology that is currently available in the market looks at over voltage and under voltage protection. The problem with that is the system does not consider the current flowing on the neutral which can make metallic objects in the house to become live and dangerous.

CBI is currently developing a unit for us that specifically deals with loss of neutral in the system. The unit monitors the current flow in the neutral conductor and a soon as the neutral is broken, the system picks it up and switch off the supply.

## CONCLUSION

The causes and impact of floating neutral in distribution systems has been presented and discussed. A high level presentation of mitigation factors and protection against floating neutral has been done. Details on protection and load balancing will be presented in details as a separate topic.

## REFERENCES

[1] M.H Xivambu, FJC Wahl, A Kotze and J.A Engelbretch, 2004, Public Liability claims due to loss of neutral, *Eskom Technical Instruction*

[2] V Cohen, 2002, *Application Guide for the protection of L.V Distribution Systems* , CBI Ltd, Johannesburg, South Africa, 20.1-20.7

[3] M Xivambu, AA Jimoh, DV Nicolae, 2006, A study of broken neutral in distribution systems, PEA 2006, Botswana