DETECTION OF BROKEN NEUTRAL CONDUCTOR IN LV NETWORKS TO ENSURE CUSTOMER SAFETY

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Abstract

The increased electrification is intensifying the stress on the existing Low Voltage (LV) network. This shortens the lifespan of network components and increases the likelihood of faults arising in LV cables, threatening the stability of the system. A damaged neutral can pose a significant risk to network operation. In this scenario, phase unbalance can lead to abnormal voltages, which may damage household appliances. In certain earthing systems, such as TN-C or TN-C-S, where the connection to earth is done by a combined Protective Earth and Neutral (PEN) conductor, the customer can lose their connection to ground, and exposed metallic parts may become live. For example, a broken neutral fault can liven the metal body parts of an Electric Vehicle (EV), posing extreme risk to EV users.

This safety hazard led us to develop a new LV Broken Neutral detection algorithm, which identifies, in real-time, the signature of these events. The method has been tested at PNDC (University of Strathclyde, Scotland), for different earthing systems (TT, TN-S and TN-C-S), load configurations and fault locations.

This paper presents the promising results of the experiments carried out at PNDC and a performance assessment of the LV Broken Neutral detection method developed by Eneida.

1 Introduction

The malfunction of the neutral conductor can disrupt the normal operation of the network. When the neutral connection is severed, the neutral point downstream to the fault changes, which may lead to voltage values that are either too low or too high for the regular functioning of home appliances. Moreover, in the cases where there is a combined neutral and earth conductor (as in the TN-C or TN-C-S earthing connection systems), the severance of the neutral connection implies a disconnection from the ground. In this case, there is a serious risk that exposed metal parts become live, leading to a potential safety hazard.

Several approaches have been used to tackle this problem. In [1], the zero-sequence voltage and current values are used to calculate an impedance value that, if greater than a given threshold, will trigger an alarm.
In [2] a three-module algorithm will act at the substation level, measuring the neutral current directly and assessing the conductor's health. In [3] different variables are assessed to determine their capability to detect a broken neutral event. In [4] and [5], the 3rd harmonic of the current is used to detect broken neutral faults.

In this work we aim at characterizing the health state of the neutral conductor in different cases. We use three junction boxes where a broken neutral fault can be simulated using a switch. At the downstream end of the network, different loads are connected to each phase to emulate both balanced and unbalanced loads. Different earthing systems are also studied - TN-C-S, TN-S and TT. The voltage and current are measured in different points of the network and, by characterizing the health state, we can better detect a fault, as in [4] and [5].

2 Methodology

To test our method, a test setup including a 11kV/230V substation, 3 junction boxes and a configurable three-phase load was built in the PNDC facilities. By switching the connections on this setup, we were able to test 3 different earthing system types (TT, TN-S and TN-C-S). For each earthing system, broken neutral faults were simulated at 3 different locations while acquiring voltage and current waveforms at 3 measurement points simultaneously. At each measurement point, the signals were sampled at 3.75kHz.

Experimental Setup

The network setups used for the TT, TN-S and TN-C-S earthing systems are depicted in fig. 1.

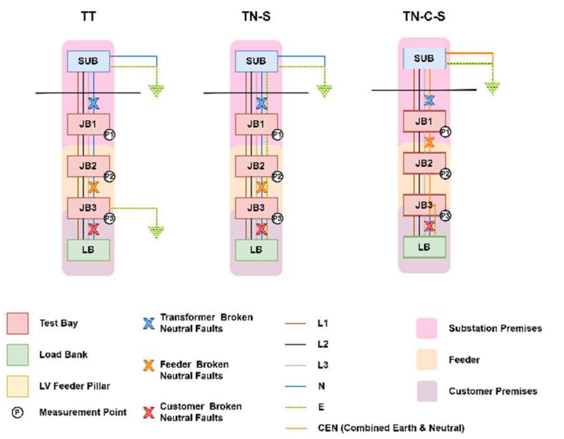


Fig. 1: Network setups for TT (left), TN-S (centre) and TN-C-S (right) earthing system types.

For each setup we used different combinations of resistors to simulate cases in which the loads are balanced and those cases in which they are not. Table 1 presents the loads used in each phase.

For each set of loads, a broken neutral fault was simulated in 3 different locations. This gives rise to a total of 45 experiments (3 earthing connection types x 3 broken neutral locations and 5 three phase load combinations).

Tab. 1: Load configurations used in the experimental setup.

Load [Ω]	Phase A	Phase B	Phase C
Balanced	10	10	10
Unbalanced	10	10	40
Unbalanced	10	20	30
Unbalanced	10	20	20
Balanced	20	20	20

Figure 2 shows the test setup built at the PNDC LV Bay.

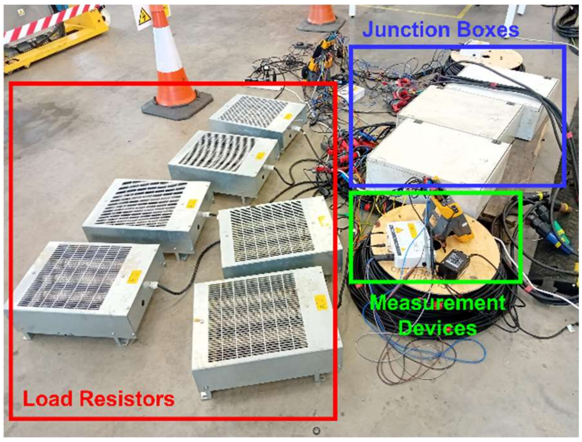
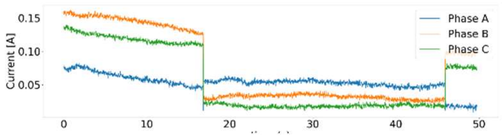


Fig. 2 – Test setup at the PNDC LV Bay.

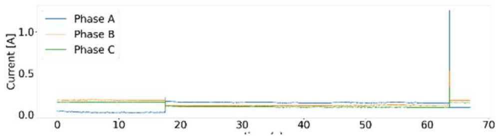
Data Treatment

The raw signals did not show any obvious signs of a fault. Thus, we followed [4] and [5] by considering the 3rd harmonic.

When looking at the root mean square (RMS) of the 3rd harmonic (fig. 3), a step in the currents can be observed when the fault starts. These changes are present regardless of the unbalance of the network. It is also possible to see a second step in the current once the fault is cleared, which signals the return to a healthy state.



(a)



(b)

Fig. 3 (a) RMS of the 3rd harmonic when the fault is located in the customer side, measured on the transformer, in the case of a balanced network (10Ω, 10Ω,10Ω), (b) RMS of the 3rd harmonic when the fault is located in the customer side, measured on the transformer, in the case of an unbalanced network (10Ω, 20Ω,30Ω).

3 Results

As expected, given the clear change in the steady state during the fault, it can be easily detected by analysing the change in harmonic content.

We used a portion of the signal before the fault to assess the statistical characteristics of the steady state and, using that signature, assess whether a given sample was part of the fault or not.

Considering the 3 different types of earthing systems studied (TT, TN-S and TN-C-S), 5 load resistance combinations (tab. 1) and 3 fault locations, there are 45 cases to be analysed. Furthermore, for each case, each phase was analysed individually, to ensure the fault can be seen from all 3 phases. The signals were then split into "faulty" and "healthy". The latter were taken from only the steady state prior to the fault, to assess whether any false positives would be identified in these healthy signals. In total, 270 signals (135 "faulty" and 135 "healthy") were analysed. Table 2 summarizes the performance metrics obtained from this analysis.

Tab. 2: Summary of performance metrics for broken neutral fault detection using the 3rd harmonic of the current. TP – True Positives; TN – True Negatives; FP – False Positives; FN – False Negatives; A – Accuracy.

	TP	**TN**	**FP**	**FN**	**A**
TT	45	45	0	0	100%
TN-S	45	44	1	0	98.9%
TN-C-S	45	44	1	0	98.9%
Total	**135**	**133**	**2**	**0**	**99.2%**

As can be seen in tab. 2, the results indicate that using the 3rd harmonic of the current to detect broken neutral faults is very promising. However, some edge cases still occur.

In this study, ensuring that no false negatives occur was deemed as a priority, since this could lead to undetected broken neutral faults and, in the case of the TN-C-S earthing system, undetected safety hazards. However, some false positives occur as a result. This is something that will need to be addressed in later stages of this work, to prevent teams to be sent on site unnecessarily.

When in healthy state, the current presents low values (3rd harmonic) and its distribution is very narrow. This may lead to a set of samples being wrongly classified, since they fall outside the defined limits even though they correspond to a healthy portion of the signal.

4 Conclusion

This work confirms the potential of analysing the harmonic content of the line currents, especially the 3rd harmonic, to identify broken neutral faults [4, 5]. The hypothesis was tested at PNDC, using a small test network, under different earthing systems and load configurations and in different locations. The method has revealed resilient to all these variables and shows very promising results. The main challenge to face in the following stages of this project is reducing the number of false positives triggered, while ensuring that no false negatives occur.

5 Acknowledgements

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6 References

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