LOSS OF NEUTRAL IN LOW VOLTAGE ELECTRICAL INSTALLATIONS WITH CONNECTED DG UNITS – CONSEQUENCES AND SOLUTIONS

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ABSTRACT

The loss of neutral conductor is a critical issue in distribution networks, yet not fully addressed in view of the forthcoming massive installation of distributed generation and storage units. An interruption of the neutral conductor may result in severe dangers for the electrical equipment and the consumers. This paper examines the repercussions of an interruption of the neutral conductor on the upstream network of the electric meter on a TN network, considering that a DG unit is connected to the electrical installation. The developed potential on the protective conductor is computed, examining the impact of the injected current by the DG unit, the load power and the grounding resistance. In addition, a methodology for the detection of neutral conductor loss in TN systems is proposed and simulation results are presented.

INTRODUCTION

Neutral conductor loss is a critical issue for the low voltage distribution networks, since it is directly related to the safety of both the human life and the electrical installation. The interruption of neutral conductor is a known issue in distribution networks, yet not fully addressed in view of the forthcoming massive installation of distributed generation (DG) and storage units (including Vehicle-to-Grid concept). Such a condition may result in serious repercussions for the connected electrical installations and the consumers. The consequences of a lost neutral conductor depend mainly on the load balance conditions in a three-phase system, but also on the type of earthing system used and the position of the neutral interruption (relatively to the load). Worst case scenarios may include both damages to connected loads (due to overvoltages on single phase circuits) and the creation of hazardous touch voltages on exposed conductive parts [1-3].

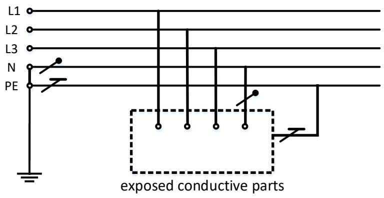
Therefore, a detailed analysis of the interruption of the neutral conductor is necessary in order to determine and restrain the repercussions and protect both the human beings and the equipment. The paper deals with an analytical description of the neutral conductor interruption effect on a TN network, considering that a DG unit is connected to the electrical installation under study. The arising potential on the protective conductor is estimated, considering the interruption of the neutral conductor on the upstream network of the electric meter and examining the role of the injected power by the DG unit, the load and the grounding resistance. Moreover, a methodology for the detection neutral conductor loss in TN systems is proposed, in an effort to avoid the dangerous consequences of the developed potential on the protective conductor.

GROUNDING SYSTEMS

The design of an electrical installation must include all the necessary measures that ensure the protection of the human life against electric shock. The extent of the consequences deriving from the touching of live exposed-conductive parts are specifically related to the neutral condition of the power system and the type of system earthing. According to [4-6], the electrical systems are classified with the combination of two letters. The first letter indicates the relationship of the power system to earth and the second letter indicates the relationship of the exposed-conductive-parts of the installation to earth; subsequent letters indicate the arrangement of neutral and protective conductors. Considering the above, the main types of distribution networks are TN, TT and IT.

In TN systems the neutral is directly earthed, whereas the exposed-conductive-parts are connected to the same earthing arrangement of the neutral. TN electrical systems can be divided into three types, whether the neutral and protective conductors are separate or not: TN-S (Fig. 1.a), TN-C (Fig. 1.b) and TN-C-S (Fig. 1.c).

In the case of TT system (Fig. 1.d) the neutral and the exposed-conductive parts are connected to earth electrodes electrically independently. IT systems have no active parts directly earthed, but they may have live parts connected to earth through high value impedances (Figure 1.e). All the exposed-conductive-parts, separately or in group, are connected to an independent earth electrode. The earth fault current returns to the power supply node through the earthing arrangement of the exposed conductive- parts and the capacities to earth of the line conductors.



(a)

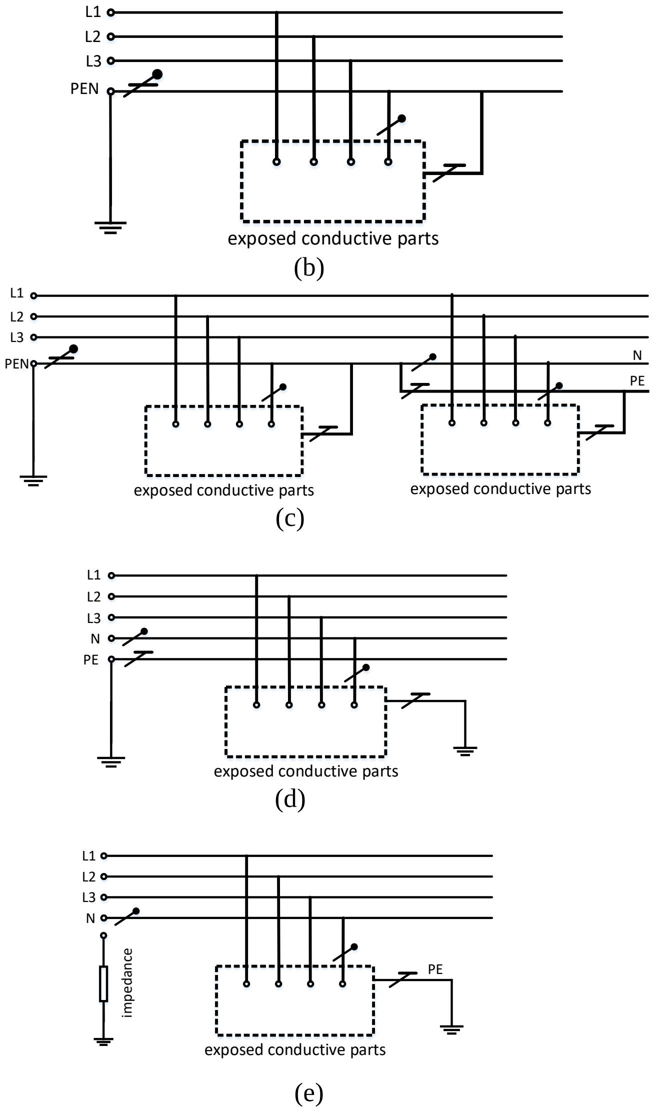


Figure 1 - Earthing systems: (a) TN-S, (b) TN-C, (c) TN-C-S, (d) TT, (e) IT

INTERRUPTION OF THE NEUTRAL CONDUCTOR FOR A TN SYSTEM

In the case of TT systems the interruption of the neutral conductor leads to overvoltages that stress the equipment of the installation and may cause catastrophic damages. Indeed, single-phase devices may be stressed by the phase-to-phase voltage, resulting in their damage. In the case of TN systems, where the exposed conductive parts are connected to the neutral, an accidental interruption of the neutral on the upstream part would lead to overvoltages on the protective conductor in the downstream part and therefore a danger for human life. Fig. 2 depicts the current flow in the case of neutral conductor interruption for a TN-S grounding system. Because of the neutral loss, load current I_L cannot return through the neutral conductor and flows through the load (Z_L), the resistance of the grounding electrode and the total resistance of the neutral conductor (R_n). Considering that the phase conductor resistance is negligible, the supplied voltage is distributed along Z_L, R_g and R_n (voltage divider). For a given R_n, the developed voltage on the protective conductor depends on the load and grounding resistances of the electrical installation.

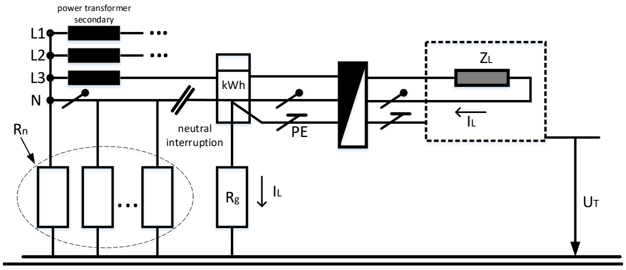


Figure 2 - Interruption of the neutral conductor for a TN system

SYSTEM UNDER EXAMINATION

In the case that a DG unit is connected to the electrical installation, the injected (by the DG unit) energy will influence the developed potential on the protective conductor. In the current work, the developed voltages on the protective conductor will be evaluated, considering an interruption of the neutral conductor on the upstream network of the electric meter, examining the role of the injected power by the DG unit, the load and the grounding resistance. Fig. 3 presents the electrical installation under study, considering a TN grounding system. From the secondary of the distribution transformer depart one or more low voltage distribution lines that are radially distributed to the consumers. A four-pole cable inserts to the energy meter, where the neutral is connected to the grounding system of the installation to be protected. All the exposed-conductive-parts of the installation are connected to the protective earth conductor (PE). In addition, a DG unit (PV) is installed on the rooftop of the building, injecting the generated electrical energy to the network.

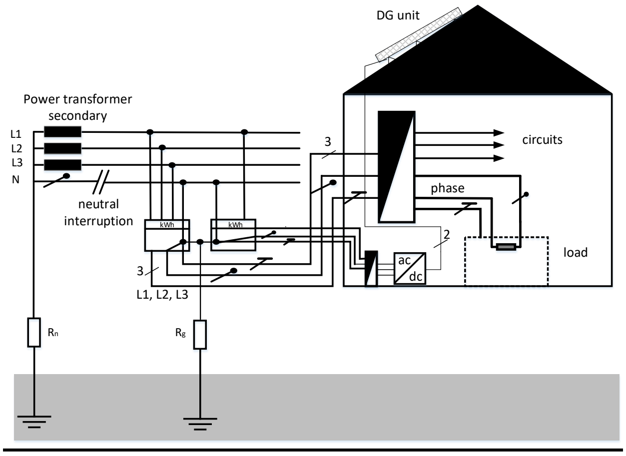


Figure 3 - System under examination.

RESULTS AND DISCUSSION

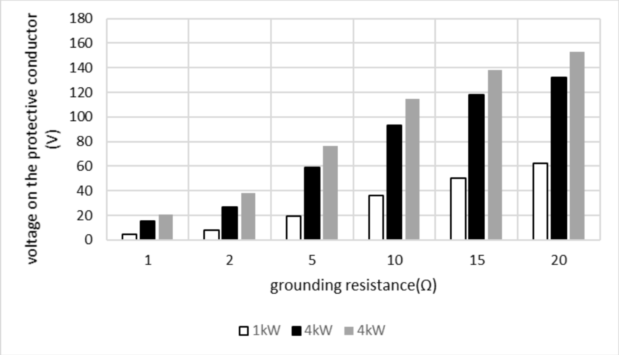
As an initial step, a sensitivity analysis for the developed voltages on the protective conductor is carried out, considering the following parameters:

- the generated electric power by the DG unit (5A, 10A, 15A)
- the local load (1kW, 4kW, 6kW), and,
- the grounding resistance of the installation (1Ω, 2Ω, 5Ω, 10Ω, 15Ω, 20Ω).

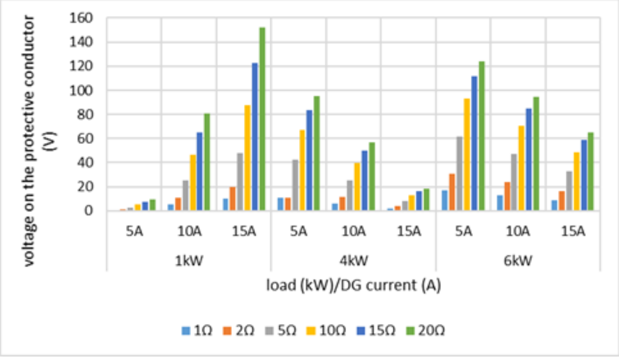
For an electrical installation without a DG unit, the grounding resistance and the power of the load determine the arising touch voltages. In the case that a DG unit is installed, its generated power influences the developed voltages on the protective conductors, in combination with the load power.

Table 1 presents the simulation results, i.e. the developed potential on the protective conductor for the examined cases. Note that the green colour corresponds to voltages below the maximum safety limit (50V), while the red colour corresponds to voltages that do not comply with the above limit. Fig. 4 depicts the obtained results in the case that a DG unit is installed or not. In the case that there is not any DG unit, the grounding resistance and the load power determine the magnitude of the developed potential on the protective conductors; indeed, the increase of the grounding resistance and the load power result in higher arising touch voltages. Considering that the load is a factor that cannot be easily adjusted, the achievement of low values of grounding resistance ensures the protection against the consequences of neutral conductor loss.

In the case that a DG unit has been installed, the generated energy (by the DG unit) and the absorbed energy (by the load) are key factors that influence the developed potential on the protective conductor. If the injected (by the DG unit) and the absorbed (by the load) currents are almost equal, then the developed voltage on the protective conductor does not exceed the safety limit of 50V (see load 1kW, DG current 5A and load 4kW, DG current 15A) for all the grounding resistance values. It is worth mentioning that even for low grounding resistance values the developed voltages can exceed the safety limit, due to the difference between the generated and the absorbed energy (see load power 1kW, DG unit current 15A, grounding resistance 10Ω).



(a)



(b)

Figure 4 - Developed voltages on the protective conductor in the case that a DG unit (a) is not installed, (b) is installed.

Table 1 - Developed voltages on the protective conductor for all the examined cases.

grounding resistance (Ω)	no DG unit installed			DG unit installed								
	load power											
	1kW	4kW	6kW	1kW			4kW			6kW		
				DG unit current								
				5A	10A	15A	5A	10A	15A	5A	10A	15A
1	4.2	15.4	20.8	0.6	5.4	10.2	10.6	6.3	2.0	16.9	12.9	8.9
2	8.2	27.1	38.3	1.2	10.7	20.1	10.9	11.9	3.8	30.9	23.6	16.2
5	19.5	58.9	76.5	2.9	25.3	47.7	42.1	25.1	8.1	61.9	47.2	32.5
10	35.9	93.2	114.8	5.4	46.7	87.9	67.0	40.0	12.9	92.8	70.8	48.8
15	50.0	117.7	137.8	7.5	64.9	122.3	83.5	49.7	16.0	111.4	84.9	58.5
20	62.2	132.4	153.1	9.4	80.7	152.1	95.1	56.7	18.3	123.8	94.4	65.0

DETECTION OF NEUTRAL CONDUCTOR LOSS

The proposed neutral conductor loss detection scheme is based on the estimation of both zero-sequence impedance $z_{0,rms,50Hz}$ and voltage $v_{0,rms,50Hz}$ at the fundamental frequency of 50Hz. Such a methodology has been successfully applied in anti-islanding detection [7-10]. The measuring point of the voltage v_{abc} and current i_n is indicated in Figure 5. The zero-sequence voltage is calculated by summing the three line to neutral voltages and by multiplying this result with a gain of $\frac{1}{3}$, as it is depicted in Fig. 6:

$$v_{0,rms} = \frac{1}{3} \cdot (v_{a,rms} + v_{b,rms} + v_{c,rms}) \qquad (1)$$

Afterwards, the voltage and current signals pass through an FFT transformation block in order to extract the corresponding rms values of the fundamental components ($v_{0,rms}$ and $i_{n,rms}$). The resulting values are used to estimate the zero-sequence impedance according to the following equation:

$$z_{0,rms,50Hz} = \frac{v_{0,rms,50Hz}}{i_{n,rms,50Hz}} \qquad (2)$$

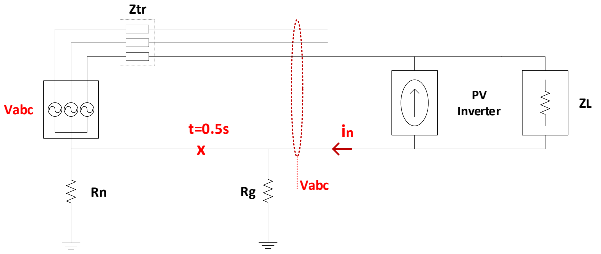


Figure 5 – Equivalent system model

This impedance ($z_{0,rms,50Hz}$) is compared with a predetermined threshold value $z_{0,thr}$ and if $z_{0,rms,50Hz} \geq z_{0,thr}$ then a neutral conductor interruption fault is indicated. It is noted that the impedance estimation method is not solely based on this proposed scheme, due to the incorrectly calculated values that arise under very high values of $z_{0,50Hz}$ (in cases that current $i_n \to 0$). For this reason, the impedance estimation scheme is activated only when the current of the neutral wire is above a threshold value, $i_{n,thr}$ (Switch1 at position 2). An overvoltage protection scheme operates complementary with the impedance estimation scheme and it is activated when the zero-sequence voltage is above the predetermined limit of 50V. This ensures the protection against hazardous touch voltages on exposed conductive parts.

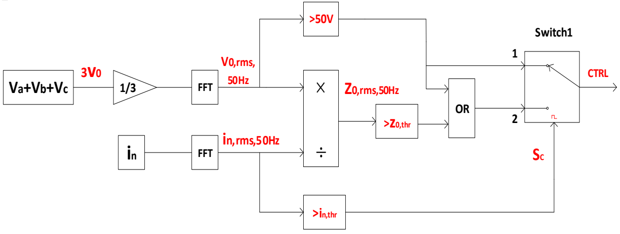


Figure 6 – Proposed Control Scheme

In the following part, a simulation of the proposed detection method is conducted. The parameters of the system are described in Table 2.

Table 2: System Parameters

$P_{pv\text{-}inv}$	4 kW
P_{Load}	6 kW
z_{tr}	0.001 + j1e-6 Ω
R_n	1 Ω
R_g	9 Ω
V_{abc}	230 V_{rms} (line to neutral)
t_{disc}	0.5 s
$i_{n,thr}$	0.5 A
$z_{0,thr}$	5 Ω

The initialization time of the system is determined at 0.45s in order for the PV-Inverter to reach its nominal power value. When the neutral conductor interruption occurs a notable arise of the zero-sequence voltage $v_{0,rms,50Hz}$ is depicted in Fig. 7 while current drops (see Fig. 8). The proposed scheme detects the fault by accurately estimating the grounding resistance value ($z_{0,rms,50Hz} = R_n+R_g = 10$ Ω, in Fig. 9).

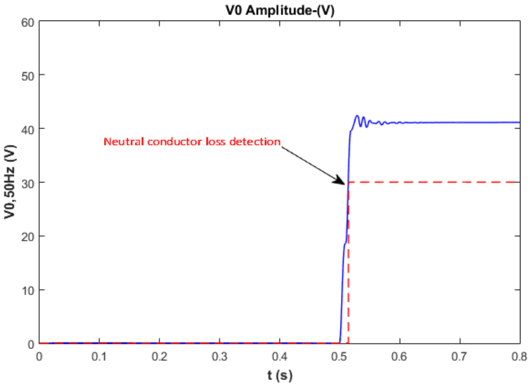


Figure 7 – Calculated Zero-Sequence Voltage at 50 Hz

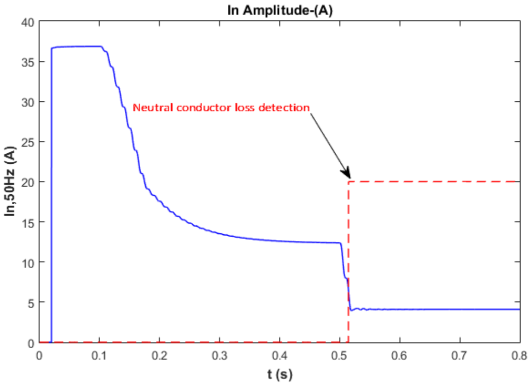


Figure 8 – Calculated Grid Neutral Conductor Current at 50Hz

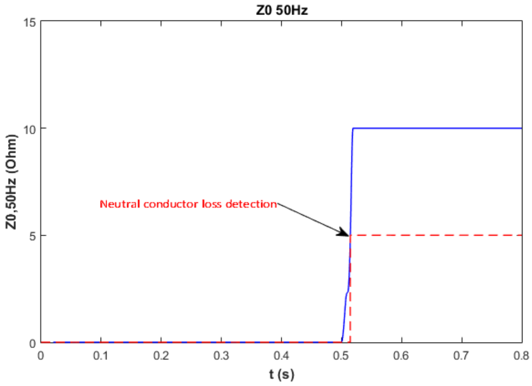


Figure 9 - Calculated Zero Sequence Impedance at 50Hz

CONCLUSIONS

The current work examines the impact of various factors on the developed voltage on the protective conductor of low voltage electrical installations, due to neutral conductor loss on the upstream network of the electric meter. The achievement of low grounding resistance is the primary protection measure against electric shock, since limits the magnitude of the arising touch voltage. Nevertheless, the load power and the injected current by the DG unit are additional critical parameters that determine the developed potential on the protective conductor.

Moreover, a neutral conductor loss detection scheme is proposed, based on the estimation of both zero-sequence impedance $z_{0,rms,50Hz}$ and voltage $v_{0,rms,50Hz}$ at the fundamental frequency of 50Hz. Simulations results have highlighted the effectiveness of the proposed scheme.

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