OVERVOLTAGES IN LOW VOLTAGE SYSTEMS DUE TO NORMAL MEDIUM VOLTAGE SWITCHING

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ABSTRACT

The number of damaged electrical appliances is experiencing a permanent increase: Many of these damages appear after a voltage interruption by means of MV switching in normal conditions.
This operation can produce an insufficiently known type of transient. While there is no overvoltage at MV, at LV side an impulse appears, which characteristics are determined by factors such a stray capacitances or earthing system.
The frequent appearance of damaged appliances proves their insufficient immunity in many cases and, consequently, an improved overvoltage protection of customer facilities is advisable.

INTRODUCTION

According to the experience in Spain, the most frequent cause of damages of LV appliances is not addressed in the standards. In fact, several thousands of complaints regarding appliance breakdowns are annually received with no apparent cause. Similar kind of problems has been also detected in other countries [1].
The common point among these events is that they occur after a voltage interruption, even in those cases in which the interruption was only for maintenance purposes, without any kind of anomaly in the network.

During the measurements carried out by Iberdrola at MV/LV transformer substations, some overvoltages were detected. One of them is shown in figures 1 and 2. They show that, at the very first moment of closing operation of MV circuit-breaker, a unidirectional overvoltage takes place at power transformer LV side.
In contrast, no transients were detected during opening operation.

TRANSIENTS DUE TO TRANSFORMER ENERGIZATION

In order to fully understand the phenomenon measured at substation transformer, some simulations have been carried out.
In view of the fact that transient includes high frequency components, stray capacitances of transformer and lines must be taken into account, as per IEC 60071-2 [2]. In this application guide, concerning insulation co-ordination, transient transmission from primary to secondary through transformer capacitance is considered to be in the range from 0 to 0.4 p.u..

In order to explain the mechanism of this kind of overvoltage, the model can be simplified to the scheme represented in figure 3. In this circuit, low frequency components (Hz to kHz) are transmitted basically by magnetic coupling through the transformer core.
However, higher frequencies (some hundreds kHz or MHz), or high dv/dt, are transferred capacitively.

Hence, figure 4 illustrates the appearance of the overvoltage at the transformer secondary.
The first thing to point out is that there are no relevant overvoltages at any of the MV points. Therefore, neither MV equipment is stressed, nor MV surge arresters play any part in this phenomenon.

The origin of the transient at LV is the rapid rise of the voltage downstream the breaker, right after the transformer energization. This fast rise represents a high dv/dt in MV, which is applied to the capacitive divider formed by transformer stray capacitance. Thus, as well as transient currents in the breaker and the transformer primary, one or several overvoltages –basically unidirectional impulses– appear at the secondary.

Figure 1: Transient during transformer energization

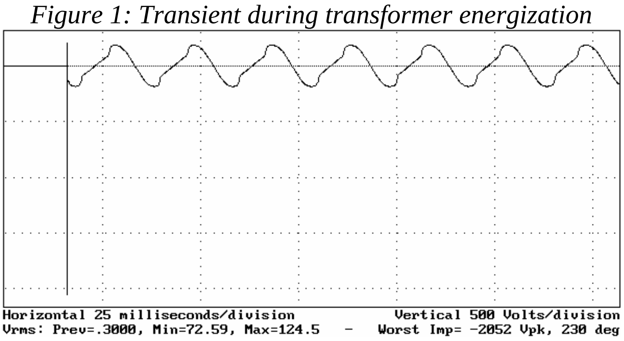


Figure 2: Impulse (detail of figure 1)

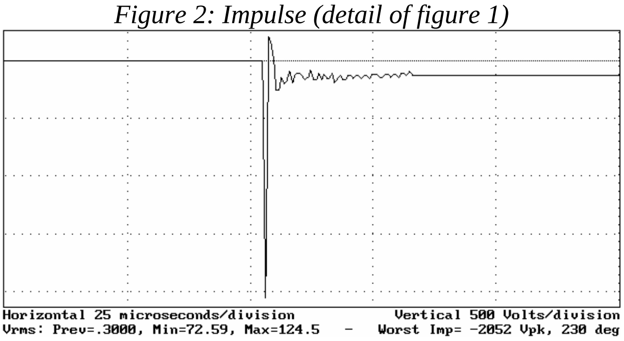
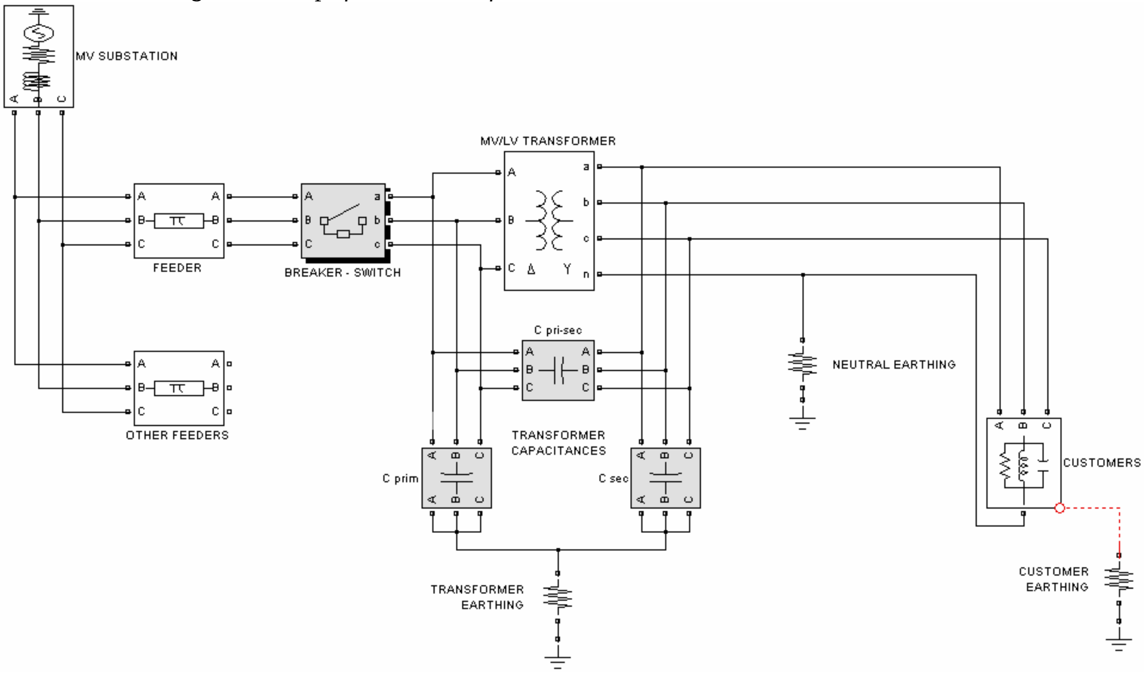


Figure 3: Simplified scheme of the elements involved in transient behaviour



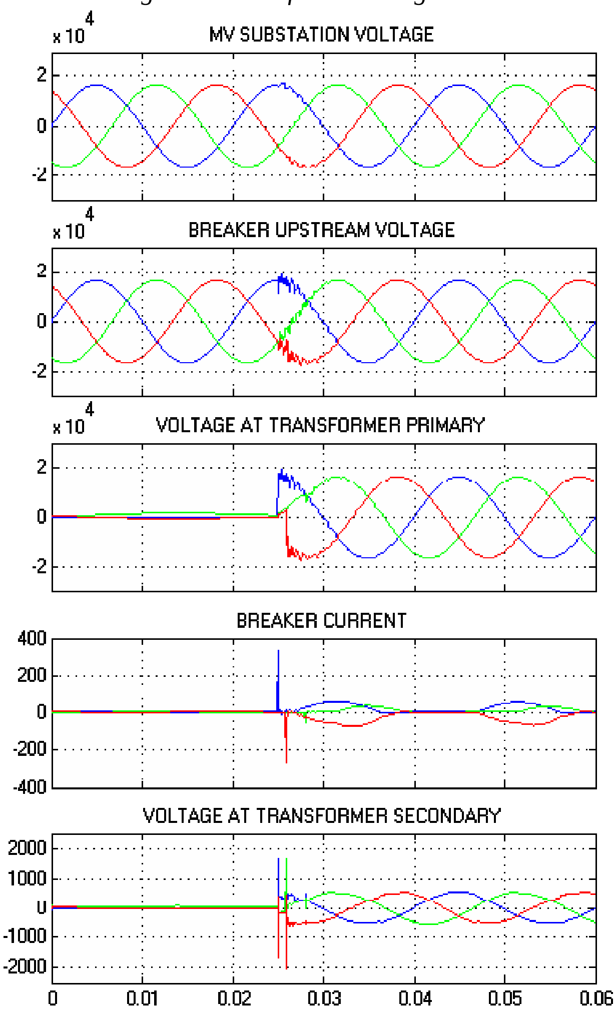
The voltage at the moment of transformer energization depends both on the feeder physical characteristics and on the breaker technology.
In figure 4 it can be seen that high frequency components are present only near the switching point. The reason is the feeder inductance, which does not allow high frequency currents to flow from MV substation. Thus, high frequency components come from the capacitance of the feeder stretch that is closer to the breaker.
The behaviour is different whether the substation transformer is fed by an underground cable or by an overhead line. Since cables store a greater amount of energy due to their large capacitance, they give rise to more severe transients than overhead lines.

The internal arc during the breaker closing represents a transient dumping. Hence, those breakers with less arcing are prone to higher dv/dt downstream the breaker
In contrast, energization by means of a switch of disconnector with more arcing could generate lower dv/dt although repetitive transients, due to pre-strikes.

Another factor to be taken into account is the distance from breaker to the transformer substation. Since transient transmission by feeder reduces dv/dt, the shorter the distance, the higher the dv/dt of the primary voltages and, consequently, the more severe the transient at secondary voltage.

Depending on the LV neutral treatment and the transformer capacitances, the overvoltage at the transformer substation can appear in differential mode (phase to neutral), in common mode or in a combination of both modes.

Figure 4: Transformer energization



TRANSMISSION THROUGH LV NETWORK

The overvoltage transmission through the LV system transmission depends on the LV wiring. However some aspects of wiring depend on earthing system.

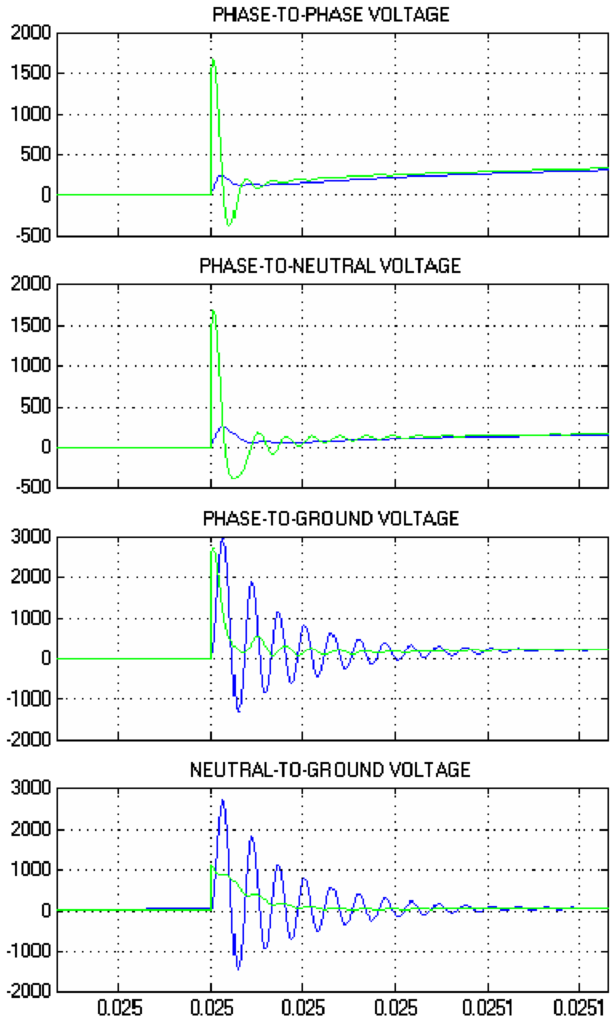
In TN networks, customer facilities are connected to the transformer substation earthing, while in TT and IT networks customer earthing is independent from utility earthing.
To achieve this, the TN wiring includes a protective earth conductor which runs together with live conductors from transformer substations to customer facilities. Depending on the TN variant, this protective earth conductor can also fulfil –partially or totally– the function of neutral, although it has not an important influence on transient transmission.

In this case, the lack of the protective earth conductor in TT and IT networks has a relevant effect.
In Spain, TT systems are mandatory for public LV networks, so the neutral is connected to earth in the transformer substation. One possibility is the one shown in figure 3, where the earthing points for neutral and transformer tank are different. In other cases, both earthing systems are interconnected. The choice depends on the possibility of transferring temporary overvoltages.

Figure 5 shows the transmission of the overvoltage, generated according to figure 4, to a customer facility through the LV wiring in a TT network. Green lines represent the transient in transformer substation, while blue lines show the voltage at the end of low voltage wires.
In this figure, several aspects are remarkable:
- If neutral earthing is not connected at the same point as transformer tank, a neutral to ground overvoltage can also appear at the transformer substation.
- The unidirectional impulse becomes an oscillatory transient, due to wiring characteristics (inductance, resistance and stray capacitance).
- The differential mode overvoltages (phase to phase or phase to neutral) tend to disappear as the distance between transformer substation and customer facility increases.
- Common mode overvoltages do not disappear or they can even increase in the case of neutral to ground.

The main reason for most of these changes is the capacitance among conductors, which represents a connection at high frequency and tends to equalize the voltage in all conductors.
Thus, in TN networks, this effect also involves the protective earth conductor, with a resulting reduction, similar to the phase to neutral voltage of figure 5.
Consequently, facilities with a TN supply have less probability of damages due to this kind of transients than those with a TT supply.

Figure 5: Overvoltage transmission from transformer substation to customer facilities



APPLICABLE STANDARDS

Damages due to these transients are usually located in electronic components of power supplies, but without arcing marks revealing the presence of short-circuits of severe isolation failures. This demonstrates that both peak value and energy of this kind of event are quite limited.

Given that rather more severe transients, either due to lightning or to other kind of switching, are expected, this kind of transient could be considered normal.
Furthermore, according to chapter 2.9 of EN 50160 [3], “transient overvoltages generally will not exceed 6 kV peak, but higher values occur occasionally”.

On the other hand, standardization on overvoltage protection is based on the idea that customer’s protection must “reduce the risk to an acceptable level of failure in the installation and in electrical equipment”.

Accordingly, IEC 60364-4-44 [4] establishes overvoltage categories for equipment, while IEC 61000-6-1 [5] and IEC 61000-6-2 [6] are generic EMC standards, which determine the immunity of the devices required at different kind of facilities.
The fulfillment of these immunity standards, together with the low energy of this kind of transient, should be enough to have a very limited amount of damaged appliances.
However, the frequent appearance of damaged appliances proves that this principle is failing. This reveals another relevant aspect of this problem, either insufficient appliances immunity or inadequate facility protection.
Sometimes the affected equipment belongs to category I and, in these cases, damages are due to the absence of the normative "protective means applied outside the equipment", necessary for this category.
In other cases, only few appliances with overvoltage category II, or even III, suffer damages, while the nearby devices keep working. This creates serious doubts about the fulfillment of immunity standards by some appliances.

SOLUTIONS

Different solutions to this problem have been evaluated. Obviously, there are no realistic methods to prevent transients from appearing, since stray capacitances cannot be avoided, and whatever MV system modification is too complex. On the other hand, there is no overvoltage at transformer primary, so MV surge arresters cannot solve this problem.
As a result, the reasonable approach is to solve the problem in LV. The first way could be to prevent its transmission to customer facilities. Given that earthing system cannot be changed, the only practical operation is customer disconnection, by means of transformer substation fuses, before transformer energization. Unfortunately, this solution is only applicable in case of maintenance works in transformer substations, but not during restoration after a fault.
Because this kind of overvoltages is not severe, significant surge suppression requires sensitive Surge Protective Devices (SPD), which should be class II or even class III.
Application of this kind of SPDs in transformer substation is unfeasible, because they require higher source impedance than the typical of the transformer. This impedance is key, both to achieve an effective voltage clamping and to prevent SPD failure in case of severe overvoltages, such as those due to lightning. Although additional impedances could be added, they must be dimensioned to carry the full transformer power, what becomes impracticable.
However, the impedance of wiring from transformer substation to customer facilities is, in general, sufficient to use this kind of SPD. Consequently, the protection in customer facilities is both, the most technically suitable solution and, also, normatively appropriate.

CONCLUSIONS

Overvoltages in LV due to MV/LV transformer energization are closely related to physical characteristics of the network elements. Stray capacitances of feeders and transformers, as well as breaker technology, play an important role in converting what is simply a transient in MV into an overvoltage in LV. Besides, overvoltage transmission from transformer substation to customer facilities depends on LV earthing system. Hence, TT and IT networks are more prone to transfer common mode overvoltages to appliances than TN networks.
From a normative point of view, it is a normal phenomenon; on the one hand, because it takes place without anomalies in the network and, on the other hand, because it is a relatively gentle overvoltage, at least in comparison with other switching or lightning overvoltages that can be expected according to the isolation coordination or EMC standards.
In contrast, the growing number of complaints due to appliances damaged in the presence of non-severe overvoltages shows the consequence of either insufficient appliances immunity, or inadequate facilities protection.
An improved overvoltage protection of customer facilities, in compliance with regulation, is advisable in order to harmonize the use of electronic devices with the existing networks.

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