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FIRES ON THE HOUSEHOLD LOW-VOLTAGE DISTRIBUTION BOARD CAUSED BY THE ABSENCE OF POLE MOUNTED FUSES AND SURGE ARRESTERS

Abstract: *This paper deals with the issue of the fire occurrence which is caused by low-voltage electrical installations (household distribution board) due to the absence of protective devices (fuses and surge arresters) on the pillars of the electrical distribution network. The example of calculation of fault currents is given, for the fault current on the basis of which it is proved the necessity of installing of pole mounted fuse on the latest pillar of low-voltage electrical distribution network. In the paper there are examples of fire expertise for fires caused by non-installation of pole mounted fuses and surge arresters are presented.*

Key words: atmospheric discharges, over-voltages, fault current, fire, pole mounted fuse, surge arrester.

INTRODUCTION

A common cause of fire is an overvoltage of atmospheric origin. Thunderstorm is the most common cause of atmospheric discharges (lightning) in low-voltage system, its environment, or sometimes directly into the building. Atmospheric discharges into the electrical network and around it, cause over-voltages in the network itself which thanks to their wave nature, come into the building in question and may cause severe damage to the electrical installation with the possibility of fire occurrence. Direct atmospheric discharges into the facility, as the cause of the fire, are much less common and usually are accompanied by significant mechanical damages of the parts of building in question.

Regardless of the location and type of lightning, electricity generated in low-voltage system must be emptied into the ground. This may occur through the surge arrester or the breakthrough on some of the pillars of the low-voltage network. However, if the breakthrough does not occur or discharging through the surge arrester is insufficient, it is achieved through the electricity consumers. The maximum quantity of power surges is discharged on the part of installation that has the lowest level of insulating strength. Even in cases of household distribution board and electrical meters of the same type, not all of them are of the same homogeneity, age, insulating spacers live parts with the same under voltage and with the same weak points, which usually results in a fatal damage to the installation of a consumer, and rarely in more.

Overloads and short circuits are also unpredictable, and thus cannot be prevented. The overloaded current is slightly larger than the nominal, while the short-circuit current is significantly higher than the nominal current, resulting in overheating of conductors, connecting places and devices that belong to the circuit. This is the cause of failure of the devices, and often malfunction that could lead to the occurrence of fire.

It could be concluded that protection devices must exist in order to surge protect the household distribution board, overload and short circuit by promptly reacting to prevent a fire. It is precisely the quality of care that is determined by how quickly it will reach an efficiency of "exclusion" of adverse events in the network. It is common practice in our electric utility companies that some of the measures of protection are not posed for unjustified reasons.

MEASURES OF PROTECTION

Measures of protection against over-voltage (surge arresters) are performed with the aim to provide not only low-voltage networks protection, as well as power lines and household distribution board with measurement group, but also to protect the internal electrical installation and the whole building from the penetration surges. The decision on the installation, replacement and maintenance of the surge arrester is solely responsibility of the supplier of electricity (power distribution companies) [1]. There is surely a need for setting up an adequate surge arrester on the pole or in the measure-distributive board, in the case of household connection at its end (last pole) of the longer section of the low-voltage network, the critical position of the building in question and the high isocerenaunic level (high number of thunderstorm days during the year) [2].

In practice, it often happens that the Supplier of electricity installs surge arresters only if the legislation requires it explicitly, while if there is a clause "installation if necessary" (for increased risk areas) it is as a rule and unreasonably interpreted as "not required". Although the Supplier of electricity is the only one that has the right and responsibility of choice and application of specific measures of protection against over-voltage (within the rules of law), the supplier of electricity has also legal obligation as must to provide protection against over-voltage [3]. Thus, the Electricity supply company has the exclusive right to decide whether to set surge arresters in a place where there is no imperative of its setting, so that in case of failure to put such a low-voltage network, it cannot be considered technically incorrect in advance, but it is considered to be more or less risky.

Melted fuses are being installed at the beginning of the circuit or the distribution line that should have the role to protect against over-current and short-circuit current. In this way, all electrical components are protected against excessive thermal stresses which could be considerable and could lead to occurrence of fire. The main parts of melted fuses are: housing and melted inset. The inset consists of a refractory cartridge, whose metal contacts are pieced together with special, easily melted wire. The wire is dimensioned according to the rated current value which appropriate cartridge can hold indefinitely, and melts if it exceeds the allowable limit, and if such a regime lasts long enough. The melting of wire breaks the circuit in which the fuse is placed. The speed of the soluble inset response depends on the intensity of the current that "passes" through the fuse. The higher the value of the current, the fuse will react faster. After melting the wire, it is prohibited to replace melted wires (by technical regulations) and it is required to replace the entire cartridge.

Surge arresters are devices that have non-linear resistors tied to the earth which while crossing of over-voltage reduce their resistance by leading some of the energy into the earth. With the disappearance of over-voltage they increase their resistance to the original value. Latest generations of surge arresters are divided into two groups according to their construction: silicon carbide (SiC) and metal oxide or zinc oxide (ZnO) surge arresters.

Figure 1 shows the external appearance of pole mounted fuse and surge arrester.

Figure 1. *The appearance of pole mounted fuse (left) and surge arrester (right)*

Although the installation of surge arresters and pole mounted fuses in financial terms as a rule, is paid by final consumers (in the same way as the consumer bears all the costs for installation, distribution board, electric meter, timer, household connection, etc.), the consumer has no technical authority over this devices. Technical competence and ownership of certain parts of the installation of a service connection are often equated, which may have significant legal as well as technical consequences. Household connection partition in two parts, outer and inner part (according to the cited technical recommendations of electrical company) in effect represents the partition to visible and invisible part of the household connection. In technical terms, the installation of a service connection is a unified, and therefore must be under a single jurisdiction, i.e. under the jurisdiction of electricity distribution companies. Liability for damage caused to the consumer facility, originated from the damage of installation of household connection (except mechanical damage by the consumer) should be borne by the electricity supply company.

CALCULATION OF FAULT CURRENTS

We will assume that the building which poses maximum power, simultaneously, of 15kW of electrical power powered through low-voltage of the excerpt of transformer station 10/0.4 kV. We will also assume that the excerpt, to which several customers are connected to, is protected (from the current overload and short circuit) by blade fuse with a nominal current of 125 A. Excerpt to the first pillar is done as underground cable PP41-Y 4x50 mm^2, and it continues as an overhead line - a bundle of bare conductors Al/Fe4x50mm^2 from the first pillar. Household connection cable type is PPOO 4 x 6 mm^2 (Figures 2 and 3).

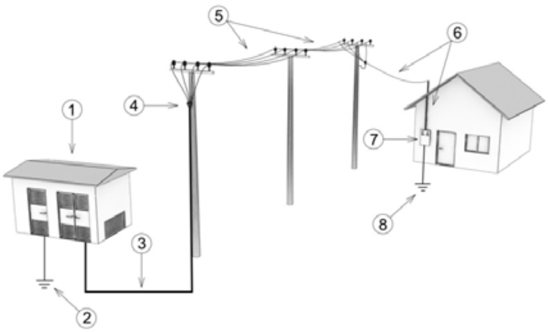

Figure 2. *The delivery of electric power*

The numbers in Figure 2 represent:
1 - Transformer station TS 10/0.4 kV
2 - Earthing of transformer station
3 - Distribution line cable
4 - Switching from cable to overhead line
5 - Overhead distribution line
6 - Household connection line (outer and inner part)
7 - Distribution board and measuring location
8 - Earthing of the building in question.

The neutral point of the secondary of transformer is grounded by earther (R_{TS}) with the resistance value of 1Ω. Protective bus in distribution board is galvanically connected with earthing (R_{OB}) of the building (TT protection system against indirect contact is applied), whose ground resistance is 2 Ω.

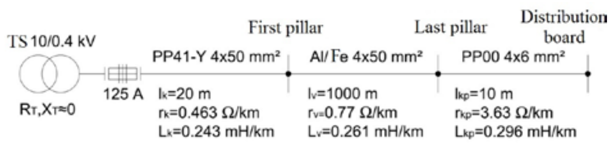

Figure 3. *Single-pole scheme of electrical installations*

One can calculate the impedance of individual stocks based on these data on the lines [4] shown on the single-pole scheme (Figure 3) of electrical installations that correspond to the analyzed case. The values of l_k, l_v and l_{kp} are lengths of cable line, overhead line and household connection line, respectively. The values of r_k, r_v and r_{kp} are longitudinal resistances of cable line, overhead line and household connection line, respectively. The values of L_k, L_v and L_{kp} are longitudinal inductances of cable line, overhead line and household connection line, respectively.

Single-phase ground fault

We will assume that the fault occurred in distribution board (Figure 4), i.e. that there has been a electrical breakdown from one phase to household connection line and protective bus (due to damage to the insulation of the phase conductors, for example).

The fault current is calculated using formula (1):

$$I_k = \frac{U_f}{Z_s} \tag{1}$$

(U_f is nominal phase voltage - 230V, Z_s is fault loop impedance).

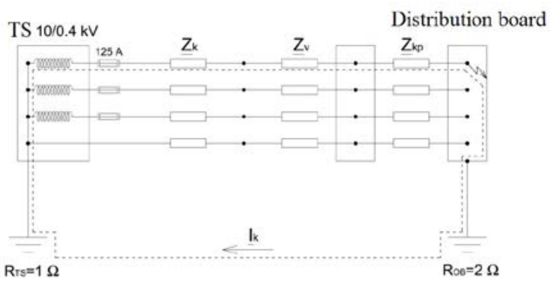

Figure 4. *Three-phase electrical scheme for single-phase ground fault*

As shown in Figure 4, the fault loop consists of a phase winding of transformer secondary, the phase conductors to the fault, the grounding of the facility, the ground electrode of the secondary transformer, as well as the land between two ground electrodes. When calculating the fault loop impedance the impedance phase of transformer winding of the secondary can be neglected (R_T, X_T≈0).

The fault loop impedance is:

$$\underline{Z_{s1}} = \underline{Z_k} + \underline{Z_v} + \underline{Z_{kp}} + R_{OB} + R_{TS} \tag{2}$$

$\underline{Z_{s1}} = (3.8165 + j0.0835)\Omega$, $Z_{s1} = 3.8174\Omega$ where :

$\underline{Z_k}$ - is impedance of cable line, $\underline{Z_v}$ - is impedance of overhead line and $\underline{Z_{kp}}$ - is impedance of household connection line.

The fault current is:

$$I_{k1} = \frac{230V}{3.8174\Omega} = 60.25A.$$

The intensity of the fault current can cause overheating and fire occurrence in distribution board. Therefore, it is necessary to interrupt the fault current timely. Function of deactivation of fault current can be performed only by a fuse in the transformer station, since it is the only in the power supply line (there are, of course, also fuses of the individual circuits of household installations, but they are not part of the fault loop for the fault that occurred in distribution board). The fuse in the transformer station cannot `see` the fault current of 60.25 A, because it is lower than the nominal current of the fuse. Therefore, the fuse in the transformer station will not react in a timely manner, nor it will react in this fault current. Thus, it is necessary to set the pole mounted fuses at the beginning of the household connection line.

Simultaneous maximum power of 15 kW (i.e. every current phase of $15000W/(3 \cdot 230V) = 21.74A$) corresponds to the inset of pole mounted fuse of 25 A. Figure 5 shows the characteristics of response of "fast" melted insets of pole mounted fuses [5]. The fuse with current rated 25 A breaks the fault current of 60 A in about 10 seconds, so it could be concluded that these fuses would likely prevent the spread of fire.

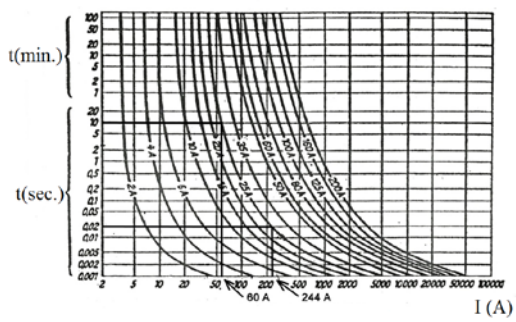

Figure 5. *Characteristics of response of "fast" melted insets*

Two-phase short circuit

Naturally, in the case of a different kind of failure, the impedance of fault loop would be different, and so would the value of the fault current. Therefore, we will assume a fault for which the fault current is greater than the nominal current of the fuse in the transformer station (125 A). Since the fault loop impedance from the previous example is dominantly impacted by the resistance grounding system of the building in question and of transformer station, it is assumed that the failure occurred again in distribution board. However, in this case there is a short circuit between two phase conductors (Figure 6).

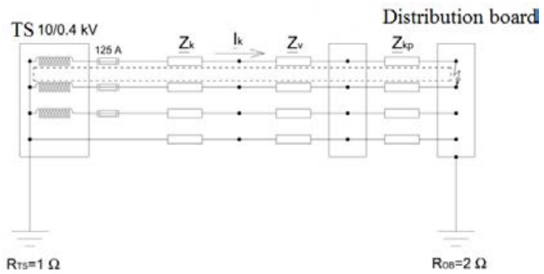

Figure 6. *Three-phase electrical scheme for the two-phase short circuit*

In this case, the fault loop consists of a two-phase winding of the transformer secondary, the phase conductors of one phase of the transformer station that lead to the fault (in distribution board) and the phase conductors of the second phase of the fault to the transformer station. When calculating the fault loop, the impedance of phase winding of the transformer secondary should be disregarded.

Fault loop impedance is:

$$\underline{Z}_{s2} = 2 \cdot \left(\underline{Z}_k + \underline{Z}_v + \underline{Z}_{kp}\right) \quad (3)$$

$\underline{Z}_{s2} = (1.63 + j0.17)\Omega$, $Z_{s2} = 1.64\Omega$.

The fault current is:

$$I_{k2} = \frac{U_l}{Z_{s2}} \quad (4)$$

(U_l nominal line voltage-400V),

$$I_{k2} = \frac{400V}{1.64\Omega} = 243.9A .$$

Since this value of intensity of the fault current is greater than the nominal value of the current of the fuse in the transformer station, there will be a response of this fuse. However, the question arises whether the circuit in the transformer station will timely (fast enough) react for that value of the fault current.

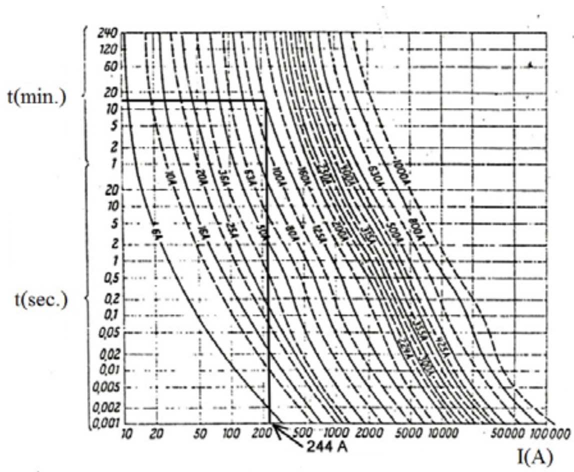

Figure 7. *Characteristics of response of high-power blade fuse insets*

Figure 7 shows the characteristics of response of high-power blade fuse insets [5]. Fuse of the nominal current of 125 A breaks the fault current of 244 A for about 15 minutes, which means that the fuse in the transformer station cannot respond in a timely manner in order to prevent the spread of fire.

From the Figure 5, which shows the curves of current load of the "fast" melted fuse insets, it can be seen that the pole mounted fuses of the nominal current 25 A interrupts the fault current of 244 A in 20 minutes (almost momentarily), so there is no danger of fire.

As we have already stated that fuses protect the distribution line (also) from overload, it is necessary to check whether the selected mounted fuses (of 25 A) can protect the household connection from the overload. The maximum allowed current value for the household connection cable type PP00 4x6 mm^2 is about 44 A [4]. It could be concluded that the overload by one phase of even 76%, would induce augmentation of heating of the conductor (with this level of overload, the fuse of 25 A will respond to in a minute).

The conclusion is that the blade fuses in the transformer station cannot adequately protect the cable of household connection from the overload, nor from the short circuit. Thus, it is necessary to set up adequate pole mounted fuses at the beginning of the household connection. However, in some rural areas it is a common practice that pole mounted fuses are not being installed, and we will, through concrete examples, show the consequences that may arise from such improper and/or irresponsible actions.

EXAMPLE OF EXPERTISE

The following specific examples are the result of expertise conducted by the Expert Commission of Faculty of the Electrical Engineering in Belgrade.

We will present only the relevant parts of expertise that are related to typical situations [6].

At the time of the fire occurrence, the building is supplied with electricity by cable of transformer station of 10/0.4 kV, of the low-voltage network of the total length of 1.9 km. Cable of the household connection type PP00 4x6 mm^2 went up to the console on the roof, and then branched out into two cables type PP00 4x4 mm^2 for the power supply of certain parts of the building which had a separate electricity meter.

Figure 8. *The appearance of pillars from which the building is supplied with electric power*

From Figure 8 it can be clearly seen that the column does not have installed fuse, and also has no surge arresters, even though it is the last on the route.

Since the distribution board is normally always energized, there is a possibility that the cause of the fire is malfunction in the electrical installation, and that there were conditions for the electricity to support the fire. The roof was completely burned except in the most remote parts of the building (from the part where distribution board was), suggesting that the cause of the fire should be first inquired to at electrical installations in the area of household connection cable and the distribution board.

Copper beads as result of the melting of copper are formed at temperatures higher than 1083°C (the melting point of copper). When a short circuit - the arc of electricity causes the fire (the primary short-circuit), there are occurrence of considerably higher temperatures with formation of beads, and/or welds. There is also possibility of interruptions of the conductor due to the falling of molten copper. Secondary short circuit could be occurred on electrical installations as a result of the transferred fire that damages the insulation of conductors, causing a new arc. The metal structure testing of welds and beads, conducted by methods based on the presence of oxygen at the place and at the moment of short circuit, gave the final confirmation. With the primary short circuit there is great oxygen presence, and very little in the secondary short circuit, thus causing differences in the structure of the place cheats (Figure 9).

Figure 9. *The copper conductor in which there is visible trace of melting as a result of the high temperature of electric arc*

The appearance of two welt beads in a locus indicates to the existence of the electrical arc when developing very high temperatures, so this locus can certainly be place of fire, i.e. place of the primary short-circuit. This may, if necessary, further be confirmed by the metallographic examinations of welds on the conductor using the method of light microscopy, followed by a definitive confirmation by the method of X-ray analysis.

The role of existing undamaged main fuses (of 20 A) behind the electricity meter is to protect the junction electrical installation facility. It cannot protect the electric meter and household connection cables that are ahead of them (from the short circuit current). If there are inadequate main fuses set, it would have a significant effect only if a fire started on the inner electrical system of the building that is, in terms of protection against short circuit current and overload, in the jurisdiction of the consumer.

The maximum allowed intensity of current of household cable conductors of the console to the distribution board (section of 4 mm^2), demanded the installation of pole mounted fuses of 25 A. The absence of such pole mounted fuses in the present case makes installation of a household connection technically incorrect. Fuses at the excerpt of transformer station due to high values cannot protect household connection port from overload and short-circuit current, nor can the main fuses on the distribution board, because it is situated behind the installation of a household connection cable in the direction of transmission of electricity.

Figure 10. *The appearance of the inside of a burnt-out electricity meter*

All material evidence indicate that the initial cause of the fire is the damage to the electricity meter contacts (Figure 10) and conductor insulation of household connection cable with cumulative function of earlier surges of atmospheric origin, the consequences of which are not suppressed in the absence of protective measures (pole mounted fuse and surge arrester). It is particularly significant that this damage may have a gradual development - partly damaged insulation, followed by a small fault currents due to the ever-present voltage in electric network, that increases over time and causes overheating, which cannot be protected by fuses that are not well dimensioned or do not exist in the observed part of the installation.

In these circumstances a fire can occur even when no consumer is involved, or when in the house for a long time no one resides. This scenario is typical for peripheral low-voltage electrical networks that are poorly maintained and inadequately protected from atmospheric over-voltage and short circuit currents, especially on the household connection cable.

CONCLUSION

The value of the material damages caused by fire with no human casualties (fires with the human losses are priceless), and whose cause is the lack of adequate protection in the form of pole mounted fuses and surge arresters, as it is presented in concrete examples, could be several times greater than the value of expenses required for the protective devices installation in order to prevent the occurrence of fire in a timely manner.

The initial cause of the fire is the damage to the electricity meter contacts and insulation of conductors in distribution board with cumulative function of earlier surges of atmospheric origin, the consequences of which are not suppressed in the absence of protective devices (surge arrester).

In our electricity supply companies there is the practice that pole mounted fuses are not installed or put out (because of the significant involvement of workforce need for their installation, even though the costs are paid by final consumers), and the reason for this behavior is been explained with inaccurate calculations that the fault current with the "metallic compound" is large enough to cause a reaction in the transformer station.

The example analyzed in part 4 of the paper, confirm that in overhead networks with TT system protection, as a rule there is no response of the fuse in the transformer station. In addition, the fault currents do not usually originate from metal short circuits, at least not in the initial stage. However, they could originate from the short circuit of the variable resistance arc. In the initial phase electric arc has a significant resistance which is later reduced. The consequence is that the fault current goes beyond from the endurance power of the household connection cable, and it is significantly less than the current of the response by the fuse in the transformer station, which finally leads to the occurrence of fire. In practice, it is often the case that fire occurs, and no fuse in the transformer station responds. Thus, it is necessary to install pole mounted fuses with currents that correspond to allowed load current for the household connection cable.

Pole mounted fuses are not only needed [3,7], due to the change of cross sections of household connection cable compared to standard cross sections of low-voltage networks, but are also required, because the fuses in the transformer station (current-dimensioned for high values), which correspond to aggregate consumption of all consumers in the arm, i.e. low-voltage networks branching, do not provide adequate protection to for household connection cable from overload and short circuit currents.

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BIOGRAPHY

Nedžad Hadžiefendić was born in Prokuplje, Serbia, in 1971. He graduated from Faculty of Electrical Engenering, University of Belgrade in 1997, on the Energy Department - Power Converters and Drives. Master degree obtained in 2001 at Faculty of Electrical Engenering, University of Belgrade. Since 2012, PhD candidate with thesis titled „The impact of bad electric contacts to the initializing of fire and method for its detection in low-voltage installations” at the Faculty of Electrical Engenering, University of Belgrade. He is currently working as a senior laboratory engineer in the Laboratory for testing of low-voltage electrical and lightning protection installations at Faculty of Electrical Engenering, University of Belgrade

POŽARI NA INSTALACIJI KUĆNOG PRIKLJUČKA UZROKOVANI NEINSTALIRANJEM STUBNIH OSIGURAČA I ODVODNIKA PRENAPONA

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Rezime: *U radu je predstavljena problematika nastanka požara na niskonaponskim električnim instalacijama (kućnom priključku) usled nepostojanja zaštitnih uređaja (stubnih osigurača i odvodnika prenapona) na stubovima vazdušne distributivne mreže. Dat je primer proračuna struje kvara na osnovu kojeg je pokazana potreba za instaliranjem stubnih osigurača na krajnjim stubovima niskonaponske vazdušne distributivne mreže. U radu su predstavljeni i primeri veštačenja požara koji su nastali usled neinstaliranja stubnih osigurača i odvodnika prenapona.*

Ključne reči: atmosferska pražnjenja, prenaponi, struja kvara, požar, stubni osigurač, odvodnik prenapona.