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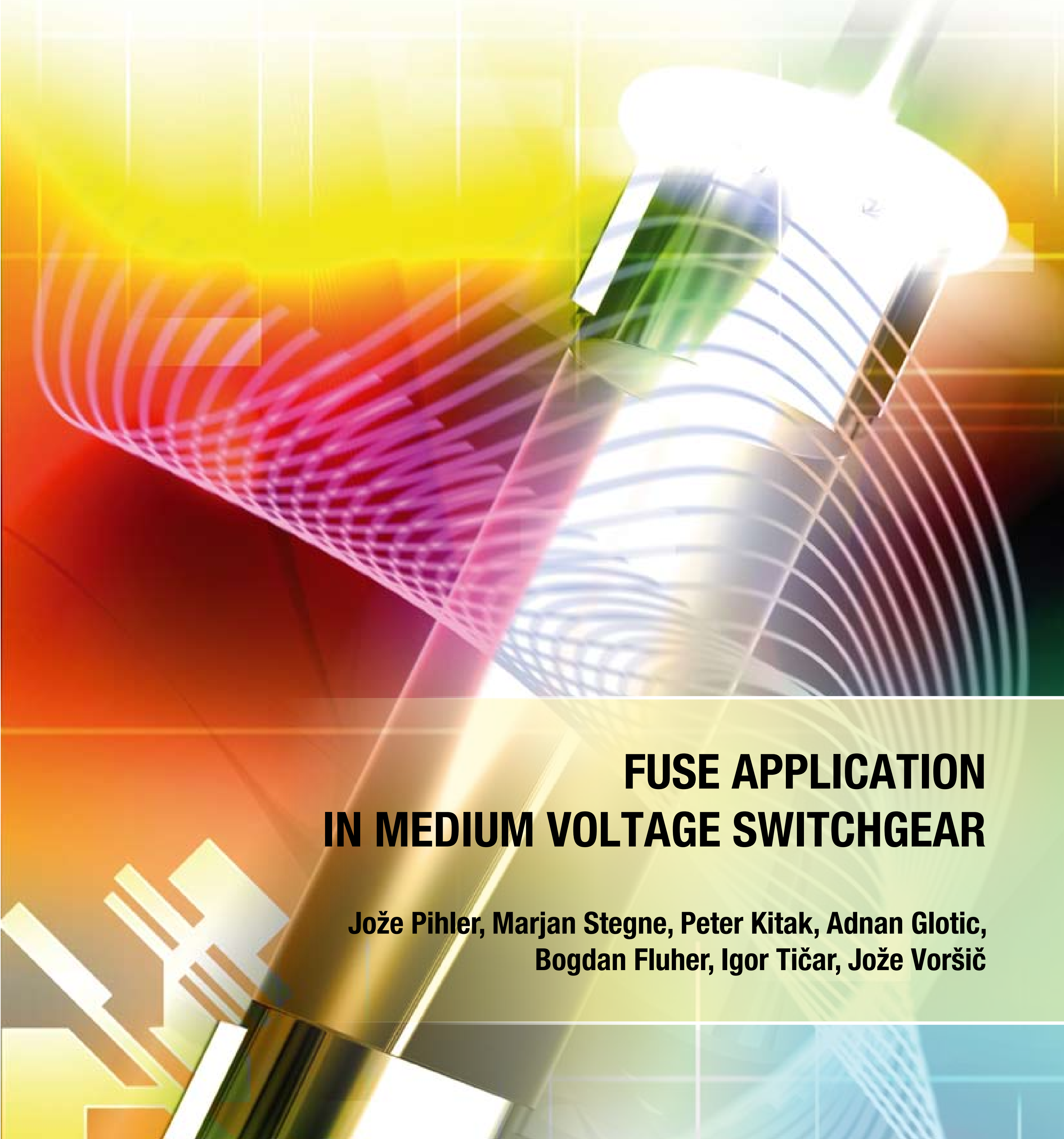

FUSE APPLICATION IN MEDIUM VOLTAGE SWITCHGEAR

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Abstract

Switch-fuse combinations are built in to most distribution and industrial medium-voltage switchgear cells. These fuses are responsible for protecting the distribution transformers. They are usually used to protect both voltage-transformers and auxiliary-transformers. In pole-mounted transformer substations, it is possible to combine the disconnector with the fuses (fuse-disconnector, disconnector-fuse) or the fuses only at the medium-voltage level of transformer protection. However, recently-constructed switchgear may exclude fuses. Instead of fuses, circuit-breakers with defined (usually lower) short-circuit breaking capacities are combined with protection devices that take over the role of protection. Moreover, it is possible that smaller pole-mounted transformer substations are no longer protected by fuses anymore when considering the medium-voltage level.

The purpose of this paper is to explore the roles and functions of those fuses mounted on indoor or outdoor systems, and applied for the protection of the medium-voltage level. Those other possibilities that exclude fuses for device protection for medium-voltage switchgear are also explored and analyzed.

Keywords: medium-voltage fuse, distribution transformer, switch-fuse combination, protection, thermal field calculation.

1. Introduction

Fuse-application, as a protection element in the power grid, practically started at the inception of electrification. Despite the fact that the fuse is a relatively old invention, from the technological point of view, it is still a crucial protection element in all electrical engineering applications. In cases of serious faults in installations or power networks, the fuse is the ultimate and last protection barrier. When all other protection elements fail, the fuse is the only one that remains.

The fuse enables the highest breaking capacity, as well as the ability to prevent short-circuit, in comparison with other protection devices (disconnectors, circuit-breakers). This property is enabled by the simultaneous workings of individual construction parts, mainly a melting element and quartz sand, which has the highest specific heat regarding vaporization. It means that the fuse is capable of quenching an arc within the shortest possible time. The consequences of the latter also include very low cross-over integrals of energy and cut-off currents, which is another advantage of the fuse. The fuse is also very affordable.

In comparison with circuit-breakers, fuse protection is more convenient for conductors and other devices, because they are less loaded in the cases of short-circuit currents. Replacing a melting fuse-element immediately after disconnection, means bringing-back the protection device to its previous condition, respectively. Nowadays, when all processes and power systems are automated, this characteristic may represent a disadvantage, which is clearly pointed out by opponents of fuse application. Power-supply interruption should be minimal (in ms), which is impossible when fuses are manually replaced. One of the goals of this paper is to research and present circumstances at medium-voltage level for external and internal devices, and to suggest fuse-applications.

2. Importance of a fuse as a protection element in distribution facilities

A fuse in a distribution medium-voltage power grid is mainly used as a protective element for:

- power transformers and auxiliary transformers and
- voltage transformers.

High voltage fuses consist of two parts, which are fuse-link and fuse-base. Based on their ability to limit the current, high voltage fuse-links can be divided into:

a) Current-limiting types [1]: This type is widely used around the world with more than 95% in Europe. They are for external use (protection of external distribution transformers) as well as the use in internal areas – switchgear cells. Properties and basic characteristics of these fuse-links are given in standard [1]. This is fuse that, during and by its operation in a specified current range, limits the current to a substantially lower value than the peak value of the prospective current. This standard defines three classes of current-limiting fuses:

Back-Up fuses, which are capable of breaking, under specified conditions of use and behaviour, all currents from the rated maximum breaking current down to the rated minimum breaking current.

General-Purpose fuses, which are capable to of breaking, under specified conditions of use and behaviour, all currents from the rated maximum breaking current down to the current that causes melting of the fuse element in 1 h or more.

Full-Range fuses, which are capable of breaking, under specified conditions of use and behaviour, all currents that cause melting of the fuse element(s), up to its rated maximum breaking current.

In practice, the most important characteristic is Back-Up, which means protection within a limited current area.

b) Non-current-limiting types [2]: Fuses with such a melting fuse-link are called expulsion. They are mainly used in the USA and the UK as well as in countries that are historically-related to the two previously mentioned. Fuse element melts and arcs, the expulsion effect of the gases produced by the interaction of the arc with other parts of the fuse results in the current interruption in the circuit. Another common characteristic is that they are essentially non-current-limiting. They are characterized by a relatively low arc voltage and so do not significantly reduce the value of the first peak of a fault current. They also, therefore, extinguish current at a natural current zero, when the proper dielectric condition have been established.

2.1 Fuse application for the protection of transformers

Fuse-links and switches are most frequently used to protect distribution transformers. In practice, there are four possible realizations:

a) Fuses for low voltage and high voltage

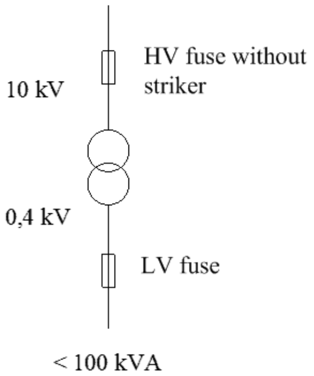

Fig. 2.1: Protection with fuses on the high-voltage and low-voltage sides.

This protection (Fig. 2.1) is used for transformers of the lowest apparent power (up to 100 kVA). In this case there must be an interruption of voltage on the high-voltage side in front of the fuses. High-voltage fuses do not require strikers. Such realization is the cheapest and is used for pole-mounted transformer substation (Fig. 2.2).

Fig. 2.2: Protection with fuses on the high-voltage side.

b) Fuse-disconnectors on the HV side and fuses on the LV side

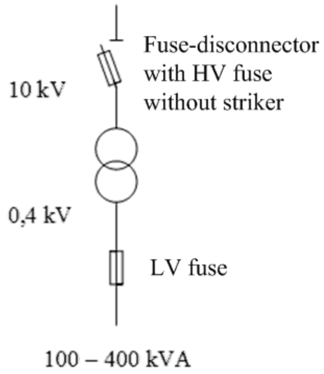

Fig. 2.3: Protection with fuse-disconnector on the HV side, and with fuses on the LV side.

A fuse-disconnector (Fig. 2.4) on the HV side enables a supply turn off and a visible separation. It is also used for pole-mounted transformer substations with apparent power from 100 to 400 kVA.

Fig. 2.4: Protection with fuse-disconnector.

c) Switch-disconnectors in combination with fuses on the high-voltage side and the fuses on low-voltage side

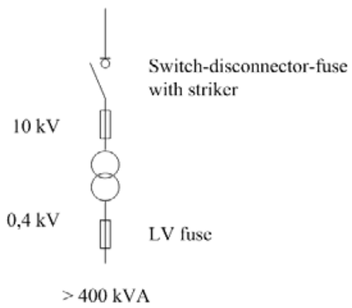

Fig. 2.5: Protection with switch-disconnector-fuse and fuses on the HV side and fuses on the LV side.

This concept is used in enclosed transformer stations with apparent power of over 400 kVA. The advantage of a switch-disconnector (Fig. 2.6), in comparison with a disconnector, is their ability to breaking nominal currents. A switch-disconnector or switch is usually equipped with a trigger mechanism, which is activated by a striker in the fuse. Short-circuit in one or two phase's causes a fuse to burn out. A switch-disconnector enables three-pole opening within the single phases of two-phase short-circuits.

Fig. 2.6: Protection with switch-disconnector-fuse on the HV side.

d) Čebulj protection

The use of Čebulj protection is an upgrade of the procedure previously described. Čebulj protection measures the current on the secondary low-voltage side, and in the case of an overload, the switch-disconnector turns off the primary-side of the transformer.

e) Recent realizations

Realizations with circuit breakers, that have lesser short-circuit breaking, and work in connection with special protective relays, have been in use for quite some time.

2.2 Standardization

Standards provide terminology, technical characteristics, and minimal technical requirements when choosing those fuses, intended for the protection of a power grid. These standards directly relating to fuses, are presented in the continuation.

a) IEC 60282-1:2005 High-voltage fuses – Part 1: Current-limiting fuses [1]

This standard is used for all types of high-voltage current-limiting fuses, which are constructed for external and internal use in AC systems of 50 and 60 Hz, as well as for nominal voltage over 1000 V. Some of the supplied fuses contain fuse-links, which are equipped with an indicator or a striker. These fuses are described within this standard. The correct working of a striker in combination with the triggering mechanism of a switch-device exceeds the area of this standard, and is covered by IEC 62271-105 [3].

b) IEC 62271-105:2002 High-voltage switchgear and control gear - Part 105: Alternating current switch-fuse combinations [3]

This standard applies to three-pole units for public and industrial distribution systems, which consist of switch-units that include a switch-disconnector and current-limiting fuses. These are capable of:

- At nominal recovery voltage, to interrupt every current up to and including the nominal short-circuit breaking current;
- At nominal voltage, to turn on circuits up to their nominal short-circuit breaking current.

In this standard, the term 'combination' is used for a functional unit, which consists of the components. Every connection of the given type of switch and fuse defines one type of combination.

In practice, different types of fuses are combined with one type of switch, which gives more combinations with different characteristics, especially in regard to the nominal current.

c) IEC 62271-107:2005 High-voltage switchgear and control gear – Part 107: Alternating current fused circuit-switchers for rated voltages above 1 kV up to and including 52 kV [4]

This standard applies to three-pole operated units for distribution systems that are functional assemblies of a circuit-switcher and current-limiting fuses designed so as to be capable of:

- breaking, at the rated recovery voltage, any load or fault current up to and including the rated short-circuit breaking current;
- making, at the rated voltage, circuits to which the rated short-circuit breaking current applies.

Their use is intended for circuits and applications that only require regular mechanical and electrical endurance. Such applications cover HV/LV protection of the distribution transformers, but they cannot be applied for distribution-transmission lines and electric machines that are used as compensation devices. Short-circuits with lower currents, all up to a current, that can be interrupted by a switch that is a part of the functional unit, are solved with additional devices (strikers, relays, etc.) that with adequate placement trigger only a switch, which is a part of the entire device. Fuses are added with the intention of ensuring that the short-circuit breaking capability, of the device, is higher than for the switch itself.

d) IEC/TR 60787 (2007-03) Ed. 1.0, Application guide for the selection of high-voltage current-limiting fuse-links for transformer circuits [5]

Basically, this standard represent a technical report for distribution transformers, which is used as a fuse 'user-guide' that fulfils the requirements of the IEC 60282-1 standard: High voltage fuses - 1. Part: Current-limiting fuses [1]. Because of that, this standard is considered to be informative and not normative.

The subject of these instructions is to determine criteria for coordination, respectively for the adjustment of high voltage fuses with other components that are part of a circuit with a transformer. It is also important to give directions when choosing fuse-links in regard to their time-current characteristics and nominal values.

3. Overview of current conditions regarding HV fuses` applications

There are five distribution companies in Slovenia and each of these five companies cover urban as well as rural areas. Electrical equipment containing fuses is built-in within external pole-mounted transformer substations, cable and wall transformer substations, and distribution transformer substations.

3.1 Pole-mounted transformer substation

Pole-mounted transformer substations are external transformer substations that are mounted onto a concrete pole or iron pole, and are of 20/0.4 kV voltage and an apparent power from 35 up to 250 kVA. The high voltage side of the transformer is constructed, in most cases with a disconnector at a previous location as well as with fuses and a discharge arrester, on the pole where the transformer is located (Fig. 2.1 and 2.2). On the low-voltage side, an electrical cabinet is located with low-voltage fuses for individual branches. A fuse-disconnector can also be used instead of high-voltage fuses (Fig. 2.3). Transformers located in some smaller transformer substations (20 and 35 kVA) are no longer protected by fuses anymore on the HV side.

On average per year, there are 5-15 faults on these transformers. The most common reasons are atmospheric overvoltage, and animals, since the transformer terminals and fuse terminals are not insulated. In that case where a fuse burns-out within a single phase, the voltages of the LV side (supply service) are no longer symmetrical. The other problem that appears is the safety of personnel when they are replacing faulty fuses.

3.2 Substations with indoor switching devices

These substations are constructed of metal sheets, concrete, or are brick-built. The electrical equipment is internally assembled and is not exposed from the weather. The apparent power of these substations is from 250 kVA to 1000 kVA and a voltage of 20/0.4 kV. They are used in both rural and urban areas. The high voltage side of the transformer is mostly protected with fuses added to a switch-disconector (switch-disconnector-fuses - Fig. 2.6), and have a striker as well as a mechanism for triple-pole disconnection of the supply when a fuse burns out (Fig. 2.5). The low-voltage branches are also protected by fuses. The described switch-fuse combination is often already replaced by combinations of a circuit-breaker and corresponding protection. This means the abandonment of high-voltage fuses.

3.3 Distribution transformer substation

These are air or gas-insulated transformer substations of 110/10 or 20 kV. The medium voltage part is always assembled internally. Fuses are applied to protect auxiliary transformers and voltage instrument transformers within measuring cells. Measuring cells that are insulated with gas SF_6, already use combinations without the protection of voltage measuring transformers with fuses.

4. Innovations and trends when using HV fuses

Recent innovations in high voltage fuses are related to new ways of applying fuses, and method for replacing fuses with other protective devices and combinations.

4.1 New methods of fuse application

The most important innovation is the application of fuses in the so-called self-protection transformer [6], [7].

Fuses are located in the housing of the transformer. The interruption of the circuit, in cases of fault, is based on the following options:

- three-phase current disconnection in the case of an internal fault,
- three-phase separation from the power-grid,

The triple protection system consists of:

- three high voltage limiting fuses,
- high voltage switch disconnector and
- low-voltage short-circuit devices with the capabilities of detecting level and oil pressures.

This transformer also contains epoxy-bushing, which prevents contact with parts under the voltage (Fig. 4.1)

Fig. 4.1: TPC transformer with epoxy-bushing for external assembly.

Another improvement in the successful application of high voltage fuses is the I_S limiter [8]. In cases of short-circuit, this quick switch-gear device triggers opening of the main conductive part. This part is designed to conduct high values of current under normal working conditions. The current switches to a parallel fuse that has high breaking capacity, which in a very short period of time limits the first increase of a short-circuited current.

The I_S limiter works as a good conductor under normal working conditions. In the case of fault, the limiter detects and limits the short-circuited current, so that its maximum value is never reached. The advantages of the limiter are:

- no additional power losses,
- no additional voltage drop,
- decrease in power grid resistance (parallel connections of transformer branches)
- limiting of short-circuit current at the first increase of the current,
- Improvement in power quality.

The I_S limiter consists of a main conductive system, which is designed for high nominal currents (yet it has a low breaking capacity), and from a parallel fuse with a high breaking capacity.

A small energy saver is used to save energy in those cases when the main conductive system is interrupted. A short reaction time, needed for a considerable limitation of the peak value of the short-circuit current, protects the system's components against distractive, dynamic and thermal overloading. A measuring and triggering system is required for a reliable working of the limiter. The electronic component constantly measures the value and the degree of current increase throughout the limiter, and compares them to previously set values. Each individual phase has a separate measuring and triggering system. In the case, if the both previously set values are reached or exceeded simultaneously in any of the phases, the limiter is trigged immediately. The primary construction parts are shown in Fig. 4.2.

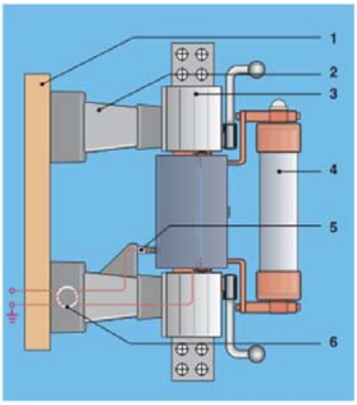

Fig. 4.2: Base and link of I_S limiter; 1-base plate, 2-insulator, 3-head pole with clamp, 4-fuse, 5-telescopic contact, 6-insulator with pulse transformer.

4.2 Fuse substitution with other protective combinations

The so-far existing method of protecting medium voltage cells is carried out with a switch-disconnector-fuse.

Quite a number of manufacturers of switchgear that contain dry air or gas SF_6 as a medium in their program, already introduced an alternative combinations. Circuit breakers and protective relays are used instead of a switch-disconnector-fuse. This combination, for its functioning, requires current transformers that send information to the relay, which than works when the circuit breaker turns off. The used circuit breaker usually has a lower breaking capacity. Realizations of circuit breakers with a vacuum or SF_6 gas are available. As a protective device, a simplified realization of the relay is applied, with an overload current and short-circuit current protection.

The next novelty is the application of a circuit breaker and a special protective circuit, which is used for circuit breaker triggering. The important elements in this circuit (Fig. 4.3) are the LV fuses. In this case, under normal working conditions, secondary currents flow through a low-impedance circuit with a fuse. Due to low impedance, a relatively low voltage occurs in the secondary circuit. In this case, practically no current flows through the triggering coil. In the cases of fault currents, one or more fuses (A, B and/or C) burn out and break the overcurrent value. The only remaining path for current to flow after fuse disconnection is a rectifier bridge and triggering coil of the circuit breaker through special voltage winding that is optimized in regard to the characteristics of the triggering coil.

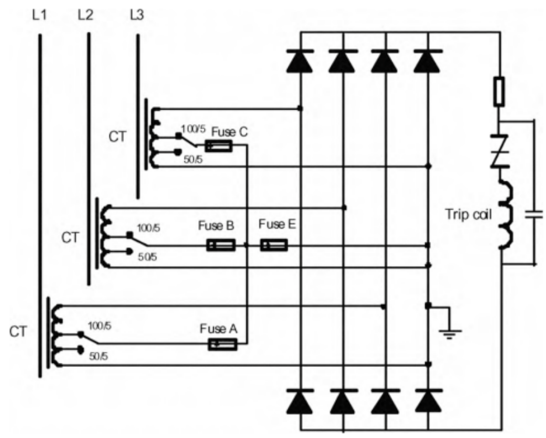

Fig. 4.3: New protection system based on the TLF (Time Limite Fuse).

The final alternative for high voltage fuses is the abandonment of those fuses for protecting small transformers (35 kVA up to 50 kVA). Fig. 4.4 shows an example of such a realization.

Fig. 4.4: Pole-mounted transformer substation with an unprotected transformer.

Transformer from Fig. 4.4 is completely unprotected because the manufacturers claim that a short-circuit current, in these grids, is lower in comparison to one that can be sustained by a smaller transformer.

5. Proposal for eventual new protection solutions regarding internally and externally assembled facilities

In regard to the available equipment, on both the European and World markets, as used to protect internally and externally-assembled transformer substations, and on the basis of expert opinions when it comes to the protection of transformer substations, the following is suggested:

- within internally-assembled air insulated facilities, it is reasonable to preserve the present condition, respectively a switch-disconnector-fuse. Within newly-built facilities, devices insulated with gas SF_6 are not recommended, due to environmental hazards. The recommended devices are those insulated with dry air and solid insulation if the solution is financially affordable and necessary due to the lack of space (small dimensions). These devices contain, instead of fuses, circuit-breakers with protection. For this type of protection, besides the price, it is necessary to consider the amount of time when the protection is active, as well as the circuit-breaker. The previously-mentioned amount of time is significantly longer in comparison to fuses. It is also necessary to consider breaking capacity, and a number of possible operations of the circuit-breaker.

- voltage transformers, located in air insulated devices are protected by fuses and because of such, in the case of a fault without protection, there is another protection, which interrupts the power supply. For other devices, the voltage transformer integrated into a device, does not need any protection.

- For the so-called small pole-mounted transformer substations, of up to 50 kVA, the suggested protection is without any fuses. But it includes overvoltage arresters and appropriate selective protection using the remote-controlled circuit breakers of the entire HV branch, from the distribution transformer substation (DTS) to the last transformer substation. The previously mentioned is based on the fact that the short circuit current value in the distribution power grid is lower, in comparison to the transformer (25 times the nominal current) for a time interval from 3 to 3.5s. By abandoning HV fuses, the problems that occur with fuse replacement, are avoided (safety). In the cases of longer faults, the entire HV branch of the distribution transformer substation is out of power (the protection of the DTS works). Due to this, when the transformer substation is unprotected by HV fuses, the use of selective protection with the remote-controlled circuit breakers of the entire HV branch is suggested, from the distribution transformer substation (DTS) to the last transformer substation.

- For other pole-mounted transformers substations of apparent power above 50 kVA, the use of HV fuses and overvoltage protection is still recommended, but with complete insulation, protection for all the transformer terminals and fuses for. Small compact transformer substations, installed on the ground are recommended, mainly because of worker safety, and the other advantages offered by mechanical protection of such transformer substations. In those areas where access to pole-mounted transformer substation is available via a crane, throughout the year, it is possible to use self-protected transformers, which contain fuses in oil. If this procedure is put into force in the Slovenian market, it will be necessary to replace the entire transformers when fuse burns out.

6. Conclusion

The goal of this paper was to research the current application of fuses within the power distribution system, trends and innovations, and the proposals of authors for the future use of fuses at different facilities.

The fundamental decision regarding, which protective device to apply in power distribution system, is based on a good knowledge of fuse properties, and the capabilities of other protective systems, as well as the actual conditions within those parts of the system, where devices are built-in. In a power distribution system, HV fuses are still utilized because they are quick and capable of interrupting high short-circuit currents. However, it is understandable that some specific distribution MV devices should be protected by new devices instead of fuses.

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