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DEVICE FOR PROTECTION AGAINST TRANSIENT AND TEMPORARY OVERVOLTAGE INCLUDING LIMITATION OF THE SPECIFIC ENERGY

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Abstract. An arrangement is presented which ensures protection against transient and line frequency overvoltage and limits the load on the consumer to a minimum even in case of transient currents. The arrangement consists of a special arrester in the shunt circuit, a fast switch in the series circuit as well as a control and measuring device. The design, mode of operation and parameters of the components of the arrangement are described based on different loads. The protective effect is discussed.

Keywords: overvoltage protection, surge protection, spark gap, semiconductor switch.

1. Introduction

Overcurrent and surge protection are, alongside other protective measures, an inherent part of low-voltage systems and the connected consumers. The requirements on the transient overvoltage protection of low-voltage supply systems are described in IEC 61643-11 [1] and those on line frequency overvoltage protection, for example, home installation, in the EN 50550 [2]. Transient loads occur as a result of, for example, lightning and switching overvoltage. Surge protective devices are installed in the immediate vicinity of the point where the energy and data cables enter buildings or facilities. Beside lightning equipotential bonding these must protect electronic devices against high-energy conducted disturbance variables. Some known faults leading to transient overvoltage are, e.g. body contacts, earth faults, short-circuits and conductor interruption [3]. Line frequency overvoltage results from, among other things, faults in low voltage and medium-voltage systems. In the case of faults in low-voltage systems, the overvoltage level can, depending on the type of fault and the system, reach the line-to-line voltage. Therefore, at a nominal voltage of 230 V with 10 % tolerance, voltages of up to 440 V are possible. Appropriate protective devices are, i.a. coupled with main protective devices like, for example, circuit breakers. In particular, transient load from lighting events results in injected impulse current which can put a heavy load on the consumers connected. The flow of current places especially heavy load on consumers in a low-impedance state until the required sparkover voltage of the protective device, for instance, 1.5 kV is reached. The level of voltage load and also the charge value [As] in connection with the current flow represents a considerable hazard for some components in the consumer devices. The withstand voltage of many electronic components is often considerably lower than 1.5 kV. Components with a thin layer of insulation, like inductances or capacitances can, however, be destroyed or their service life considerably reduced relatively quickly as a result of even quite low overvoltage. Figure 1 shows a simplified view of the timespan of overvoltage which can be tolerated by sensitive electronic components in consumers. More detailed information can be found in, e.g. the ITI (CBEMA) CURVE for AC [4] for under- and overvoltage.

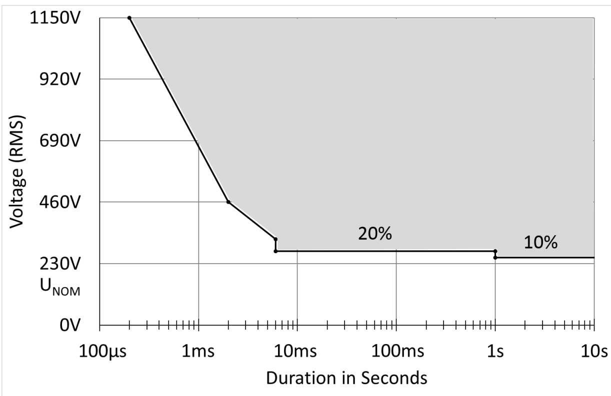

Figure 1. Voltage tolerance curve proper for 230 Volt AC equipment

For instance, the most consumer devices have capacitors in the input circuit, also in DC applications, they can be damaged by impulse current, especially high-level lightning current, before the transient protective devices are triggered. Any existing devices which protect against line frequency overvoltage on the basis of a mechanical switch are ineffective in the face of such loads as a result of the long effective dead time before disconnect the consumer. During this time commonly some 10 ms exists no protection against overvoltages.

The recommended new protective arrangement is capable of limiting the current load of the devices connected, even in the case of injected lightning current and provides uninterrupted surge protection of the transient area until the line frequency protection takes effect.

2. Design and components of the arrangement tested

The arrangement tested is shown in Figure 2. It consists of two basic components: an arrester A which is capable of carrying lightning currents and a semi-conductor based switch, as can be seen in Figure 2. Switch B1 is provided with a control device B3 which is coupled with a monitoring unit B2.

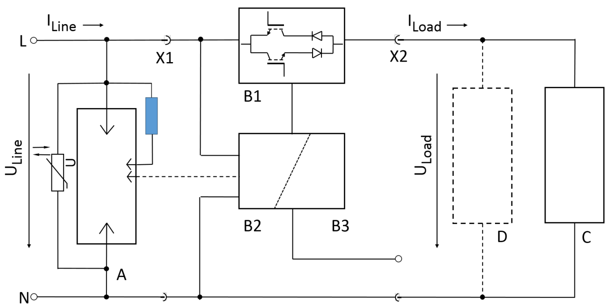

Figure 2. Principle of the recommended protective arrangement A - triggerable spark gap; B1 - switch; B2 - monitoring unit; B3 - control device; C - consumer; D - secondary protection

The voltage, current and current steepness at the switch are monitored. The switch, see also picture within Figure 3, is designed for a nominal current strength of approx. 16 A at 230 V and possesses a peak withstand voltage of 1.2 kV. Passive cooling is sufficient at this capacity. The arrester is executed as spark gap A with a deion chamber and, where necessary, a parallel varistor. The protection level of the spark gap is lower than 1.5 kV. The arrester has an additional control input for activating the spark gap. This input is connected to the control device of switch B2. The switch is put in conductive mode when the voltage level is in the range of the operating voltage. By a nominal current of 10 A the efficiency of the total arrangement is over 99 %. When active, inrush currents of the connected equipment of, for example, 170 A are possible without any functional restrictions. This value can be adjusted within the framework of the performance capacity of the semi-conductor. Likewise, it is possible to realise the functionality of an electronic overcurrent fuse or consider the characteristics of an existing surge protective device D. In the case of deviations in voltage, the current value, the temperature of the switch or the current steepness, switch B1 is put in non-conductive mode. It returns back to conductive mode automatically as soon as the operating conditions are normal again.

3. Mode of operation of line frequency overvoltage

The selected switch can be used at voltages of approx. 440 V AC and, as such, at numerous operating voltages. Corresponding with the selected operating voltage, the power supply of the consumer can be switched off if the threshold value is exceeded by, for example, only 10 % with an accuracy of approx. 2 %. Once the current returns to the permitted range, the consumer C is automatically connected again. The spark gap can remain passive by line frequency overvoltage up to a peak voltage of approx. 800 V. Connection and disconnection takes place via the switch B1 alone. Disconnection takes place after reaching the threshold value of approx. 400 µs. Should the voltage increase to a higher value, the spark gap is set to conductive mode. This can occur repeatedly until the overcurrent protective device is triggered. In addition to the control of the switch through its own monitoring unit, the switch and also the spark gap can be directly and instantaneously controlled by an external signal, e.g. from a consumer to be protected with its own internal monitoring unit. Figure 3 demonstrates the disconnection and connection of a consumer C by the switch at a nominal voltage of 230 V_{eff} and a threshold value of 360 V. When the voltage at the input of switch B1 increases to about the threshold value, the voltage at the output for the end device C is interrupted until the input voltage falls back below the threshold value.

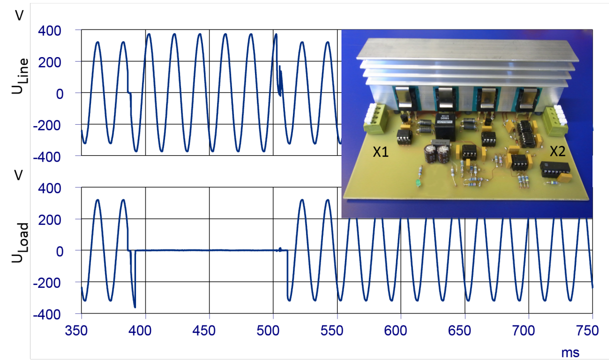

Figure 3. Behaviour of the arrangement in case of line frequency overvoltage top - line voltage; bottom - load voltage, picture of the switch B1 with control and monitoring unit

4. Mode of operation with transient overvoltage

As an example, in consumers with energy storage systems in the input circuit or where the internal surge protection has a low sparkover voltage a certain amount of current from transient interference flows to the end device before sufficient voltage is built up to trigger spark gap A or switch B1. Beside the current intensity, the monitoring unit of the switch also registers the rate of rise in current. Here, the current is measured by a shunt. The rate of rise in current is used to produce an additional voltage drop which has an instant impact on the blocking signal of the switch B1. This makes it possible for the switch to block very quickly, even when the current value is still below the permitted inrush current, for instance

170 A. Blocking the switch leads to a rash build-up of voltage on the spark gap, allowing this protective device to trigger. In addition, the monitoring unit of the switch can control the spark gap via the additional control input which allows it to trigger even at low voltages.

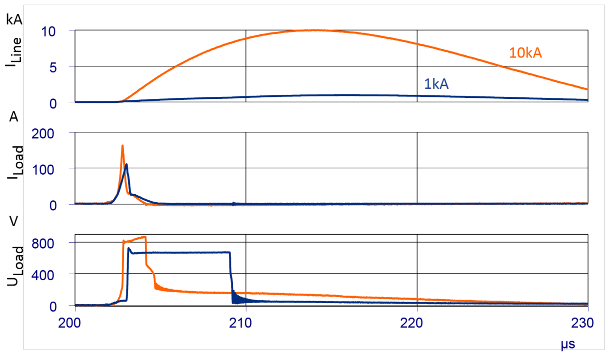

Figure 4. Behaviour of the arrangement in case of transient currents 1 kA (blue) and 10 kA (orange) 8/20 µs top - transient impulse line current; middle - transient impulse load current after switch; bottom - load voltage

This limits the necessary switching capacity of the switch. Very fast ignition can be achieved using a spark gap with diverging electrodes. The extremely low arc voltage after ignition (see Fig. 6) leads to a considerable reduction of the switching capacity of the switch even in highly inductive networks [4, 5]. The ensuing increase in arc voltage in the deion chamber to extinguish follow current remains limited to values under 600 V, whereby falling way below the dielectric strength of the switch. Figure 4 shows the behaviour of the arrangement with transient currents of 1 kA and 10 kA with the pulse form 8/20 µs. The spark gap is not additionally triggered, but rather ignited via the normal trigger switch as a result of the voltage build up from blocking the switch at a current level of under 170 A. Tripping of switch B1 is initiated after just <1 µs by the flow of current in the consumer due to the current steepness.

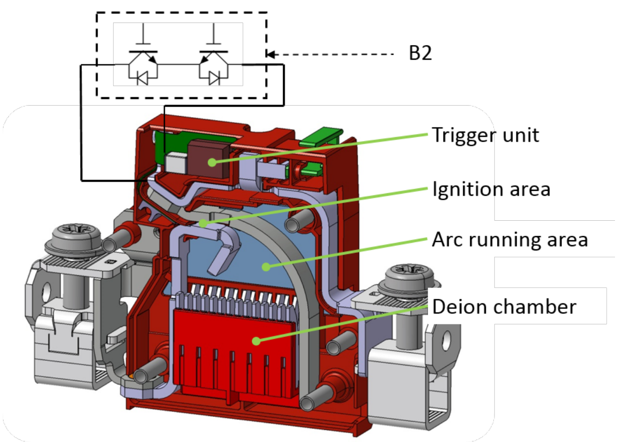

Figure 5. Spark gap with trigger unit and additional actuation by B2

The peak current value is reached at the beginning of the tripping and voltage builds up over switch B1 and thus also over arrester A. After the switch has been triggered and the spark gap ignited, the voltage sinks below 100 V. This considerably relieves the switching capacity of the switch's semi-conductor. The load on the downstream consumer and surge protective device compared with the charge and the current intensity of the transient disturbance is greatly reduced. As well as a voltage-switching element, the triggering has an electronic switch for additional actuation which is actuated by the control unit B3 or the consumer C. The basic construction of the spark gap with additional actuation can be seen in Figure 5. The spark gap with diverging electrodes, trigger circuit and deion chamber is described in detail in [4–6]. The additional actuation on the basis of a semi-conductor is connected with the existing auxiliary electrodes of the spark gap and bridges the transient ignition elements. This arrangement allows the spark gap to trigger by minimal surges. Figure 6 shows such an actuation and subsequent follow current extinction at approx. 230 V mains voltage without pulse stress. After ignition of the spark gap current flows out of the network and is quickly limited when the arc enters the deion chamber.

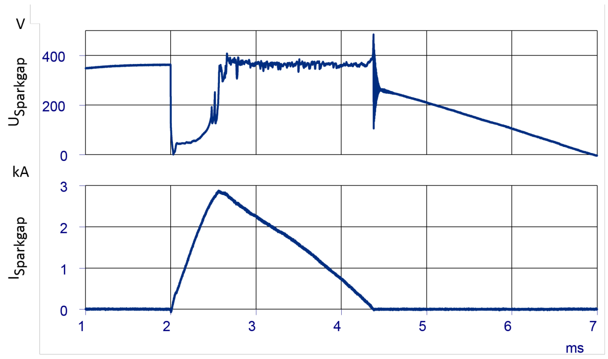

Figure 6. Arc extinction at a mains voltage of 230 V AC at a prospective short-circuit current of 25 kA

Here, the arc voltage when quenching the follow current remains well under the maximum blocking voltage of the switch so that the latter is not jeopardised by the function of the spark gap. Hence the functionality of the switch and the arrester are coordinated whatever the operating conditions.

5. Protective effect of the arrangement

The explanations show that the characteristics seen in Figure 1 are completely realisable with this arrangement. In contrast, when using normal devices for transient and line frequency surge protection, sensitive devices i.a. between approx. 2 ms – 20 ms are not sufficiently protected. In Figure 7 we can see the load on a commonly used varistors (e.g. S20K275) in consumers C when using a triggerable spark gap at a short distance from the consumer under a load of a lightning current (25 kA 10/350 µs). The current intensity in the varistor can, by all means, increase to readings in the several kilo ampere region before the spark gap is triggered and the varistor unloaded. The thermal load here is in the region of 40 A^2s and the energy load of this varistor lies by approx. 23 J [7].

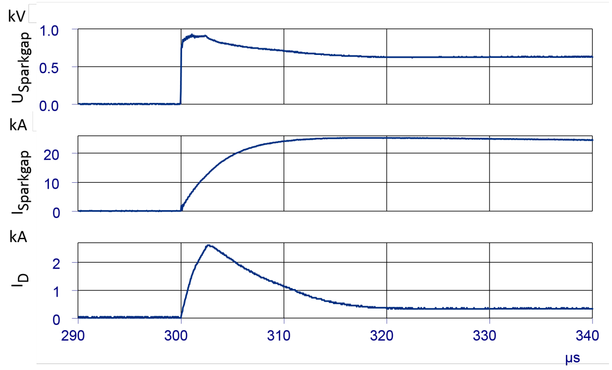

Figure 7. Behaviour of common triggerable spark gap during a lightning current of 25 kA 10/350 µs top - voltage spark gap and consumer, middle - impulse current spark gap, bottom - impulse current load / consumer in case of an varistor (S20K275) within the consumer

With the protective arrangement demonstrated, the current load, see Figure 4, is largely independent of the waveform of the impulse current (8/20 µs and 10/350 µs). The peak value is lower than 250 A, the thermal load lower than 15 mA^2s and the energy load of an SMD varistor (Cu3225K250), even with a low mA point, smaller than 60 mJ.

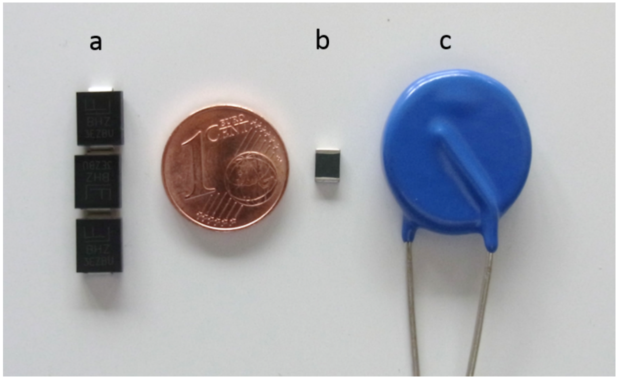

Figure 8. Picture of suitable overvoltage protective components for use as secondary protection D or within consumer C by use of the tested arrangement a - suppressor diodes; b - SMD varistor; c - normal varistor S20K275

Due to the extensive limitation of transient current, components for the secondary protection D (see Fig. 1) with lower performance and very low protection levels, for instance, suppressor diodes or SMD varistors, can be used upstream of or directly in the devices to be protected. The load amount allows the use of SMD components with a considerably lower capacity without additional protective measures, even by exposure to lightning current. Similarly, it is possible to use suppressor diodes with power losses of only 1.5 kW depending on the voltage level. Figure 8 shows some of these components to help us visualise the size and the applications of the protective devices.

6. Conclusions

The protective arrangement presented consisting of a lightning arrester and an electronic switch guarantees complete surge protection for sensitive devices and equipment in case of transient and line frequency disturbances. In addition to surge protection, the intensity and duration of the load on the consumer as a result of transient current can be considerably reduced. The possibility of controlling the switch and the spark gap externally means that the protective device can also be actuated directly by consumers with internal monitoring. The load on the electronic switch when tripping is supported by the almost instantaneous triggering of the spark gap, the low arc voltage of the spark gap after triggering, and the delayed and limited voltage build-up in the spark gap when quenching follow current. The arrangement can be used in AC and, with simplified electronic switches, also in DC power supplies.

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