A circuit simplification for AC power supply surge protection devices

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1. Introduction
The increasing use of integrated circuits in modern electronic systems has resulted in a growing awareness about lightning overvoltage hazard. The integrated circuits, especially large-scale integrated circuits, are vulnerable to lightning overvoltage transients, since they have very low insulation strength [1].

The overvoltage transients can cause either permanent damage, or temporary malfunctions in microelectronic components and systems. Owing to the fact that lightning surges frequently invade the electronic systems through AC power supplies [2]-[3], it is necessary to install the surge protective devices (SPDs) on the supply lines to protect the electronic equipment against lightning overvoltages.

As far as the design of SPDs is concerned, the need exists for simplifying its circuit structure in fulfilment of the prerequisite condition of protective reliability. The circuit simplification for SPDs is of benefit to lower the cost of manufacture and reduce the size of chassis. Considering that the traditional SPD that has been extensively used on single-phase AC power supply lines requires to be assembled by more protective components, a simplified circuit is proposed in this paper for an improvement on SPD design.

Based on the simplified circuit, a significant reduction can be made in the number of the protective components. For examination of the validity of the circuit simplification, an impulse experimental arrangement is built to measure the residual voltage responses of the traditional and simplified circuit. The measured results demonstrates that the simplified circuit can be fit for the design standard [4]-[6] and have a better applicability in lightning overvoltage protection of AC power supplies of electronic systems.

2. Traditional and simplified SPD circuits
The SPD under consideration is installed on the single-phase AC power supply lines to protect the electronic system against lightning overvoltage, as shown in Figure 1. According to IEC standards [5]-[6], it should include both protective modes, namely common and differential protective modes.
A traditional SPD circuit with the both protective modes is shown in Figure 2. Metal oxide varistors M1~M6 and gas discharge tubes G1 and G2 are used in the two stages. In the first stage, M1 provides overvoltage limiting for differential mode, while M2-G1 and M3-G1 for common mode. A similar overvoltage limiting situation holds for M4, M5-G2 and M6-G2 in the second stage. L1 and L2 are decoupling inductances which are used to coordinate the protective characteristic between the two stages.

The traditional circuit shown in Figure 2 complies with the IEC standards, and is widely used on single-phase AC supply lines to protect electronic equipment from damage by lightning overvoltages. However, an obvious drawback can be seen in Figure 2. It contains more protective components and
so results in a higher manufacturing cost and a larger chassis size.

In order to overcome this, a simplified SPD circuit is employed, as shown in Figure 3. In comparison with the traditional circuit, the simplified circuit reduces the number of metal oxide varistors from six to two. The SPD assembled from the simplified circuit is appreciably smaller in size than that of the traditional circuit, as shown in Figure 4.

![Figure 3: Simplified SPD circuit](image)

In the simplified circuit, the common-mode overvoltages appearing between L-PE and N-PE are limited by M7-G3, M8-G4, and G3, G4, respectively. The differential mode overvoltage appearing
between L-N is limited by M7 and M8.

Considering the circuit asymmetry between L-PE and N-PE, the limitation on the common-mode overvoltages may give rise to a differential-mode overvoltage between L-N. In such a situation, M7 and M8 can limit the resultant differential-mode overvoltage. G3 and G4 are directly connected between N-PE, so that the power frequency follow current can be prevented after the overvoltage transient is completed.

3. Experimental verification of protective performances

For the purpose of contrasting the protective performances of Figure 2 with that of Figure 3, experiments are made for their respective assembled SPDs. The diagram of the experimental arrangement is shown in Figure 5, where DUT denotes the assembled SPD under test.

![Figure 5: Diagram of experimental arrangement](image)

The impulse current generator, as shown in Figure 6, can generate the 8/20µs standard impulse currents. The range of its output current amplitudes is 0.3kA~40kA.
In the assembled SPDs, the varistor voltage \( V_{1mA} \) for M1, M2, M3 and M7 is taken as 621V and that for M4, M5, M6 and M8 as 511V. The nominal DC breakover voltages \( V_{DC} \) for G1 and G2 are 600V. The values of the decoupling inductances \( L_{1-L4} \) are varied from 5\( \mu \)H to 100\( \mu \)H. Such a parameter selection is suitable for protective application on the 220V AC power supply lines.

In the experiments, 8/20\( \mu \)s-20kA impulse currents are injected into the input terminals (L and N) of the assembled SPD respectively in differential and common modes. The residual voltages between the output terminals (L, N and PE) are measured by voltage divider and digital storage oscilloscope. The measured and simulated peak values of the residual voltages are given in Table 1 for the assembled SPDs corresponding to Figure 2 and Figure 3.

### Table 1: Comparison of residual voltage peak values between traditional and simplified circuits

<table>
<thead>
<tr>
<th>Decoupling inductance ( L_{1-L4} ) (( \mu )H)</th>
<th>Traditional circuit Difference mode L-N (V)</th>
<th>Simplified circuit Difference mode L-N (V)</th>
<th>Traditional circuit Common mode L-PE (V)</th>
<th>Simplified circuit Common mode L-PE (V)</th>
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Also, the residual voltage waveforms at inductance values of 10 and 80µH are shown in Figures 7-10, respectively. It can be seen from Table 1 and Figures 7-10 that the residual voltages from the simplified circuit approximate those from the traditional circuit. This verifies the validity of replacing the traditional circuit by the simplified one in lightning overvoltage protection of AC power supplies.

**Figure 7: Residual differential mode voltages at inductance 10µH**

**Figure 8: Residual common mode voltages at inductance 10µH**
4. Conclusion
A simplified circuit has been proposed for carrying out a practical improvement in the design of the SPD installed on single-phase AC power supply lines. The experimental measurement has verified that the simplified circuit has a qualified protective performance.

The pronounced advantage of the simplified circuit over the traditional circuit is the significant reduction of the number of protective components used in the SPD. Accordingly, the SPD assembled from the simplified circuit is smaller in size and cheaper in cost than that of the traditional circuit. This shows a better applicability of the simplified circuit in lightning overvoltage protection for AC power supplies of electronic systems.

References

33, 2000


[5] IEC 61643-1 Low-voltage surge protective devices – Part 1 Surge protective devices connected to low-voltage power distribution systems - Requirements and tests, 2005


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