Lightning Protection Against Dangerous Induced Voltages

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Lightning Protection Systems(LPSs), for many years, were designed to assure efficient protection against direct strokes only. This protection was meant mainly for the protection of lives and the protection of electrical systems, which consisted , in general, of electric power networks. This type of protection system is referred to as
" External Lightning Protection System" (ELPS).
For years the ELPSs were the only protection systems designed and constructed for buildings, installations, etc. During the last decade or two, with the increased use of sophisticated and advanced electrical and electronic devices and systems, severe failure problems did occur. The problems were accentuated in electronic equipment, which included sensitive elements, capable of withstanding voltages of few tens or hundreds of volts, and in many cases even less. Several of these failures occurred in cases where no direct lightning strokes were involved.
Study of these problems, done by several researchers, revealed that the failures occurred because of dangerous induced voltages. One of the main sources for the abovementioned induced voltages, is the lightning phenomenon. The marked lightning current, whether in the case of direct stroke or an indirect one, is the source for a considerable electromagnetic field. The electromagnetic field induces electric field strength components and thus voltages, in sensitive electric and electronic devices and systems. Therefore, a new approach for the protection of the abovementioned sensitive equipment was required, as the ELPSs were not a solution to these specific problems. A new type of protection was needed in addition to the ELPS. This type of protection is referred to as the "Internal Lightning Protection
System"(ILPS). It is mainly based on the study of the induced voltages. Therefore, in many cases, an effective lightning protection system should be a combination of an ELPS and an ILPS.

As it was mentioned above, the main source of the dangerous induced voltages is the electomagnetic field. Electromagnetic fields can be produced by either direct or indirect lightning strokes, EMI, NEMP, etc. More possible sources can be pointed out, such as: Switching phenomena, Electrostatic discharges, Inductive and capacitive coupling and parasitic currents, see Fig. 1.

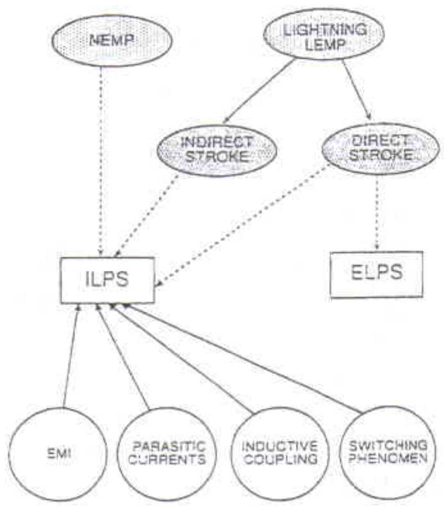

Fig. 1: Possible sources to the phenomena, for which lightning protection systems is the answer

The calculations of the induced voltages are based on the electromagnetic field concepts and Maxwell equations. The induced voltage (or current) waves can be characterized by the following parameters:

a) the maximum value of the voltage (or current) wave,

b) the rise time of the voltage (or current) wave,

c) the half time or the decay time of the wave from its maximum value to half of
that value,
d) the amount of electrical energy involved in the phenomenon.

The induced voltages can penetrate the system in one or two ways, namely:
a) by induction due to incoming electromagnetic waves,
b) by penetration via metal conductors or pipes. see Fig. 2.

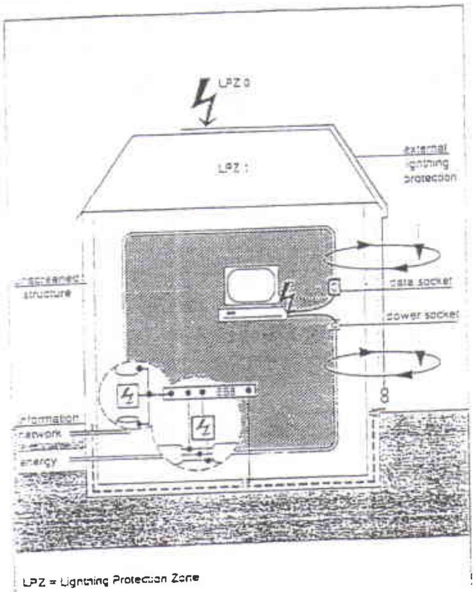

Fig. 2: Schematic induced voltages by induction and penetration

Possible penetration channels to buildings, installations, etc., are:
a)electric power feeders,
b) communication lines,
c) data lines,
d) I/O lines,
e) control lines,
f) telephone lines,
g) metal pipes and systems.

When dangerous induced voltages are discussed ,it means potential differences between two points. These two points may be "floating" above the ground, or one of them may be at the ground potential. The Internal Lightning Protection System (ILPS) must, in principle, clamp down or "cut" down the incoming dangerous voltages to voltage levels determined by the system withstand capability. The protection system should fulfill two predetermined conditions, namely:
a) at normal operation conditions of the protected system, the protection system should not influence, in any way, the operation of the protected system,
b) when dangerous induced voltages do appear, the protection system should limit them to such levels, so that both the protected system and the protecting one should not be damaged.

The ILPS is, in principle, a combination of some devices and elements. In some specific cases, one device may be the answer to the problem at hand. As it can be understood, dealing with dangerous incoming induced voltage waves, means dealing with clamping high voltages and high levels of the energy involved. This means that , in most cases, one device or element would not be enough. A combination of elements is, then, required.
Before describing the various devices, the typical characteristics of a device, required for the right choice of protection, should be discussed. These characteristics are:
a) the rated voltage- this term refers to the rated voltage of the protected system,
b) the maximum voltage- this voltage is the maximum permissible operation voltage, for which no damage to the protected circuit will occur. It is 5 to 10 percents above the rated voltage,
c) the rated current- this is the current flowing in the protected circuit at normal operation conditions,
d) the clamping or residual voltage- this voltage is the maximum voltage at the output terminals of the protecting device, when an induced voltage wave appears at its input terminals,
e) the rated discharge current- this current is the maximum current, which flows in the protecting device during its operation without causing any damage,
f) the response or reaction time- this response time (or ignition time) is the time required for a protecting device to change from normal operation conditions to induced voltage condition,
g) the normal operation current- this current denotes the load, which the protecting device forms on the protected circuit, to which it is connected, under normal operation conditions,
h) the frequency response- this response denotes the signal attenuation through the protecting device under normal operation conditions,

I) the energy absorption capability- this term describes the capacity of the protecting device to absorb energy, during the induced voltage phenomena, with no damage to the device itself.

After defining the requested characteristics of the elements, which by certain combinations , form the ILPS devices, the main groups of the elements are described.
These elements are divided into four main groups:
.1) spark air gaps and gas filled gaps- the gas filled gaps, which are very common in use, are gas discharge elements, where the gaps are in a gas medium, usually Argon.
These elements have a relative high discharge current, a relative high ignition voltage,
a reaction time in the hundreds nsec range and a relative high energy absorption capacity,
.2) varistors- the varistor is a bipolar element with a non-linear resistance, made usually of Zinc-Oxide. The Metal-Oxide varistor (MOV) has a very high resistance at normal operation conditions, and it decreases markedly under induced dangerous high voltages. The varistor has a medium discharge capacity, its ignition voltage is relatively low, the reaction time is some tens of nsec and its energy absorption capability is high,
.3) Zener diodes and surge suppressing diodes- these diodes are, in principle, fast current diodes capable of withstanding a high pulse current wave. They are characterized by a low discharge capacity, relatively low ignition voltage, a short reaction time (a few tens of psec) and a low energy absorption capability,
.4) elements in the frequency domain- such elements may consist of series connected inductors and/or parallel connected capacitors. It should be pointed out that such a device cannot be used independently, unlike the abovementioned elements.

By a careful study of the elements described above with their characteristics, it can be observed that the protection against induced voltage phenomena should involve, in most cases, a combination of various elements. Moreover, the clamping of the induced high voltages, taking into account the incorporated energies, cannot usually be performed in one stage only. Thus, in practical cases, the ILPS includes a "course protection" and a "fine protection". The first one acts as the first line of defense, cutting down the induced voltages and their associated energies to certain levels. While the "fine protection" cuts the residual voltages (and energies) to such levels, which are harmless to the protected system ,see Table 1.

Protection type	Element
Course	1,2
Fine	2,3,4

Table 1: Course and fine protection

The application of the abovementioned elements in ILPSs, is done according to the protected system characteristics and the required protection. As two systems, to be protected, are not identical in their components and topological layout, every solution has to be designed accordingly. This means that every ILPS is "tailor made".
As an example, a combined protection device, including a gas filled gap, a varistor, a suppressing diode and some inductors connecting the elements, is studied ,see Fig. 3. The characteristic data of the elements are given in Table 2. The inductors, in the protection device, "time" the operation of the various elements, according to the time function of the induced voltage wave. Thus, each element will not be damaged and the protection device will operate efficiently.

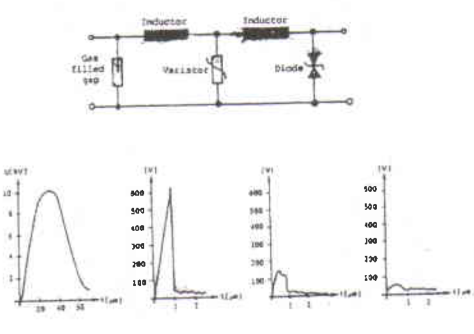

Fig. 3: A protection device, its layout and voltage characteristics

	Gas filled gap	Varistor	Diode
Discharge current	50kA	5kA	0.2kA
Reaction time	500ns	<25ns	<10ps
Clamping voltage	65-12000v	20-2000v	6-190v
Normal operation current	<15μA	<0.2mA	<5μA

Table 2: The electrical characteristics of various protection elements

As it can be observed, the fast suppressing diode, with its short reaction time, is the first to react, and not the gas filled gap and the varistor. With the voltage increase of the induced voltage wave front and the contribution of the series connected inductor, the varistor "ignites" and it cuts off the incoming voltage wave, while absorbing its energy. Finally, the gas filled gap operates and takes care of the induced voltage. This means that the diode and the varistor should be able to withstand the incoming voltage wave front, until the gas filled gap is "ignited".

As it was mentioned above, a protection device may include one or more elements. The combination of elements can be performed by series and/or parallel connections.
For example, the protection of the power network in a building or an installation, may consist of series or parallel connections of gas filled gaps and varistors, depending on the protection requirements and the topology of the system to be protected.

The goal of this paper is to present the basic ideas, strategy and methods of efficient lightning protection against dangerous induced voltages. With a better understanding and knowledge of the complicated phenomena, the various elements and devices and their characteristics, a better approach to these problems and their solutions, can be expected.