SURGE OVER-VOLTAGE PROTECTION FOR SUBSTATIONS

Mohamed Adel Abdallah

Faculty of Eng.
Beirut Arab University
BEIRUT - LEBANON

Abstract:- The protection against line surges entering an electrical substation; or a solitary step-down transformer has been limited to the installation of a conventional line voltage arrester. In theory, that is a practical solution that justifies the practice. However, in practice there are several factors that are overlooked because of the lack of understanding of the factors that influence the arrester effectiveness.
This paper discusses the need for arrestor performance improvement through circuit configuration improvement. It introduces the application of series-hybrid technology to the protection of the substation and illustrates this technologies advantage. Their use has proved that the protected circuits are more reliable and free of surge and transient related losses. When applied to an electrical substation they reduce the transient voltages allowed to reach the transformer bushing and other substation components to pre-selected safe levels. The end result is two factors that improved substation reliability and life expectancy.
The series-hybrid design provides for a Surge Interceptor (SI) between the primary station class arrester and a secondary arrester installed at the transformer bushing. This configuration can limit the voltage to levels to lows of 1.5 times the expected peak line voltage. The Surge Interceptor is a series inductor with negligible input to output capacitance and a parallel resistor to damp out potential ringing. They can be used at any voltage; however the operating current flow through it will influence cost proportionately.

Key-Words: - Basic insulation level(BIL), Surge interceptor(SI), Arrester, EMTDC software, Fast rising high current , direct strikes.

1-INTRODUCTION

A key element in the design of electrical substations is the surge protection sub-system concept. The effectiveness of this subsystem will determine the basic insulation level (BIL) requirements for the transformer and related components' life expectancy. Since the transformers are the major cost factor in the substation, and its BIL requirement is the major cost factor in transformer design, reducing the substation BIL requirements can have a major impact on cost, risk, and ultimately the substation's reliability. The primary driving function for the BIL requirements are related to the risk of incoming very high surges or switching transients entering via the transmission lines. A close-in lightning strike (within a kilometer) is considered the limiting case. The high frequency components created by the fast rising surges require fast-reacting protectors. Switching transients and distant strikes are a lesser concern because they rise to peak current slower and are usually of a lesser magnitude. To eliminate the risk created by fast-rising high-current surges within the substation, two protection system characteristics are required:
1. The prevention of direct strikes to any operational component within the substation.
2. The prevention of fast-rising high-current surges from entering the substation via the incoming or outgoing lines. This paper deals with that risk.

2-IMPEDING THE SURGE

Usually some form of station class surge arrestors are provided as substation protection from lightning strikes entering via the transmission lines. These devices limit surge peak voltages and resulting over voltage by simultaneously forming a low-impedance path to ground. However, the performance of a conventional surge arrestor alone, in this function, depends upon many factors, some of which cannot be controlled. When a lightning

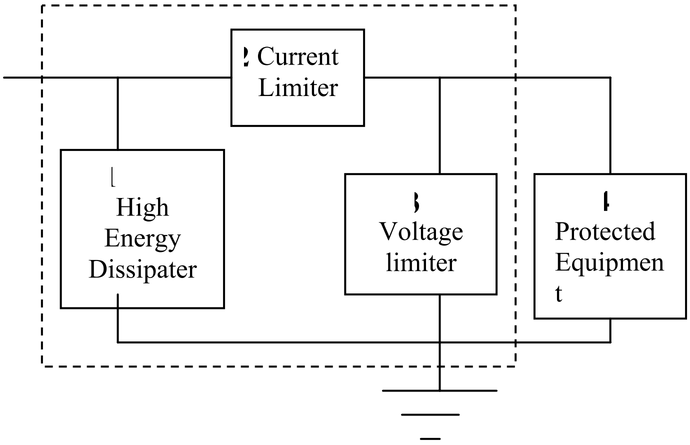


Fig1. Typical Surge Hybrid Circuit

arrestor is installed at some distance from the apparatus to be protected (transformer, circuit breaker, etc.) there is always the potential for some over voltage across the transformer due to the interconnecting lead lengths. As a result, where conventional arrestors fail to operate or operate too slowly; the surge wave is reflected from the transformer causing the voltage to rise and almost double in amplitude. This endangers the transformer insulation and results in requiring a high BIL.

Regardless of the arrestor reaction time, its use in a parallel circuit with the connecting wire impedance prevents instant reaction because of the connecting circuit wire inductance. The conventional construction of substations is not governed by an objective that maximizes the effectiveness of these arrestors. Other factors take precedent. As a result, long wires are used to connect the arrestor to the phase conductor and, most often, that connection is at 90 degrees with the phase conductor. A lightning wave travels very fast and is impeded by those 90-degree turns.

The series hybrid-based form of protection is illustrated by **Figure 1**. They are composed of three elements.

1- **The High Energy Dissipaters (HED)** function is to dissipate most of the surge energy within the arrester and the grounding system impedance, a function similar to the conventional station class arrestor.

2- **The Current Limiter** is a Surge Interceptor (SI) developed to slow down the incoming surge long enough to allow the HED (surge arrester) to conduct and limit the peak voltage to a safe level without any overshoot.

3- **The voltage controller** is the secondary parallel arrestor selected to limit the peak voltage at some level well below the protected system BIL. As a result, the surge rise time has been reduced by factors of up to 100 to 1 because of the Surge Interceptor's function. The residual surge energy is insignificant and can be dissipated by a small arrestor. This function can be provided by a distribution class arrestor.

There are literally thousands of the surge eliminator systems (SE) in use on line voltages from 120 V rms to 4160 V rms. No SE protected systems have ever suffered damage, provided that the customer installed them correctly. They carry up to a life time warranty against damage to the customer's equipment. Extending this SE concept to the primary voltages is an obvious application. The only new component required (not already in use) is the series element, the "Surge Interceptor" (SI).

The SI must present high impedance to the incoming surge, but virtually none to the operating voltage. Further, it must not allow the higher frequency transients to pass through or bypass the SI. This requires an input to output capacitance of less than 50 pico farads. There are several forms of SI packages for substation applications (both large and small). These SI's provide the performance required to impede the passage of these lightning-related transients. The concept has been proven and patented. The size is related to the operating current it must pass.

3-PERFORMANCE ANALYSIS

To illustrate the concept and the resulting system performance, a review of a simple test performed on these units is most effective. **Figure 2** illustrates the equivalent test circuit. The SI presents between 60 and 100 micro heneries inductance with less than 50 pico farads capacitance, input to output. The tests are carried by using software EMTDC. One SI configuration is illustrated as **Figure 3**. For this example test, the substation input circuit is assumed to be equal to about 2 ohms of resistance and 20 micro heneries of inductance; the inductance between the SI and the transformer bushing is assumed to be 2 micro heneries. The transformer parameters used are as indicated and are considered typical for a medium-sized substation transformer.

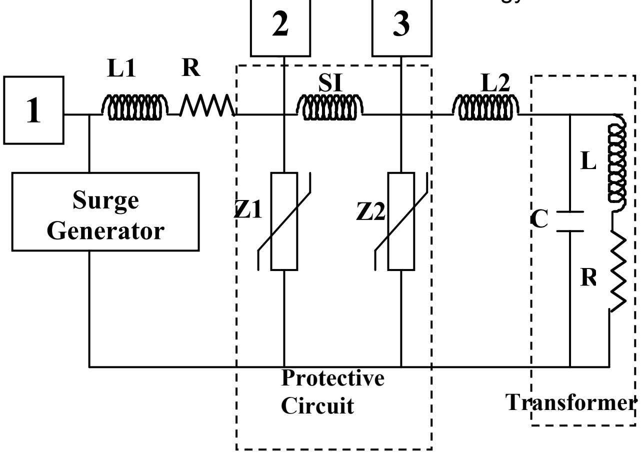


Fig. 2 Equivalent test circuit for substation protection

Where : L1= 20 μH
L2= 2 μH
R1= 2 Ω
SI= 60 μH
Z1 Station class Arrester
Z2 Distribution class Arrester
Transformer Parameters
C= 1000 pF
L= 0.15 mH
R= 4 Ω
Selection based on operating voltage

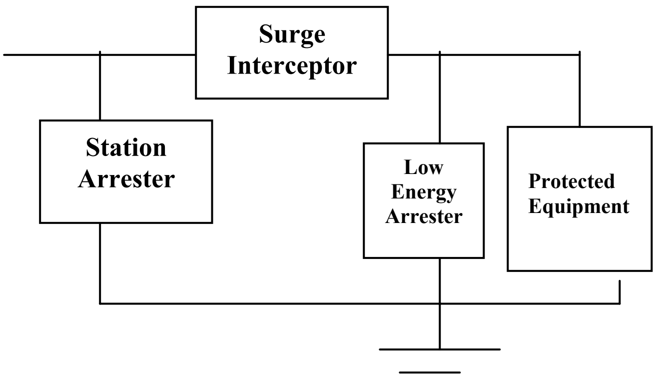


Fig. 3 Surge Interceptor configuration with possible placement

To this circuit is applied a test waveform this circuit is applied a test waveform approximately applied to position "1" of the equivalent input circuit, as illustrated by **Figure 4**. The resulting voltage waveforms are illustrated by **Figure 5** where the voltage at points 2 and 3 are superimposed. Note that the test surge wave reached a peak of 50 kV in one microsecond. It was reduced to 12.5 kV at the input to the SI (position 2) and down to 7.5 kV, (the let through voltage) at the output of
the SI (position 3). The difference, 5 kV was developed across the SI.
For this test, the clamping point or let-through voltage for the output was set for 7.5 kV at the transformer bushing. It could have been set higher or lower, depending on the normal line voltage and the required protection level. The ratio of SI input peak voltage to output peak voltage will remain approximately the same, regardless of the substation operating voltages. That is, the output of the SI is expected to be not more than 60 percent of that at the input of the SI, and again it is dependent on the **selected** clamping voltage.
A clamping voltage of 1.5 times the normal peak voltage is recommended. It also should be obvious that the voltage at peak surge current will be much less than with conventional protection.

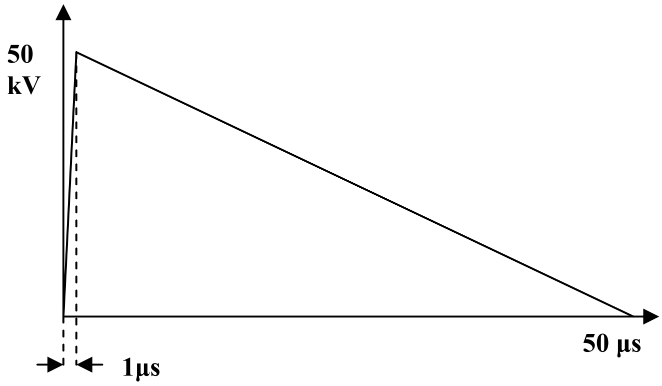
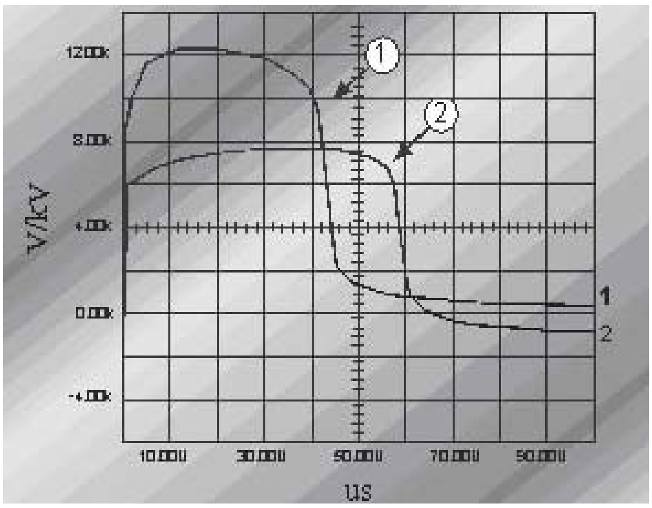


Fig. 4 Illustrates the theoretical waveform used to evaluate the SI performance



Surge voltage 500 kV, surge current 90 kA
V1=15.5 kV, V2= 8.5 kV

Fig. 5- Presents the waveforms for the input (1) and output(2) of the series hybrid circuit of Fig. 2 when subjected to the waveform illustrated as Fig. 4.

4-SERIES-HYBRID RELIABILITY FACTOR

The use of a Surge Interceptor in the subject station protection system package offers increased reliability in two forms:

1 Tighter control of the voltage applied to the substation components.

2 Through the effectiveness of component redundancy.

The influence of voltage control (limitation) has been discussed. The reliability through redundancy can best be explained through an analysis of the potential failure modes illustrated by **Figure 6** where Part A is the normal state of operation. Part B illustrates the loss of the secondary arrester and Part C illustrates the loss of the primary arrester.

To determine the result of these failed components, the same test described before must be applied to each of these circuits.

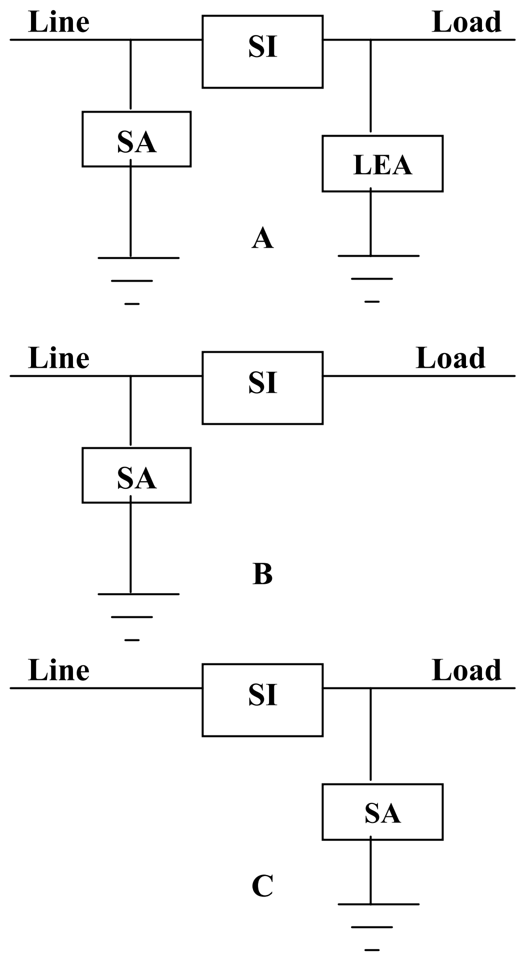
First, the test of the primary (station class) arrestor was subjected to the test wave of **Figure 4.** The resultant surge rose to 16 kV even when no series inductance was considered.

The test of configuration "B" representing the loss of the secondary arrestor, with the same waveform resulted in the current rising to a peak of 9 kV. The test of configuration C, representing the loss of the primary arrestor, the peak current rose to only 9 kV.

For further details refer to **Table 1**. From these data, it is clear, the use of SI in a series hybrid circuit will provide both better voltage control and much higher reliability.

PERFORMANCE SUMMARY TABLE 1

Protector Configuration	Surge Voltage (kV)	Surge Current (kA)	Peak Voltage V2 on Transformer
Series Hybrid (fig.6-A)	50 500 500	10.5 90 155	7.9 8.5 9.5
SI Before surge Arrester (fig.6-C)	500	155	11
SI After surge Arrester (fig.6-B)	500	155	9
Surge Arrester **only**	500	155	16



SI : Surge Interceptor
SA : Station Arrester
LEA : Low Energy Arrester

Fig. 6 A shows pie configuration; B shows junction input L configuration and C shows leg input L configuration.

5-Implementation recommendation for SI and Substation Line interface

How a device is used can determine its ultimate effectiveness as much as the characteristic of the device itself. This is particularly true of the use (implementation) of surge arrestors. It is, therefore, necessary to assure the proper installation of both the surge arrestors and the Surge Interceptor. The substation layout must take into account the influence of lightning, the related path inductance, and the traveling wave factors.

To illustrate, consider the situation where only 5 meters (about 16 feet) are used to connect the arrestor to the phase conductor. Assuming that an average lightning strike of 25,000 amperes terminates to or near the substation phase entrance it can be shown that the voltage between that phase conductor and the arrester could rise to one million volts because of that connection impedance.

The following are some arrestor installation factors to consider:

1- Lightning-related traveling waves will not make abrupt 90 degree turns.

2- Wires in parallel with the transformer primary and in series with the arrestor will permit excessively higher voltages applied to the transformer. Note that the voltage on the substation transformer is the sum of that across the arrestor, plus that across the connecting wires.

3- Conversely, the proper use of 90 degree turns can be used to improve the overall lightning protection system efficiency.

1- First, the incoming transmission lines are applied directly into the arrestor.

2- Next, the substation feed lines are taken off from the top of the arrestor, making a 90-degree turn to enter the substation, directly into the bottom of the SI.

3- The SI is set on an insulator (rated for the line voltage). The line voltage makes a second 90-degree turn to pass through the SI.

4- The line voltage is taken off the top of the SI, creating a third 90-degree turn and is directly connected to the transformer bushing, to or through any other substation component.

6-Conclusion

The use of a Surge Interceptor at all of the substation/transmission line interfaces virtually eliminates the risk of damage or outages caused by line surges and lightning-related intrusions. Further, it offers increased substation reliability by suppressing the peak voltages applied to the substation components; and in new construction, permit the safe use of lower BIL rated transformer and other components. Configuring the substation to make use of the surge waveform inertia adds an additional protection factor. The only constraint is that the station arrestor must be sized to handle all of the surge energy reaching the station.

References

[1] J. Panek, P.F. Albreacht, and H. Elahi, “Design Criteria for Lightning Protection of HV Substations”, *IEEE Trans. On Power Delivery*, Vol. 7 No. 2, p489-p.498, April (1992).

[2]R. Brocke, T. Goehlsch, "Numerical simulation of surge protective devices", *International Symposium on EMC,* Zurich (1993).

[3] IEEE Working group 3.4.11, "Modeling of Metal Oxide Surge Arresters", *IEEE Trans. On Power delivery*, Vol.7, No. 1, January (1992).

[4] S. Yanabu, H. Murase, "Estimation of fast transient overvoltage in gas insulated substation", *IEEE Trans. On Power Delivery* , Vol.5, No. 4, pp 1875-1881, (1999).

[5] S.Shirakawa, S.Kojima, " Review of surge Arrester for Power systems and Transmission", *IEE Trans.*, Vol.124, no. 8, (2004).