Sources of over voltages I

There are two main sources of transient over voltages on utility systems, *capacitor switching* and *Lightning*. These are also sources of transient over voltages as well as many of other switching phenomena within end-user facilities. Some power electronic devices generate significant transients when they switch.

Transient over voltages can be generated at high frequency (load switching and lightning), medium frequency (capacitor energizing), or low frequency.

3.1.1 Capacitor switching

Capacitor switching is one of the most common switching events on utility systems. Capacitors are used to provide reactive power (in units of vars) to correct the power factor, which reduces losses and supports the voltage on the system. They are a very economical and generally trouble-free means of accomplishing these goals. Alternative methods such as the use of rotating machines and electronic var compensators are much more costly or have high maintenance costs. Thus, the use of capacitors on power systems is quite common and will continue to be.

One drawback to the use of capacitors is that they yield oscillatory transients when switched. Some capacitors are energized all the time (a fixed bank), while others are switched according to load levels.

Various control means, including time, temperature, voltage, current, and reactive power, are used to determine when the capacitors are switched. It is common for controls to combine two or more of these functions, such as temperature with voltage override.

3.1.2 Oscillatory transient

An oscillatory transient is a sudden, non–power frequency change in the steady-state condition of voltage, current, or both, that includes both positive and negative polarity values. An oscillatory transient consists of a voltage or current whose instantaneous value changes polarity rapidly. It is described by its spectral content (predominate frequency), duration, and magnitude.

The spectral content subclasses defined in Table 3.1 are high, medium, and low frequency. The frequency ranges for these classifications are chosen to coincide with common types of power system oscillatory transient phenomena.

Oscillatory transients with a primary frequency component greater than 500 kHz and a typical duration measured in microseconds (or several cycles of the principal frequency) are considered *high-frequency transients*. These transients are often the result of a local system response to an impulsive transient.

A transient with a primary frequency component between 5 and 500 kHz with duration measured in the tens of microseconds (or several cycles of the principal frequency) is termed a *medium-frequency transient.*

A transient with a primary frequency component less than 5 kHz, and a duration from 0.3 to 50 ms, is considered a *low-frequency transient.* This category of phenomena is frequently encountered on utility subtransmission and distribution systems and is caused by many types of events. The most frequent is capacitor bank energization, which typically results in an oscillatory voltage transient with a primary frequency between 300 and 900 Hz.

Back-to-back capacitor energization results in oscillatory transient currents in the tens of kilohertz as illustrated in Fig. 3.1. Cable switching results in oscillatory voltage transients in the same frequency range. Medium-frequency transients can also be the result of a system response to an impulsive transient.

Categories		Typical Spectral Content	Typical duration	Typical Voltage magnitude
Impulsive Transient				
1.	Nanosecond	5 ns rise	< 50 ns	
2.	Microsecond	1 s rise	50 ns -1 ms	
3.	Milli second	0.1 ms rise	> 1 ms	
Oscillatory Transient				
1.	Low Frequency	< 5 KHz	0.3 - 50 ms	0 - 4 pu
2.	Medium Frequency	5 - 500 KHz	20s	0 - 8 pu
3.	High Frequency	0.5-5 MHz	5s	0 - 4 pu

Table 3.1 Categories and Characteristics of Power System Electromagnetic Phenomena - Transients

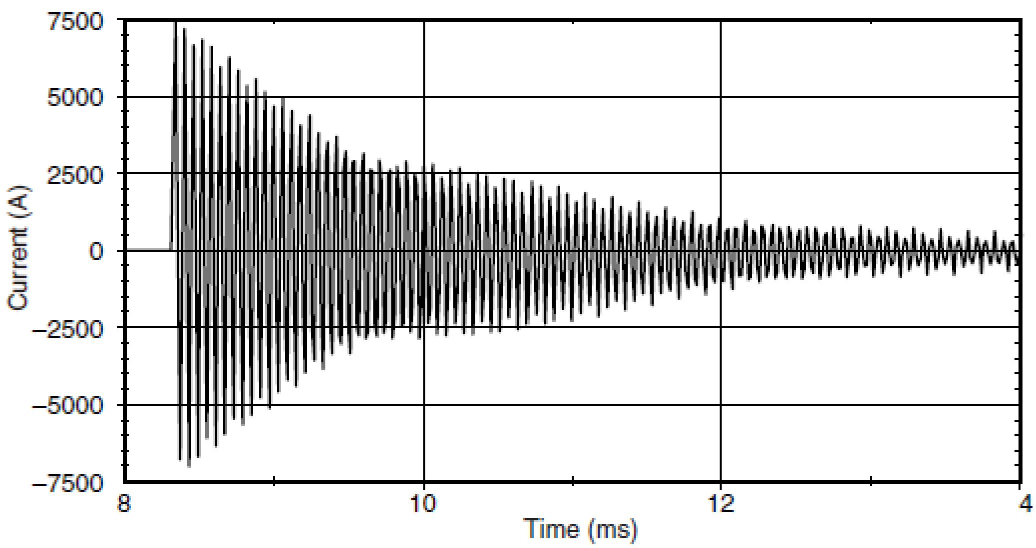


Figure 3.1 Oscillatory transient current caused by back-to-back capacitor switching

Figure 3.2 shows the one-line diagram of a typical utility feeder capacitor-switching situation. When the switch is closed, a transient (Fig. 3.3) may be observed upline from the capacitor at the monitor location. In this particular case, the capacitor switch contacts close at a point near the system voltage peak. This is a common occurrence for many types of switches because the insulation across the switch contacts tends to break down when the voltage across the switch is at a maximum value. The voltage across the capacitor at this instant is zero. Since the capacitor voltage cannot change instantaneously, the system voltage at the capacitor location is briefly pulled down to zero and rises as the capacitor begins to charge toward the system voltage.

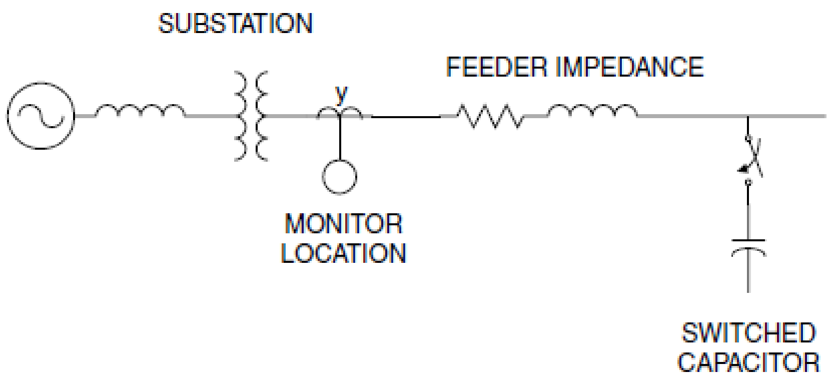


Figure.3.2 capacitor Switching

Because the power system source is inductive, the capacitor voltage overshoots and rings at the natural frequency of the system. At the monitoring location shown, the initial change in voltage will not go completely to zero because of the impedance between the observation point and the switched capacitor. However, the initial drop and subsequent ringing transient that is indicative of a capacitor-switching event will be observable to some degree.

3.1.3 Lightning

Lightning is a powerful source of impulsive transients. We will concentrate on how lightning causes transient overvoltages to appear on power systems.

Figure 3.3 shows some of the places where lightning can strike that results in lightning currents being conducted from the power system into loads. The most obvious conduction path occurs during a direct strike to a phase wire, either on the primary or the secondary side of the transformer. This can generate very high overvoltages, but some analysts question whether this is the most common way that lightning surges enter load facilities and cause damage. Very similar transient overvoltages can be generated by lightning currents flowing along ground conductor paths. Note that there can be numerous paths for lightning currents to enter the grounding system. Common ones, indicated by the dotted lines in Fig. 4.6, include the primary ground, the secondary ground, and the structure of the load facilities. Note also that strikes to the primary phase are conducted to the ground circuits through the arresters on the service transformer. Thus, many more lightning impulses may be observed at loads than one might think.

It is to be noted that grounds are never perfect conductors, especially for impulses. While most of the surge current may eventually be dissipated into the ground connection closest to the strike, there will be substantial surge currents flowing in other connected ground conductors in the first few microseconds of the strike.

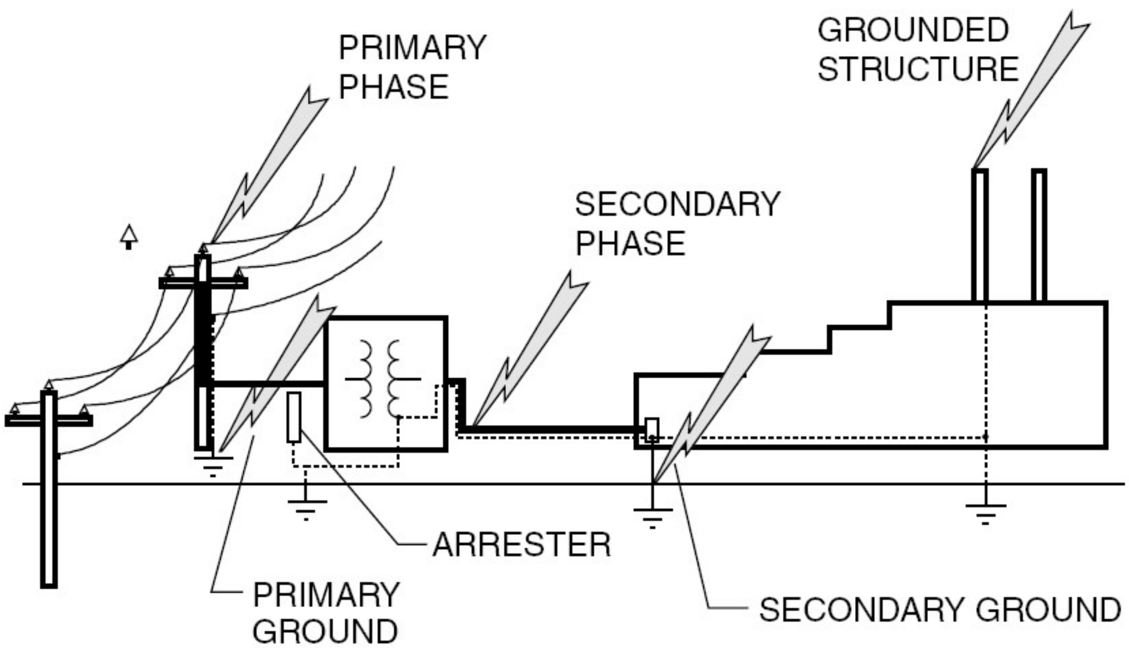


Figure 3.3 Lightning strike locations where lightning impulses will be conducted into load facilities

A direct strike to a phase conductor generally causes line flashover near the strike point. Not only does this generate an impulsive transient, but it causes a fault with the accompanying voltage sags and interruptions. The lightning surge can be conducted a considerable distance along utility lines and cause multiple flashovers at pole and tower structures as it passes. The interception of the impulse from the phase wire is fairly straightforward if properly installed surge arresters are used. If the line flashes over at the location of the strike, the tail of the impulse is generally truncated. Depending on the effectiveness of the grounds along the surge current path, some of the current may find its way into load apparatus. Arresters near the strike may not survive because of the severe duty (most lightning strokes are actually many strokes in rapid-fire sequence).

Lightning does not have to actually strike a conductor to inject impulses into the power system. Lightning may simply strike near the line and induce an impulse by the collapse of the electric field. Lightning may also simply strike the ground near a facility causing the local ground reference to rise considerably. This may force currents along grounded conductors into a remote ground, possibly passing near sensitive load apparatus.

Many investigators in this field postulate that lightning surges enter loads from the utility system through the interwinding capacitance of the service transformer as shown in Fig. 3.4 The concept is that the lightning impulse is so fast that the inductance of the transformer windings blocks the first part of the wave from passing through by the turns ratio. However, the interwinding capacitance may offer a ready path for the high-frequency surge. This can permit the existence of a voltage on the secondary terminals that is much higher than what the turns ratio of the windings would suggest.

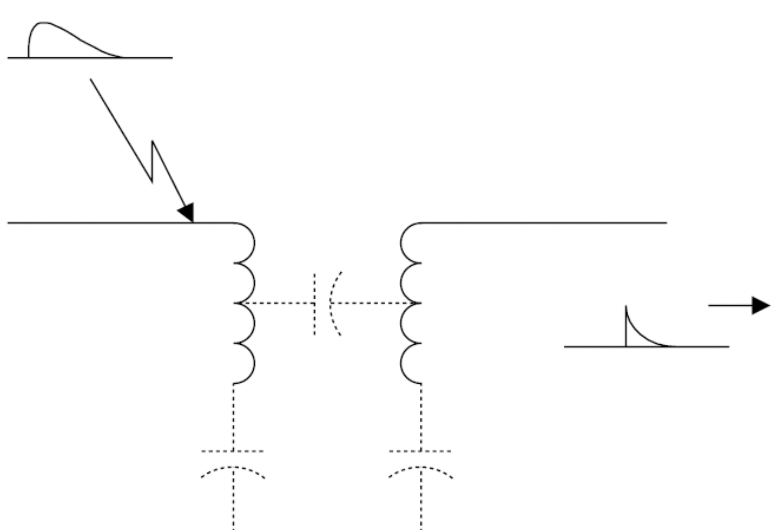


Figure 3.4 Coupling of impulses through the inter-winding capacitance of transformers

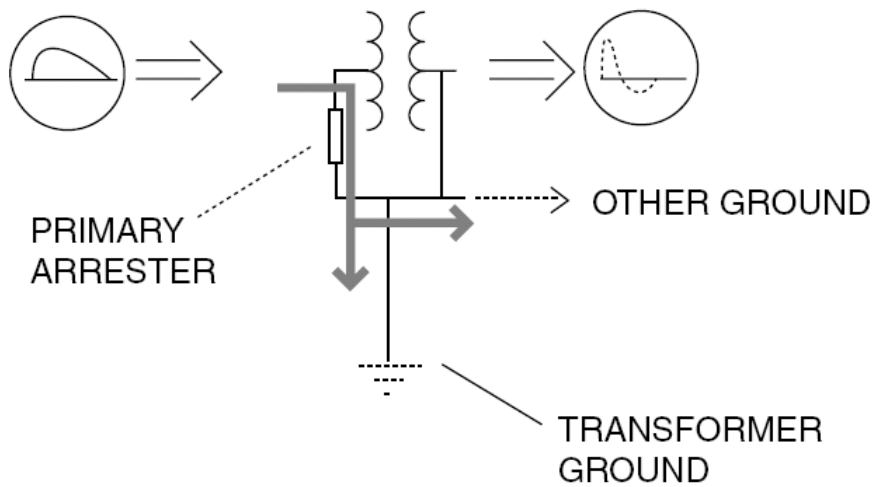
The degree to which capacitive coupling occurs is greatly dependent on the design of the transformer. Not all transformers have a straightforward high-to-low capacitance because of the way the windings are constructed. The winding-to-ground capacitance may be greater than the winding-to-winding capacitance, and more of the impulse may actually be coupled to ground than to the secondary winding. In any case, the resulting transient is a very short single impulse, or train of impulses, because the interwinding capacitance charges quickly.

Arresters on the secondary winding should have no difficulty dissipating the energy in such a surge, but the rates of rise can be high. Thus, lead length becomes very important to the success of an arrester in keeping this impulse out of load equipment.

Many times, a longer impulse, which is sometimes oscillatory, is observed on the secondary when there is a strike to a utility's primary distribution system. This is likely due not to capacitive coupling through the service transformer but to conduction around the transformer through the grounding systems as shown in Fig. 3.5. This is a particular problem if the load system offers a better ground and much of the surge current flows through conductors in the load facility on its way to ground. The chief power quality problems with lightning stroke currents entering the ground system are

- They raise the potential of the local ground above other grounds in the vicinity by several kilovolts. Sensitive electronic equipment that is connected between two ground references, such as a computer connected to the telephone system through a modem, can fail when subjected to the lightning surge voltages.
- They induce high voltages in phase conductors as they pass through cables on the way to a better ground.

The problems are related to the so-called low-side surge problem. Lightning causes more flashovers of utility lines than previously thought. Evidence is also mounting that lightning stroke current wavefronts are faster than previously thought and that multiple strikes appear to be the norm rather than the exception. Durations of some strokes may also be longer than reported by earlier researchers. These findings may help explain failures of lightning arresters that were thought to have adequate capacity to handle large lightning strokes.



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