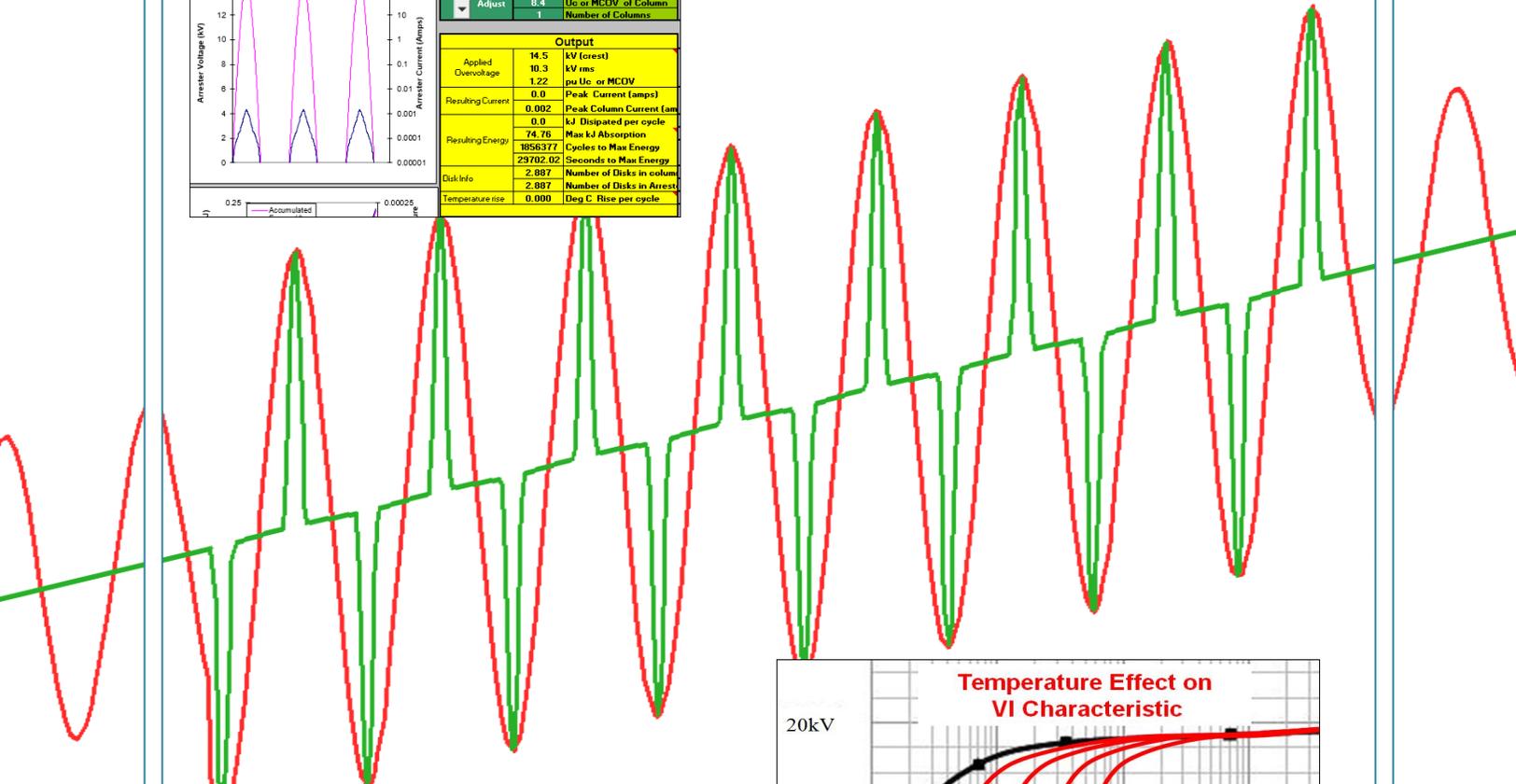
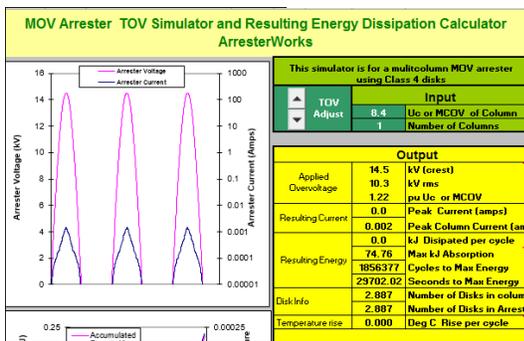




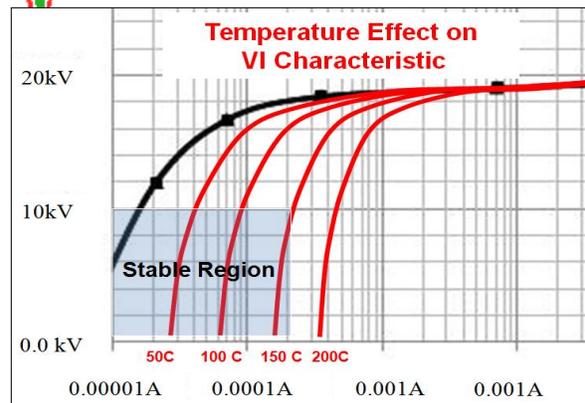
Understanding Temporary Overvoltage Behavior of Arresters

Plus New Arrester TOV Simulation Tool



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Understanding Temporary Overvoltage Behavior of Arresters Ed 2.0

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Introduction

How an arrester responds to power frequency temporary overvoltages (TOV), is seldom discussed in the literature and a phenomenon that is studied even less. This ArresterFacts is a short synopsis of the topic that should introduce the reader to some of the aspects of TOV with respect to arresters. Also, included in Edition 2 is a link to an excel based Arrester TOV simulation tool based on MOV disk characteristics.

Definitions

The IEC and IEEE definitions are the same.

Temporary Overvoltage (TOV)

An oscillatory overvoltage, associated with switching

or faults (for example, load rejection, single-phase faults) and/or nonlinearities (ferroresonance effects, harmonics), of relatively long duration, which is damped or slightly damped. In some cases, its frequency may be several times lower or higher than power frequency.

Background

With the introduction of the MOV type arrester, the notion of TOV was born relative to arresters. Prior to that, arresters did not have TOV curves and for that matter, there were no TOV considerations.

Because MOV arresters are generally energized at all times, they must withstand system voltage swings as high as 1.5 – 1.6 times their Maximum Continuous Operating Voltage (MCOV). Because gapped Silicon Carbide arresters were designed with power frequency sparkover levels about 1.5 times the line to ground voltage of the system, they were immune to these short duration system voltage swings. MOV arresters however are not immune from these swings and the notion of TOV became an important arrester characteristic with their introduction. As a young engineer in the industry in the 80's I recall vividly the many arrester failures of early designs because the TOV withstand of arresters were not set high enough. The lower than practical TOV withstand capability was resolved in a few short years by all manufacturers of arresters by fundamentally changing the designs.

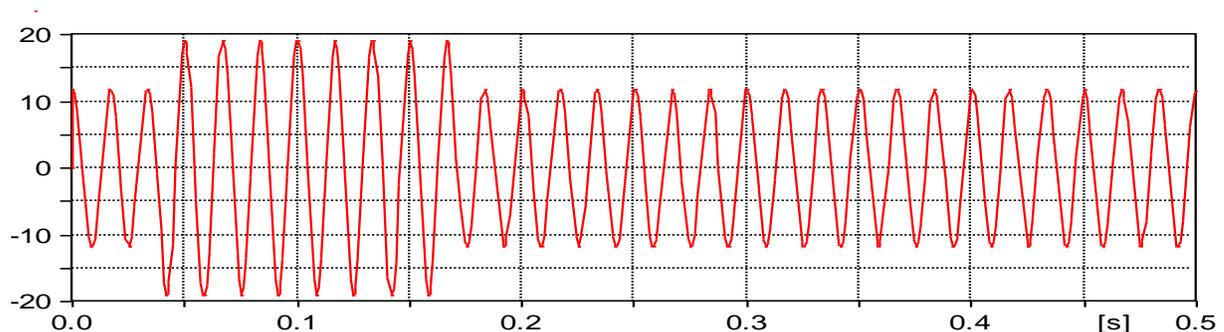


Figure 1: The TOV event - The voltage on a 13.8kV circuit with a 1.6pu overvoltage event for 8 cycles

The TOV Event

In Figure 1 the voltage changes due to a temporary overvoltage can be seen. Under steady state conditions the line to ground voltage is 8.3kV rms and 11.8kV peak. With the TOV the voltage across the arrester increases from 11.8kVp to 18.8kVp which is a 1.6pu increase. This is typical for a rise in voltage on an ineffectively grounded circuit. During the 8 cycles, the current increases to about 80amps peak through the 8.4kV MCOV arrester.

current is conducted through the arrester. Once the arrester turns on and begins to conduct, the current can approach 80 amps.

While the arrester is managing the voltage by conducting current, it is absorbing considerable energy during every cycle. This energy absorption can be seen in Fig 3. The energy is measured in joules and in this particular event, the arrester absorbs 32kJoules. The electrical energy is converted directly into heat. The resulting temperature increase is directly proportional to the energy absorbed.

Arrester Response to TOV

Figure 2 shows the current through the arrester during the TOV event. During normal operation, only leakage

Figure 4 shows a temperature rise of 333Deg C just during the TOV event, as you can see, before and after the event, the temperature remains the same.

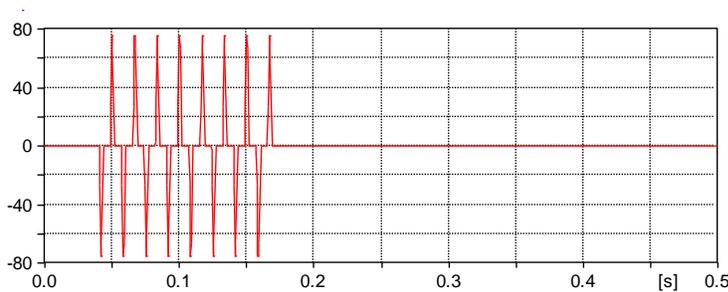


Figure 2: Arrester Current During TOV Event. Arrester current on an Ampere scale is 0 before and after the event and during the event the peak current approaches 80 amps.

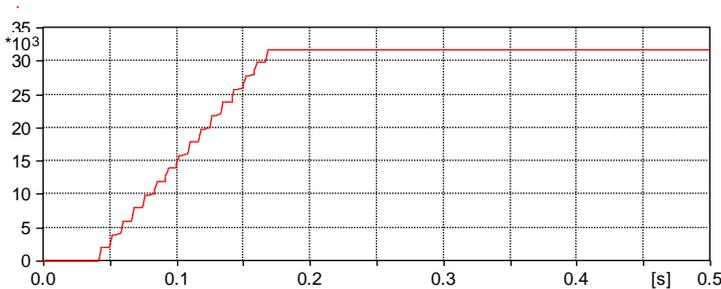


Figure 3: Energy absorption in Joules for the 8 cycles.

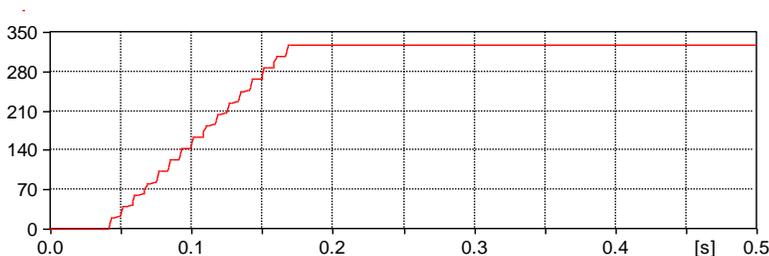


Figure 4: Temperature Rise in Degree C of the Arrester Due to the Energy Absorption

From the temperature rise, it can be determined if the arrester will be stable or not after the event has passed. Arrester manufacturers do design testing during the development process providing them with a good idea of how hot their arrester can operate and remain stable.

The energy absorption can also be compared to the thermal energy handling capability of the arrester. If the absorbed energy exceeds the thermal energy rating, it is possible that the arrester will fail from the TOV event.

Relationship of Temperature and Stability

Metal Oxide Disks, the heart of an arrester, has a positive temperature coefficient at operating voltages. In other terms, as an MOV disk increases in temperature, its leakage current also increases. Leakage current is current that flows through the disk during steady state operation. This leakage current is also converted into joules and heats the arrester during each cycle. If the leakage current and associated heat input exceeds the ability of the arrester to shed it, it increases in temperature. Fig 5 shows this effect graphically on the Arrester Voltage-Current Characteristic Curve.

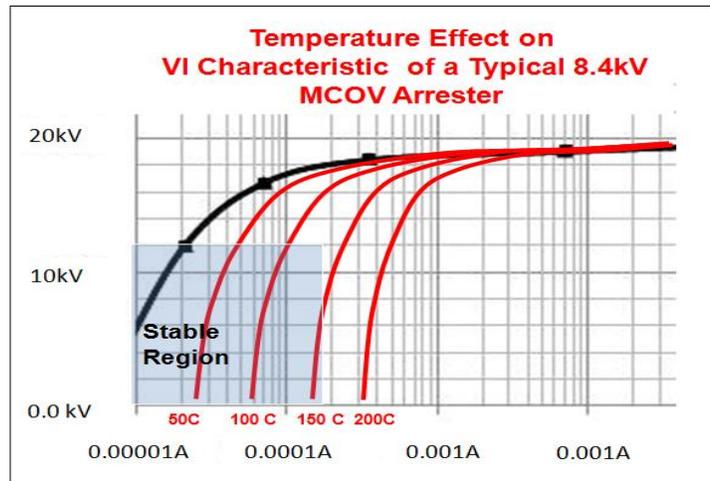


Figure 5: Temperature Effect on VI Characteristic

Arrester TOV Curve

The arrester TOV curve is a tool that allows users of arresters to determine if the arrester they have chosen for a particular application can withstand expected overvoltages. It is very important to note for standard arrester applications, the arrester is not designed to clamp or suppress the overvoltage, but instead they are designed to ride through the event without failure. To make the curves applicable to all arrester rating, the vertical axis is in terms of MCOV of the arrester. By multiplying the per unit PU overvoltage by the MCOV of the arrester, the actual rms overvoltage can be determined. This is the voltage that the arrester is capable of withstanding up to the time as reflected by the horizontal axis. This TOV capability check is an essential part of selecting an arrester.

See figures 13 (IEEE) & 14 (IEC) at the end of this document for typical TOV curves.

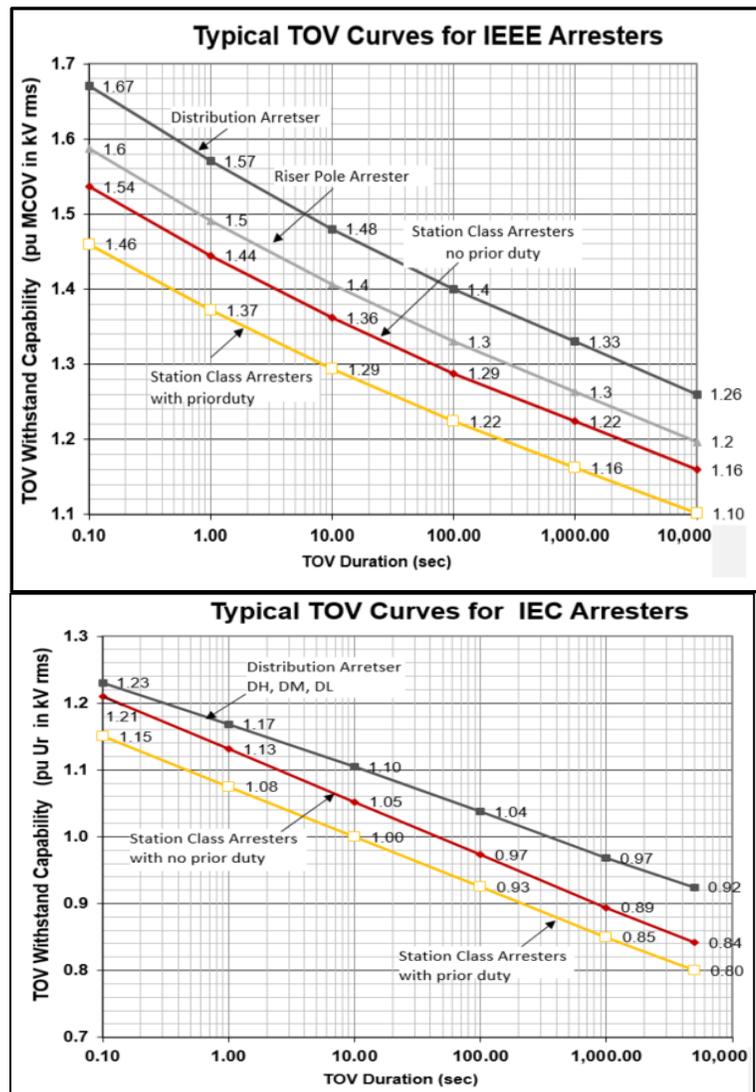


Figure 6: Typical TOV Curves

Application of TOV Curves

TOV curves are utilized for arrester selection for both distribution systems and transmission systems. The most critical application is in the substation where the maximum protection is required from arresters and at the same time TOV events are not uncommon. Once an arrester MCOV rating is selected in the selection process, the next step is to test the TOV withstand capability of the selected arrester. The first step in this process is to identify the maximum expected TOV amplitude and durations. The expected TOV characteristics can be calculated from typical system fault study programs or from hand calculations using

methods outlined in C62.22 Annex C. In either case, the amplitude of the TOV is determined by the system impedances, while the duration of the event is generally determined by settings on the breakers or reclosers. Once this data is determined, it can be compared to the arrester withstand capability by plotting it directly on the TOV curve as shown in Figure 7.

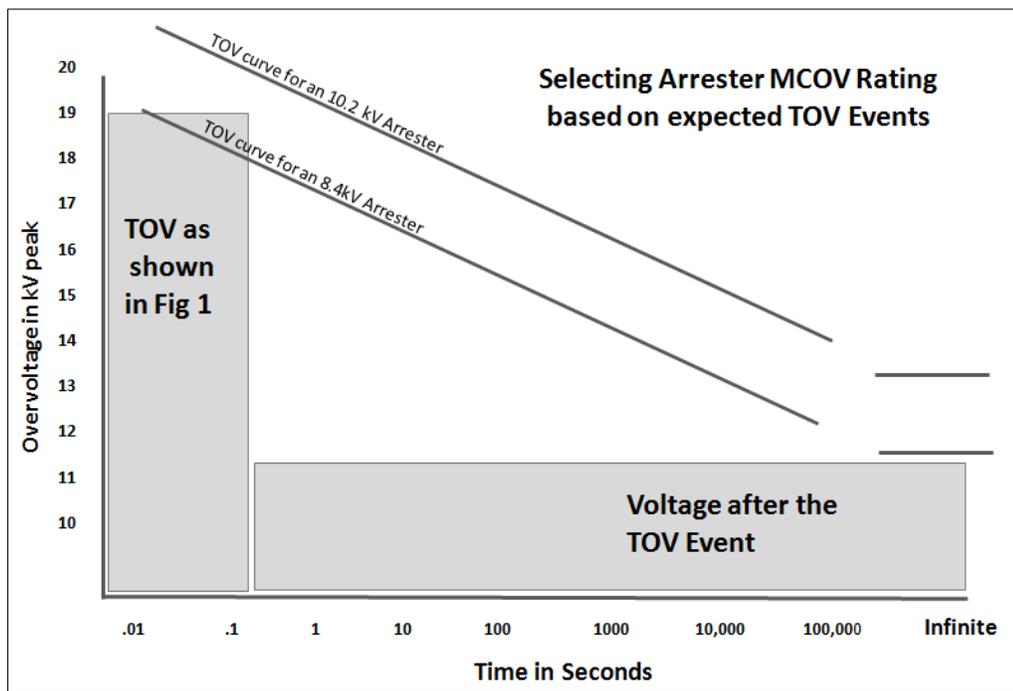


Figure 7: Using the TOV curve to test an arresters withstand capability. Note that the TOV capability of an 8.4kV MCOV arrester in this case does not suffice. However, if the arrester MCOV Rating is increased to 10.2kV, the arrester will likely survive the event.

10.2kV MCOV Arrester’s Response to the “TOV Event”

As it can be seen in Fig 7, an 8.4kV MCOV rated arrester will be stressed beyond its guaranteed TOV rating. This was also indicated by the temperature rise the arrester experienced as shown in Fig. 4. If the

arrester MCOV rating is increased to 10.2kV rms, the current through the arrester during the same amplitude TOV event will decrease to just a few milliamps as shown in Fig. 8. Fig. 9 shows that the temperature rise will only be a few milli-°C which is insignificant.

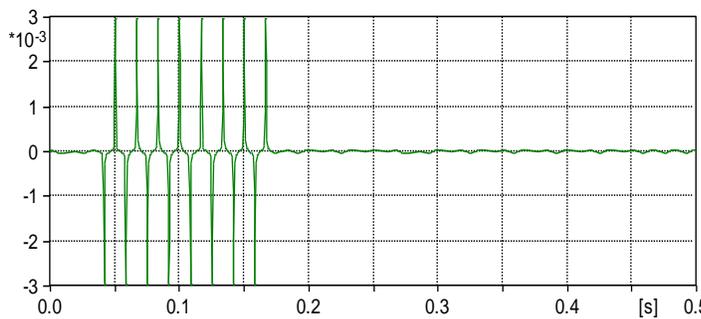


Figure 8: Response of a 10.2kV MCOV arrester to a 1.6pu TOV as shown in Fig 1. Peak current is 3 ma

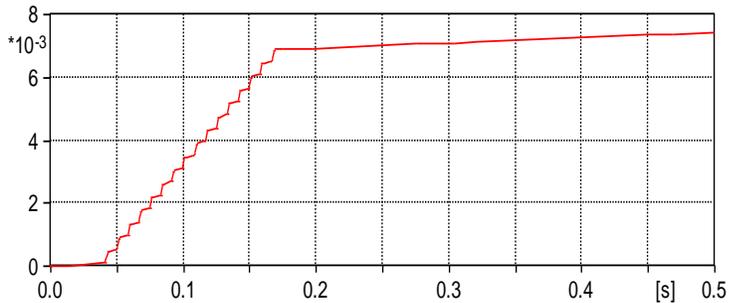


Figure 9: Temperature rise of a 10.2kV MCOV rated arrester to a 19kV peak overvoltage. Temperature rise in about 7milli-degrees C

Arrester TOV Withstand Capability and V_{ref}

The TOV withstand capability of an arrester is a function of several arrester characteristics however, the two primary characteristics are:

1. $V_{ref}/MCOV$ ratio
2. Thermal sensitivity of the MOV material

As shown in Fig 10, the peak operating voltage of an arrester is 15-30% below the reference voltage of an arrester. It is this difference in voltage that strongly affects an arrester's TOV withstand. If the difference between V_{ref} and MCOV was larger, the TOV withstand capability would be larger, given that all other characteristics were held constant. Essentially when a higher MCOV arrester is chosen for a lower operating voltage as done in the example above, the difference between V_{ref} and MCOV is increased. This is a very good way to increase TOV capability of an arrester design, however at the other end of the VI curve; the lightning clamping voltage is also increased. This increase in clamping

voltage is sometimes not an acceptable solution to increasing TOV.

The second governing characteristic of an arrester's TOV capability is one that is not easily quantified. The thermal sensitivity of any particular disk is a strong function to its formation process including the formulation of the material and the thermal treatments it receives during manufacturing. MOV disks that demonstrate a small change in leakage over a large temperature increases are better than disks that change leakage rapidly in the face of temperature changes. See Figure 5 for a graphic overview of this characteristic. Ideally there would be no change in conduction with respect to temperature, but today's technology does not allow for that precision.

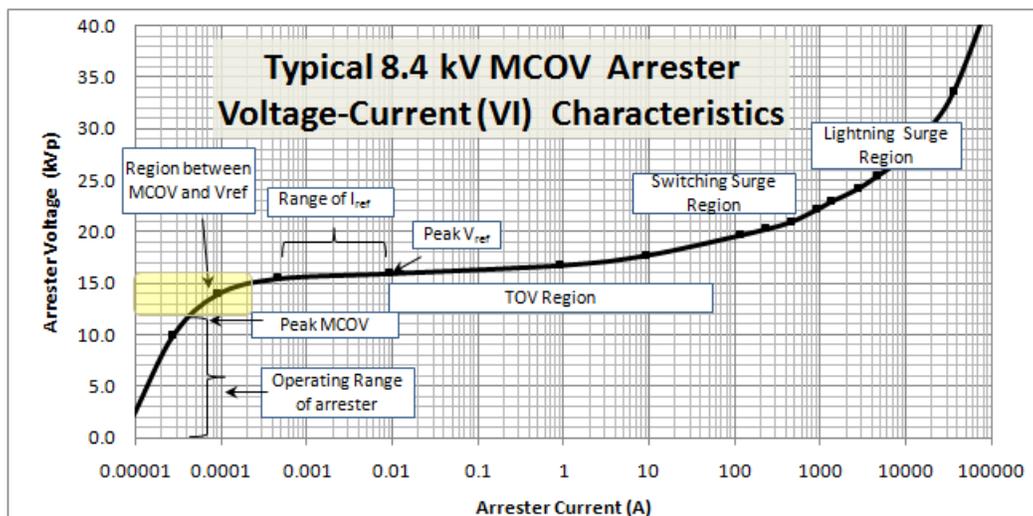


Figure 10: VI Characteristic of an 8.4kV arrester showing the TOV region and the typical operating region

Testing an Arresters TOV withstand capability

The test procedure used to generate an arrester's TOV curve (see Fig 6) is outlined in detail in IEEE Standard C62.11 and in IEC 60099-4. The circuit and test procedure is quite simple. The circuit in Figure 11 is most commonly used. With two AC sources, the arresters are energized at two voltages in the proper sequence for specific time periods. Numerous samples are tested to verify if the claimed TOV curve can be met. If the test samples survive the overvoltage event, then the point is used to create the published curve. If the arrester does not pass, then a lower curve is created to replace the target curve. It is important to note, that the supply impedance needs to be low to ensure that the arrester clamping capability does not distort the voltage and give false voltage readings. The circuit in Fig 14 is also the ATP model that was used to produce all the 8 cycle graphs in this ArresterFacts.

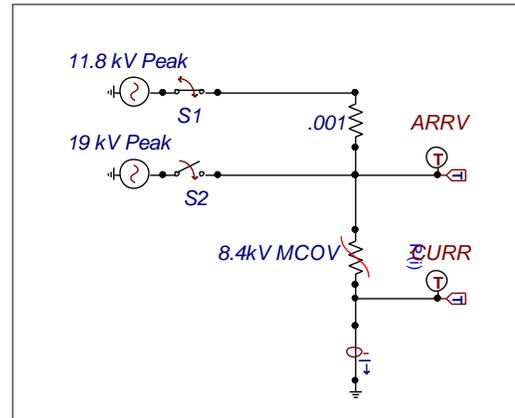


Figure 11: Simplified TOV Test Circuit

TOV Simulation Tool

An excel based TOV simulation tool is associated with this ArresterFacts. This tool is used by arrester designers to determine the approximate TOV capability of an arrester design.

Summary

The arrester TOV characteristic is very important in determining the proper arrester MCOV rating to apply to systems. Understanding all the aspects of the TOV Characteristic can be useful to anyone selecting an arrester. As usual, if this ArresterFacts does not answer the questions you have regarding this characteristic, please contact me Jonathan Woodworth at jonathan.woodworth@ArresterWorks.com and I will be glad to discuss it with you.

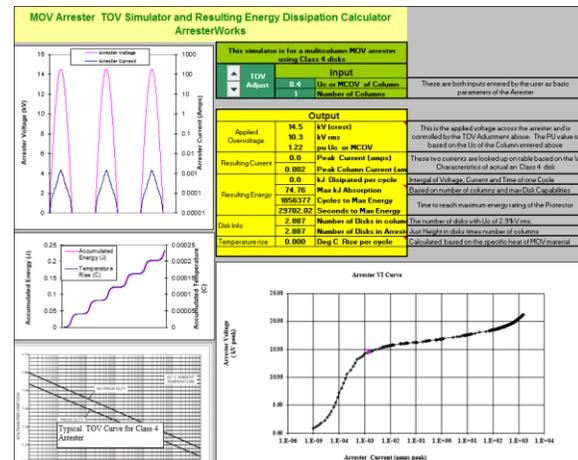


Figure 12 Arrester TOV simulation Tool

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