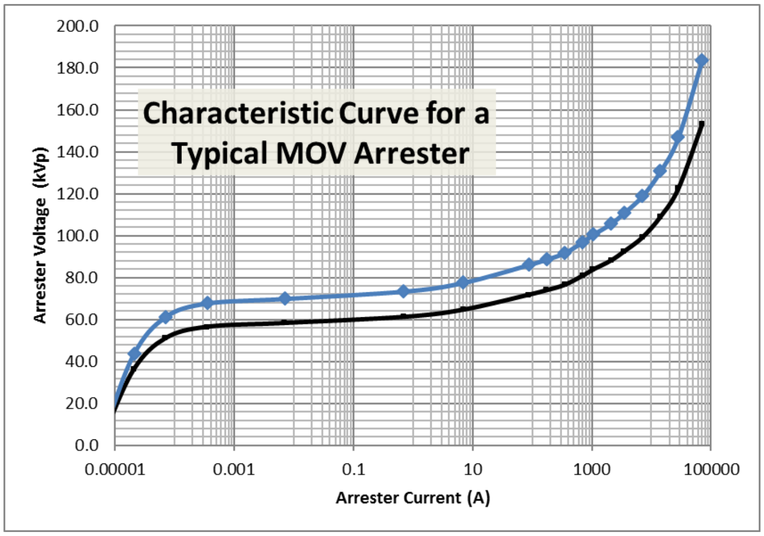
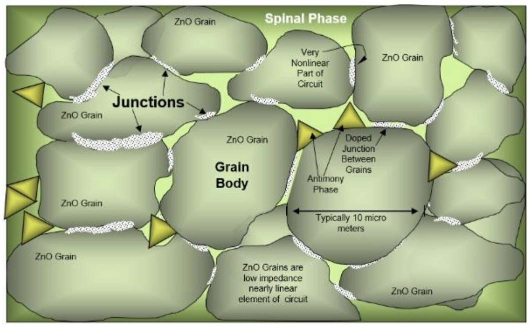
# ArresterWorks

# Understanding Arrester Voltage-Current Characteristic Curves

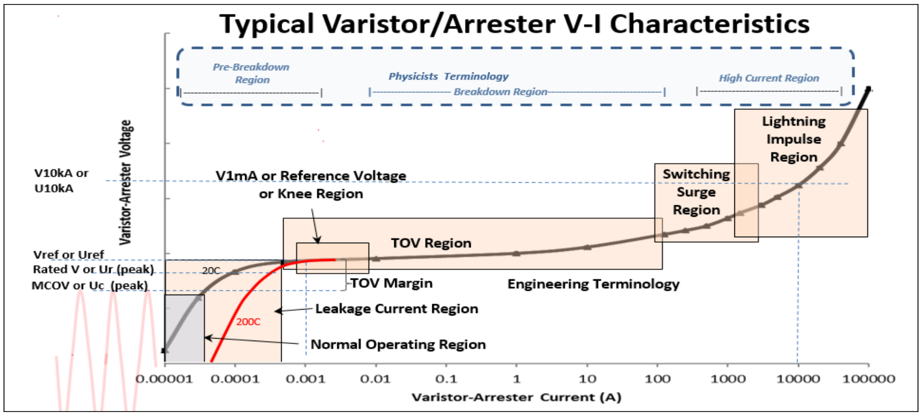
## *and Interactive Curve Generator (ArresterFacts 003.1)*




| Arrester Class | | |
|---|---|---|
| Select Arrester Type | Heavy Duty | |
| Arrester Uc or MCOV (rms) | | Tweek The Resulting Discharge Voltage in % |
| Enter Desired Uc or MCOV (rms) -----> | 30.6 | 20 |
| Current (A) | Volts Peak | Peak Volts |
| 0.000009 | 7,286 | 8,743 |
| 0.000027 | 36,429 | 43,714 |
| 0.00009 | 51,000 | 61,200 |
| 0.00045 | 56,464 | 67,757 |
| 0.009 | 58,286 | 69,943 |
| 0.9 | 61,200 | 73,440 |
| 9 | 64,661 | 77,593 |
| 112.5 | 71,764 | 86,117 |
| 225 | 73,950 | 88,740 |
| 450 | 76,500 | 91,800 |
| 900 | 80,871 | 97,046 |
| 1350 | 83,786 | 100,543 |
| 2700 | 88,157 | 105,789 |
| 4500 | 92,529 | 111,034 |
| 9000 | 99,086 | 118,903 |
| 18000 | 108,921 | 130,706 |
| 36000 | 122,400 | 146,880 |
| 90000 | 153,000 | 183,600 |

| Current (Amps) | Resulting Voltage | Voltage for Adjusted Values |
|---|---|---|
| 10,000 | 100,521 | 120,626 |
| 30,000 | 118,701 | 142,441 |

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Jonathan Woodworth

**ArresterFacts 003**

# Understanding Arrester Voltage-Current Characteristic Curves

Jonathan Woodworth ArresterWorks

Without a doubt, the Voltage-Current (V-I) Characteristic of an arrester is one of its most important parameters. With a quick look at an arrester's (or disk's) characteristic curve one can tell the rating of the arrester, the protective level of the arrester, and indirectly how well it will do during a temporary overvoltage. This ArresterFacts explains all of this in detail. Even though the general user of arresters isn't exposed to this characteristic as a graph, they do see it as a table of discharge voltages and reference voltages. But understanding the data behind the tables as seen in specification sheets, can be quite useful to any student of surge protection.

The V-I characteristic curve can also be referred to as the resistance curve of a varistor or arrester. For any given voltage or current there is a corresponding voltage or current. The varistor, also referred to as the MOV disk, receives its name from the fact that it is a variable resistor and the resistance depends strongly on the voltage applied across its terminals. The higher the voltage the lower the resistance. It is this voltage sensitive resistance characteristic that makes the varistor so well suited for surge protection.

**Pre-Breakdown**

Physicists and material scientists prefer to break the varistor characteristic curve into three regions as can be seen in the graph Figure 1. The pre-breakdown region is where the varistor is not in severe conduction. In the pre-breakdown region, there are only micro-amperes flowing through the semiconductor. The varistor and arrester design engineers refer to this region as the operating region which is a sub region of the leakage current region. This area of the V-I curve represents the vast majority of the varistors life. In this region, very little heat is generated and the varistor can operate indefinitely. In this region, the resistance or conductivity of the varistor

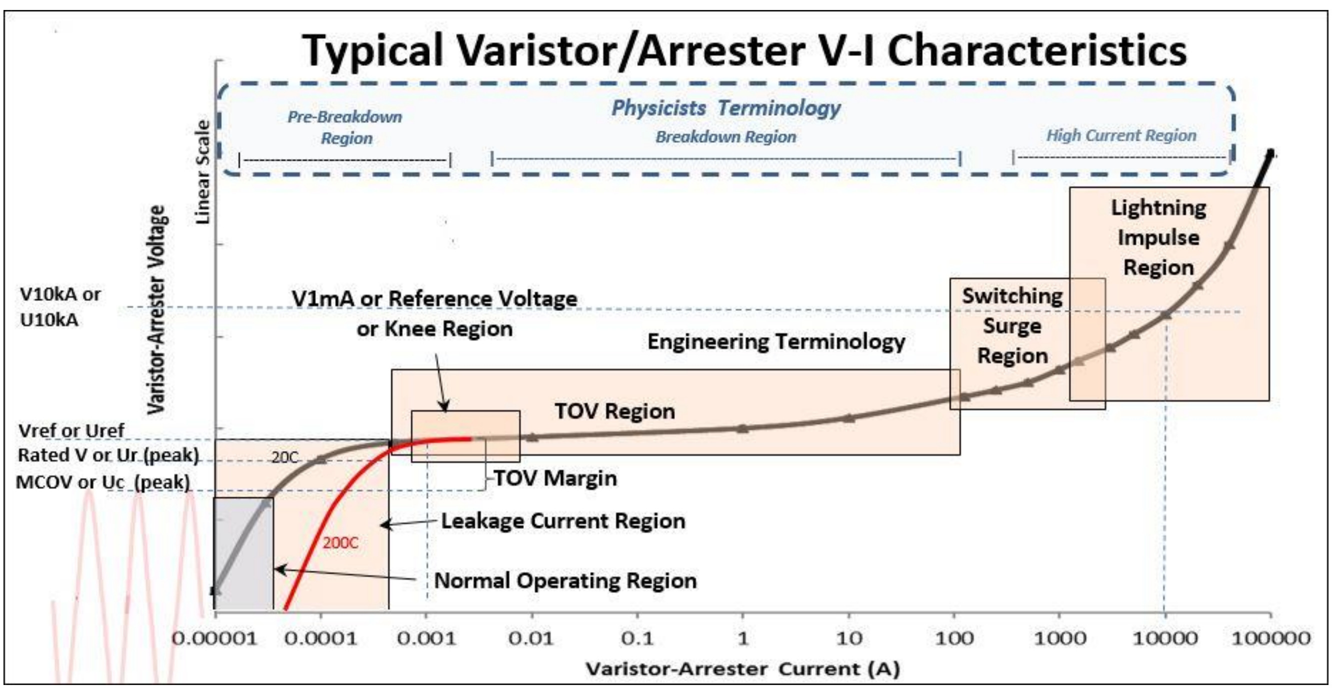


**Figure 1 Arrester and Varistor V-I Characteristic Curve**

is very temperature sensitive and if the temperature of the varistor body increases from a surge or external sources, the resistance decreases. This moves the V-I characteristic to the right in the leakage current range. The red section on the curve represents how the characteristic would look if the arrester was at 200C.
The pre-breakdown region is also the only region that is affected by a high current impulse. With some varistor formulations, a high surge impulse can result in the pre-breakdown characteristic being permanently shifted down or to the right. If the shift is significant enough it can lead to a failure of the varistor over time.

**Breakdown Region**
At the start of the breakdown region is a very important and very small region on the V-I characteristic curve referred to as the V1mA reference voltage or characteristic voltage. The reason this area is important is that at this current level, the resistance of the varistor begins to more rapidly decrease and the varistor starts to conduct. From this point forward as the voltage increases the varistors resistance is rapidly decreasing allowing more current to flow. Because this region of the V-I curve is not temperature sensitive, it is an excellent point to predict the rest of the characteristic curve.

The voltage level of the characteristic curve at V1ma is a significant indicator of the operating voltage of the device. During normal operation of the arrester, the peak AC voltage should never reach this level or the arrester would run hot and have very little TOV capability. It is generally the case that the peak value of the operating voltage is about 15-25% below the peak reference voltage as shown in Figure 1. The difference between Reference Voltage (Vref) and the peak MCOV is also an indicator of the TOV margin and capability.

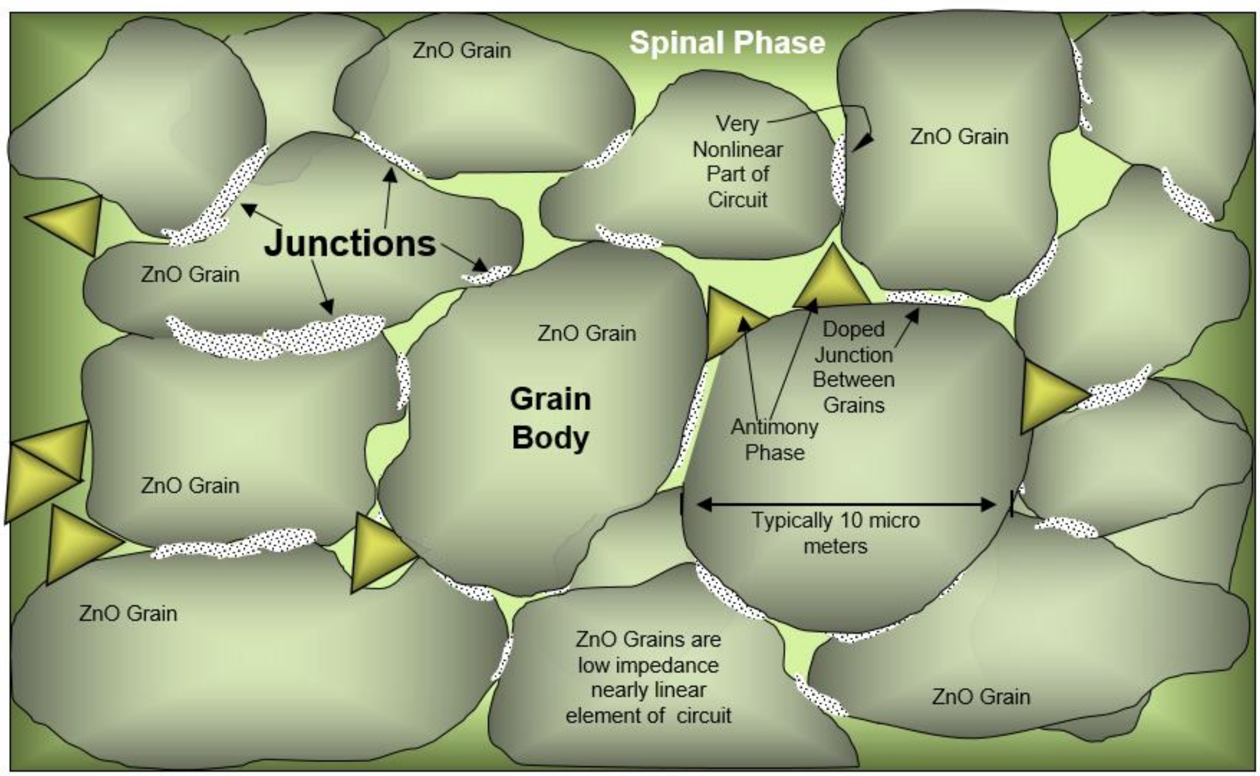


**Figure 2 Varistor Microstructure at 5000X Magnification**

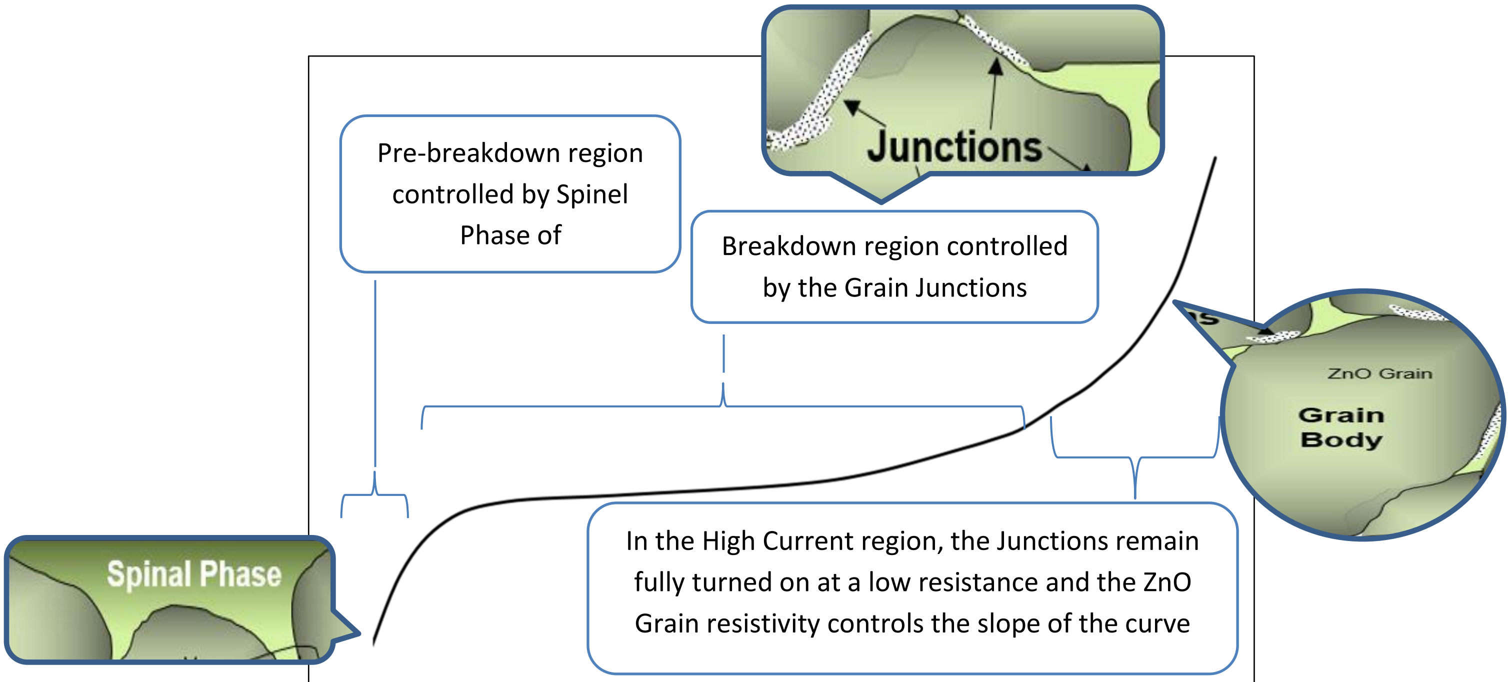


**Figure 3 Conduction Region vs Microstructure Relationship**

The rest of the breakdown region covers the current levels from the 1mA level to the ampere level. In this region, the nonlinearity of the resistance is at its highest. Turing a temporary overvoltage event, the varistor and the complete arrester can conduct currents that will rapidly raise the temperature of the device. If the varistor is forced into conduction in this region for more than a few seconds, it will likely over heat and lead to failure.

**High Current Region**

The higher current region is where the varistor is performing its surge clamping function. In this region, the varistor is conducting significant levels of current per square cm. The conductivity interval in this region is milli-seconds down to micro-seconds. The higher the current, the shorter the surge length. In this region, the Zinc Oxide Grains are controlling the resistance of the varistor. The lower end of the high current region is where switching surges occur and from this point and higher the surges are usually lightning in nature. This is the region that gives us the discharge voltage or residual voltage data we find in all the specification charts of arresters.

**Region Summary**

Each region is important in its own particular way and together they provide us with the varistor action of surge protection. Of course, there are many varistor characteristics that are important, but understanding the V-I characteristic curve is important for anyone designing or modeling an arrester.

**Correlating Varistor Microstructure and the V-I Characteristic**

**Spinel Phase**

In Figure 2, the microstructure of a typical varistor is shown. For those interested, this graphic helps show the relationship of the V-I curve and the key elements of the varistor material. In the pre-breakdown region of the V-I curve the current flow is through the spinel material as shown in Figure 3.

**Junctions**

If the voltage across the arrester/varistor increases high enough to reach the breakdown region it is the grain junctions that become the controlling part of the microstructure. The junctions are the most complex part of the varistor microstructure and are highly doped zinc oxide grain boundaries. The dopants are bismuth,

 

**Arrester VI Characteristic Tool by ArresterWorks**

| Arrester Class | | |
|---|---|---|
| Select Arrester Type | Light Duty | |
| Arrester Uc or MCOV (rms) | | Tweek The Resulting Discharge Voltage in % |
| Enter Desired Uc or MCOV (rms) -----> | 30.6 | 20 |
| Current (A) | Volts Peak | Peak Volts |
| 0.000007 | 7,286 | 8,743 |
| 0.000021 | 36,429 | 43,714 |
| 0.00007 | 51,000 | 61,200 |
| 0.00035 | 56,464 | 67,757 |
| 0.007 | 58,286 | 69,943 |
| 0.7 | 61,200 | 73,440 |
| 7 | 64,661 | 77,593 |
| 87.5 | 71,764 | 86,117 |
| 175 | 73,950 | 88,740 |
| 350 | 76,500 | 91,800 |
| 700 | 80,871 | 97,046 |
| 1050 | 83,786 | 100,543 |
| 2100 | 88,157 | 105,789 |
| 3500 | 92,529 | 111,034 |
| 7000 | 99,086 | 118,903 |
| 14000 | 108,921 | 130,706 |
| 28000 | 122,400 | 146,880 |
| 70000 | 153,000 | 183,600 |

| | Current (Amps) | Resulting Voltage | Voltage for Adjusted Values |
|---|---|---|---|
| it here.. | 10,000 | 104,031 | 124,837 |
| it here.. | 30,000 | 124,474 | 149,369 |

About button

Copy Values to Clipboard

| Amps | Volts Peak |
|---|---|
| 0.00001 | 10000 |
| 0.00003 | 50000 |
| 0.0001 | 70000 |
| 0.0005 | 77500 |
| 0.01 | 80000 |
| 1 | 84000 |
| 10 | 88750 |
| 125 | 98500 |
| 250 | 101500 |
| 500 | 105000 |
| 1000 | 111000 |
| 1500 | 115000 |
| 3000 | 121000 |
| 5000 | 127000 |
| 10000 | 136000 |
| 20000 | 149500 |
| 40000 | 168000 |
| 100000 | 210000 |

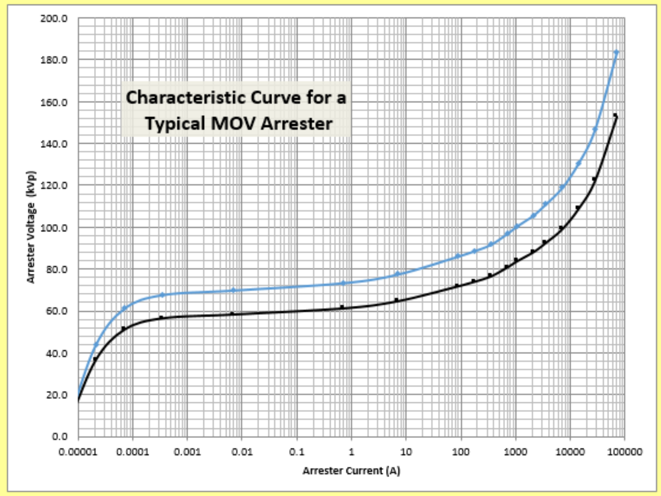


Figure 4: Interactive V-I Characteristic Curve Generator for Arresters -(ArresterFacts 003.1)

antimony cobalt, nickel, silver, tin and trace amounts of aluminum. The junctions are present throughout the semiconductor and if the material is manufactured properly the current is shared quite evenly across the varistor. These junctions are also known as the electronic switches that turn the varistor on an off. During a short-duration AC overvoltages that can occur on power systems during a fault on another phase, these junctions are turned on and can lead to significant temperature increase of the disk. As long as the temperature of the disk remains under the 300C range, there is no long-term effect on the varistor. However, if the overvoltage lasts too long, the temperature of the varistor can rise to critical levels and a thermal runaway failure can occur.

**ZnO Grains**

During a switching surge or lightning surge, the current flow is through the junctions and the bulk of the ZnO grain bodies. It is the resistivity of the grain that controls the resistance in this region. The resistance in this region is not nearly as nonlinear as it is in the breakdown region. The energy dissipated and the heat generated during a surge is due to the grain resistance.

**Interactive VI Characteristic Curve Generator**

The V-I characteristic curve from low currents to impulse currents exists in many forms but is not usually available from the arrester or disk suppliers. To that end Arresterworks created this excel based V-I characteristic curve generator that can be used by anyone studying the characteristic curve of an MOV arrester. In particular, those running transient studies can use this tool to generate the arrester characteristic curve for their transient software, however it can be used by anyone trying to better understand this varistor characteristic. (ArresterFacts 003.1)

This easy to use and understand calculator only requires that you enter the arrester type and arrester MCOV (Uc). If the curve generated does not exactly match the specifications of the suppler, it can be adjusted by changing the MCOV or the % adjust curve.

It can be downloaded from the ArresterFacts Page.

Comments on this ArresterFacts are welcome.
Feedback will always be answered.
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