

# **Lightning & Surge Protection**

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# 1. What is Lightning? How to Protect Instruments?

Computers and electronic instruments are essential for processing various kinds of information in a high speed manner. However, they are often subject to the induced energy caused by lightning, because of their generally low dielectric strength.

Lightning is a phenomenon in which negative electric charges generated in a thunderstorm discharge to the ground as a result of dielectric breakdown in the air. A lightning surge, even an indirect one, causes a surge voltage on the cable lines, and transmits a momentary high voltage impulse to the sensors/transmitters in the field, or to the inputs of computers and instruments in the control room.

## 1-1. Emergence of thundercloud

There are a variety of theories how thunderclouds emerge, but generally it is explained as below.

When atmosphere near the earth surface or ocean surface containing a large amount of water vapor warms up by the heat from the sun and other sources, it expands and ascends. When it reaches a high altitude, it is cooled down, resulting the vapor in the atmosphere becomes water droplets and then a cloud. When it ascends even higher, water droplets in the cloud becomes ice grains and some of them concentrate and grow to hailstones.

At that time, these ice grains and hailstones are decomposed by electric current. Then, ice grains are charged positively and hailstones are charged negatively. Ice grains ascend even higher by riding updraft and hailstones grow bigger and fall by the gravity. Charge separation continues by the coulomb force. Before long, top of the cloud is positively charged and the bottom negatively. A cloud accumulates electrical energy, which is when a thundercloud emerges.

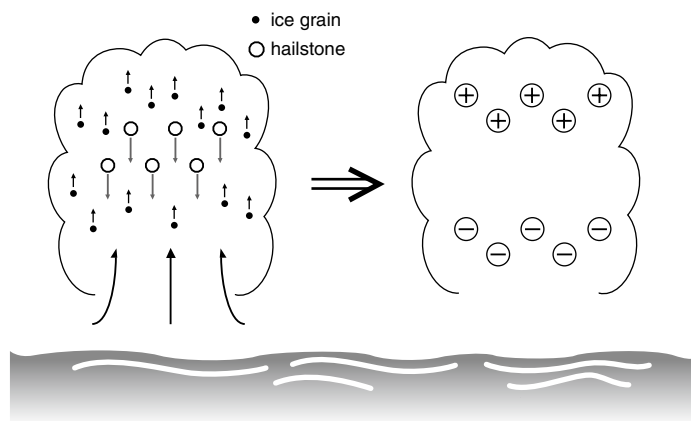


Figure 1 – 1

## 1-2. What is lightning surge?

When electric charges are built up in thunderclouds to such level that could break atmospheric insulation, an electric discharge eventually occurs between these clouds or between the clouds and the ground. Electric current reaches 20-150 kA.

An abnormally high voltage generated by direct lightning discharge applied to electric power cables or communication cables at that instance is called 'direct lightning surge'.

Correspondingly, such voltage induced by electrostatic or electromagnetic induction on those cables located close to the point where a direct lightning hits, is called 'induced lightning surge'.

Also, when lightning strikes a lightning rod and the ground potential rises, instruments' grounding potential becomes also high. This causes an abnormally great potential difference between the cables and the ground, which is called 'lightning surge caused by increased ground potential'.

Direct lightning surge energy is enormous. A surge protector alone cannot protect the instruments. It is necessary to share the job by lightning rods and overhead grounding wires to absorb most of the energy, and by surge protectors to absorb only the rest of the energy.

Here, we explain the mechanism how lightning surges occur, except for the direct lightning surge.

### 1-3. Electrostatic induction

When thunderclouds located above a power cable or communication cable contain negative charges at their bottom parts, high level positive charges are induced electrostatically within the cable and high voltage is developed by electrostatic induction from thunderclouds (Figure 2-1).

At that instance, the negative charge at the bottom of the thundercloud disappears by discharging between the clouds or between the clouds and the ground. Then, the positive charge which is trapped by the cable are freed and led to both directions on the cable as a surge voltage (Figure 2-2).

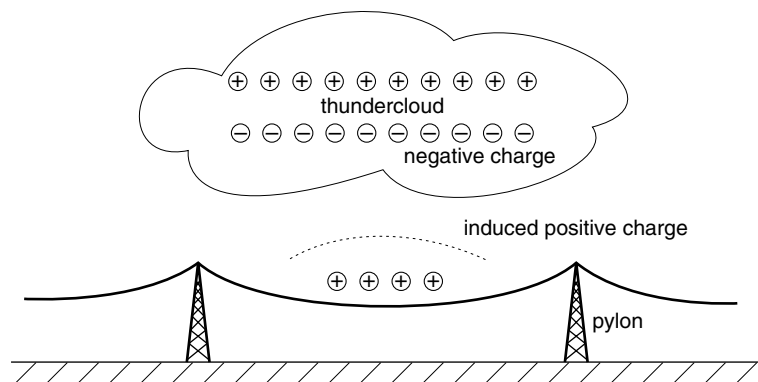


Figure 2 – 1

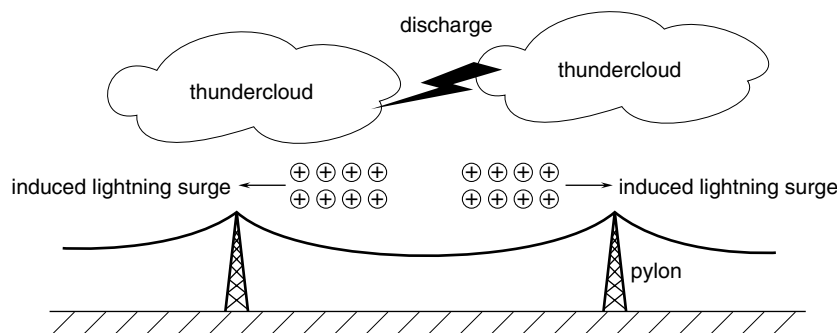


Figure 2 – 2

### 1-4. Electromagnetic induction

A discharge between the clouds and the ground occurring near from a power cable or communication cable generates a magnetic field due to its surge current. When the magnetic waves propagated within the field reach the cable, a lightning surge is induced (Figure 3-1).

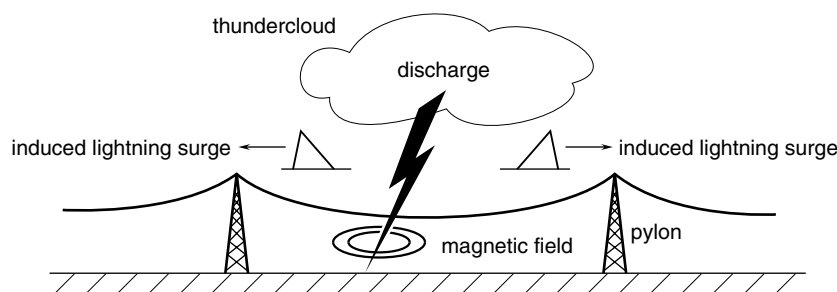


Figure 3 – 1

## 1-5. Increased ground potential

When lightning strikes a building or a lightning rod, high current flows to the ground and the ground potential rises. This causes a potential difference between the equipment No. 1 located close to the lightning rod (high potential) and the equipment No. 2 located far away from it (low potential), and as a result the lightning surge is directed from the ground to the cable between these locations (Figure 4-1).

In addition, if a building is in charged state by thunderstorm's electrostatic induction, an atmospheric discharge dissipating the electric charge at the bottom of the cloud causes the electric charge on the building to flow toward the ground. This also leads the ground potential to rise and the lightning surge directed to the cable from the ground (Figure 4-2).

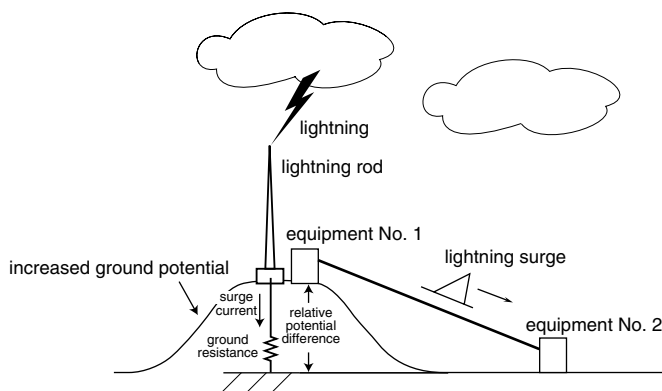


Figure 4 – 1

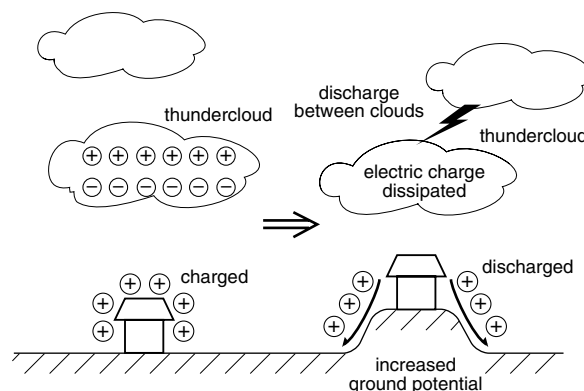


Figure 4 – 2

## 1-6. Entry pathway of lightning surge

Due to the online application of modern electronic systems, there are multiple interfacing parts to the outside for an instrument. One of such interface parts is signal cable and the other one is power cable. These cables pulled from the outside can be perfect entry pathways for the lightning surge.

The effects of induced surge on a connected device will be more severe when the connected cable is longer and the device is located closer to the place where the actual lightning strikes. Even lightning rods with minimal cable length do not always protect as they are hoped.

The effect of lightning surges depends upon the cable location and its environment. Surge protectors installed in those paths absorb and eliminate the high voltage impulse energy and protect the electric instrument from damage (Figure 5-1).

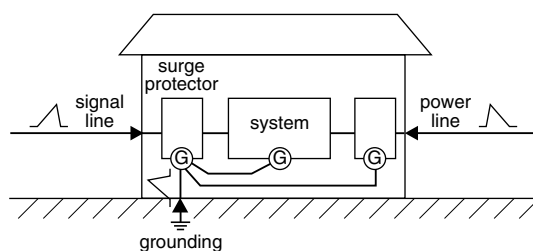


Figure 5 – 1

## 1-7. Breaking mode of electrical instrument

Surge voltage generated between a cable and the ground might reach several tens of thousands of volt, however, lightning occurs at a voltage typically five thousand volts between the cable and the ground, while it induces several hundred volts between lines.

When analyzing breaking condition of the instrument, it is often broken by this line voltage. We call it 'interline breakdown'. Characteristics of interline breakdown is that semiconductor parts near the entry point of lightning surge breaks.

Also, breaking mode between the cable and the ground is called 'discharge breakdown'. Because the lightning surge voltage is very high against that of the ground, an arc discharge is generated between an electronic circuit and a grounded enclosure. Characteristics of discharge breakdown is that weak part of insulation between the circuit and enclosure breaks down.

Our surge protectors keep the surge voltage level at which instrument does not get damaged and prevent interline breakdown and discharge breakdown.

### Interline breakdown (V1)

This occurs when the surge voltage between cables is directly applied to the electronic components in the instrument. Usually, only these components that are located near the termination of the cable where the surge entered are destroyed.

### Discharge breakdown (V2, V3)

Lightning surges cause a very high potential (voltage) difference between two conductors and the ground, and a discharge occurs between some part of an electronic circuit and those electrically connected to the ground, such as metal housings. Electronic components become damaged because some of the discharge current flows through the electronic circuit (Figure 6-1).

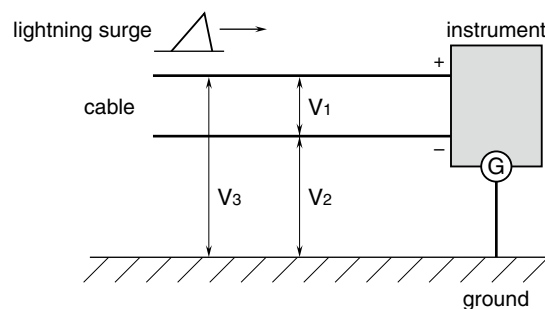


Figure 6 – 1

## 1-8. Fundamentals of surge absorbing

Induced lightning is a current source which tries to flow the current. This current is the lightning surge current. When current does not flow smoothly, it generates high voltage and forces to let the current flow. The high voltage generated at that time is lightning surge voltage.

Now, let us explain the fundamentals of lightning surge protector. Here we explain them with an example of a most commonly used model, the MDP-24-1. The diagram below is a simplified circuit of the MDP-24-1. On the cable, lightning surge voltage V1-V3 is generated to let the current flow. We call V1, interline surge voltage, and V2 and V3, line to ground surge voltage.

The surge protector absorbs V1 at the discharge element SA1 and V2 and V3 in SA2 and SA3. SA1-SA3 can be considered as voltage-dependant switches. When the voltage is high, an arc is discharged and they suppress the arc discharge of V1-V3 around 30V. It is important to limit the surge voltage as low as possible. Especially, V1, which is applied directly to the protected instrument, is eliminated by the discharge element SA1 and the voltage limiting element D1.

SA can bypass high current, however, its firing potential is high and the setting voltage varies widely. In order to compensate these disadvantages, it is combined with D1 of which firing potential is low and the setting voltage does not vary much and suppresses the surge voltage to a low level. D1, which does not tolerate high current, is also protected by R1 which limits the surge current (Figure 7-1).

The discharge element and the voltage limiting element together are called the surge absorber element. Since there is no one ideal surge absorber element, i.e. small size, small setting voltage variation, fast response time, high discharge withstand current rating, no failure in shortcircuit mode, the surge absorber circuit is designed with combinations of components to bring out their good characteristics.

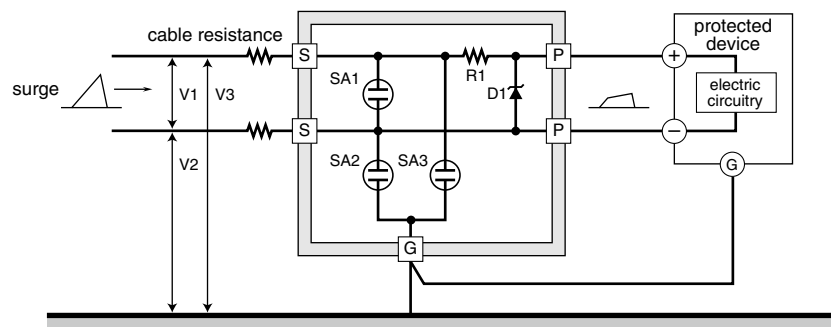


Figure 7 – 1

## 1-9. Surge protector selection

### Maximum surge voltage (clamping voltage)

The maximum surge voltage of the surge protector must be lower than withstand voltage of the protected instrument (Figure 8-1).

### Discharge current capacity

Our surge protectors have different ratings from 1 kA to 20 kA. Choose an appropriate rating considering how often lightning strikes your installation and how important is to protect the instrument (Figure 8-2).

### Maximum load current

Choose an appropriate model considering how much current, in mA, you need it flow for a signal line or how much power, in VA, you need for a power line.

### Maximum line voltage

The maximum line voltage must be higher than the rated voltage of protected instrument (Figure 8-2).

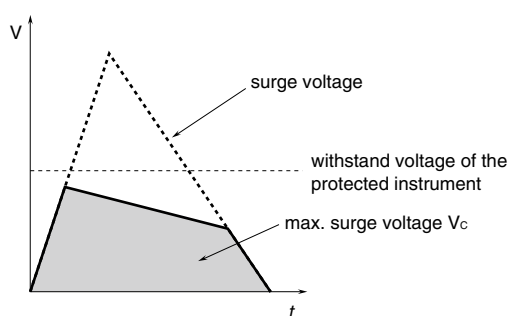


Figure 8 – 1

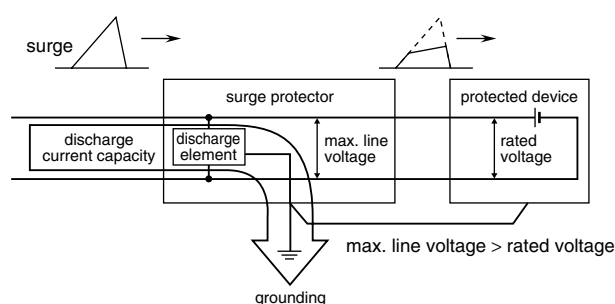


Figure 8 – 2

### Which surge protector do you choose?

#### Surge protectors for signal line

Our surge protectors are classified according to sensor/signal types, such as standard 4-20 mA signal, RTD, thermocouple, potentiometer, strain gauge and pulse generating device. We also have those specific for various field networks such as RS-485, Ethernet, PROFIBUS and DeviceNet.

#### [Example]

A 2-wire transmitter in general transmits 4 to 20mA DC output signal, powered by 24V DC power source on the same loop.

Choose the lightning surge protector for standard signal (ex. MDP-24-1). Both transmitter and control room instrument incorporate electric circuits. Therefore, surge protectors are needed at the both side.

In case of RTD, choose the lightning surge protector for RTD use (ex. MDP-RB). Even though the sensor has no electric circuit, a surge protector should be connected at the detection side in order to prevent the platinum resistance probe from breaking, in addition to the transmitter side.

#### Surge protectors for power line

Maximum load current up to 200 A is selectable. Single-phase/two-wire, single-phase/three-wire, three-phase/three-wire and DC power supply systems are selectable. Choose one based on the load current and the number of phase.



## 1-10.Points of caution when installing surge protectors

### Grounding

Not only surge protectors, but also computer systems and electronic instruments are connected to the earth grounding to prevent noise interference. Make the crossover wire thick and short to prevent a potential difference built up between the protector's earth terminal and the instrument's earth when the line is subjected by a precipitous rise of lightning surge.

There are reports saying that only one instruments among many has been damaged because this one was left unconnected to the ground with a crossover wire after the connection had been taken out during a regular checkout (Figure 9-1).

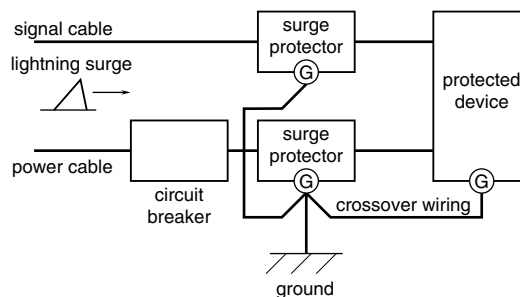


Figure 9 – 1

### Insulation test

Before performing the insulation test for an instrument panel equipped with lightning surge protectors, you must disable the surge protectors because they will start discharging during the test and possibly cause insulation failures.

With signal line protectors, simply unplug the element from the base socket.

With power supply line protectors, remove all the grounding wires connected to the ground terminal. Be sure to re-connect all wires back after the test is completed.

### Molded-case circuit-breaker

A power supply line protector usually incorporates a circuit protector, however, it may not be able to handle a lightning surge far exceeds its discharge withstand current rating such as direct lightning strike.

Be sure to set a molded-case circuit breaker. Choose one that its current rating is equivalent to the maximum load current of the surge protector (Figure 9-2).

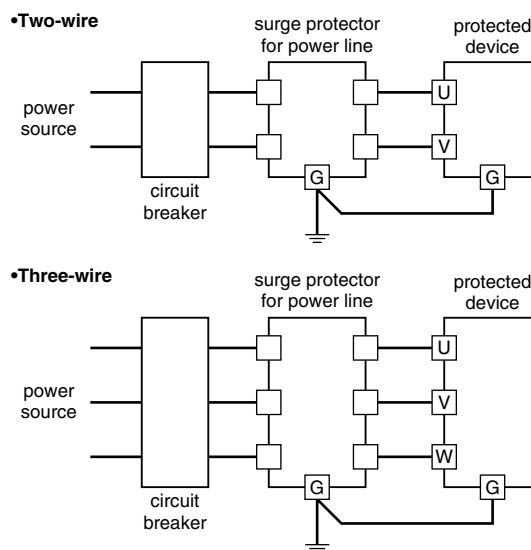


Figure 9 – 2

## 2. FAQ for Surge Protectors

### QUESTION 1

Is there a way to protect electronic instrument from a direct lightning strike?

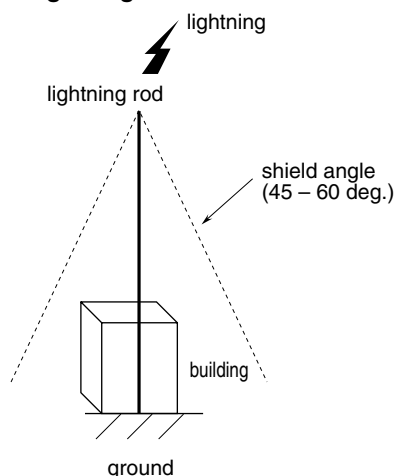
### ANSWER

We recommend to use both lightning rod and surge protector at the place where direct lightning might strike.

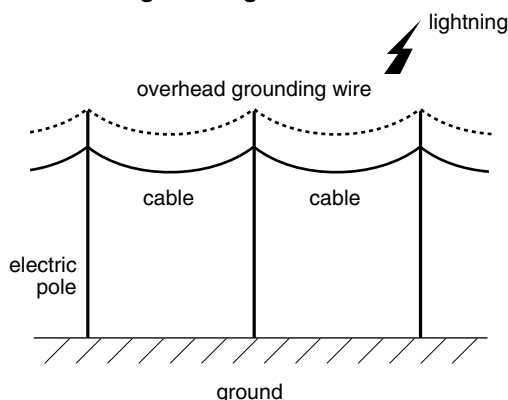
### DISCUSSION

Energy of the direct lightning strike is enormous, only surge protector alone can not protect the instrument. Buildings which lightning might strike should set the lightning rod at the place where building is located in the shield angle. Also, set the overhead grounding wire on the cable. Arrange as most of lightning energy is absorbed by the lightning rod and overhead grounding wire and absorb only the rest by the surge protector.

#### • Lightning rod



#### • Overhead grounding wire



#### • Lightning rod

It induces the lightning strike voluntarily and works as the lightning does not strike buildings nearby. The shield angle range is between 45-60 degree conic. Simply burying cables is not effective due to the induced electromotive force that occurs around the cable because of impulse current in the ground near a lightning strike.

#### • Overhead grounding wire

This is a grounding wire which is attached to a overhead transmission line. Its effect is similar to having several lightning rods in a row which shield the lines under them from the lightning strike.

## QUESTION 2

A remote field transmitter connected to a local indicator which is protected by a surge protector begins to show inconsistent display value. What could be the trouble?

## ANSWER

It may be time to replace the surge protector due to its lessened capacity, if the problem just started recently.

Each surge protector has a different lifetime. Surge protectors, which have been installed in areas where lightning occurs frequently, should be tested and replaced periodically. Replacing the surge protector with a new one in this instance may solve the problem.

## DISCUSSION

Surge protectors can be thought of as consumable items in areas where lightning is common. We would recommend you to periodically check your surge protectors and keep enough replacements on hand for next lightning season. Model C-106A-1 M-Rester Tester can be used to check most surge protectors for proper function.

We have unique lightning surge protectors with life monitoring function. These lightning surge protectors tell us that it is time to change by the monitor lamp or relay contact so you do not need to worry if it is time to change.

## QUESTION 3

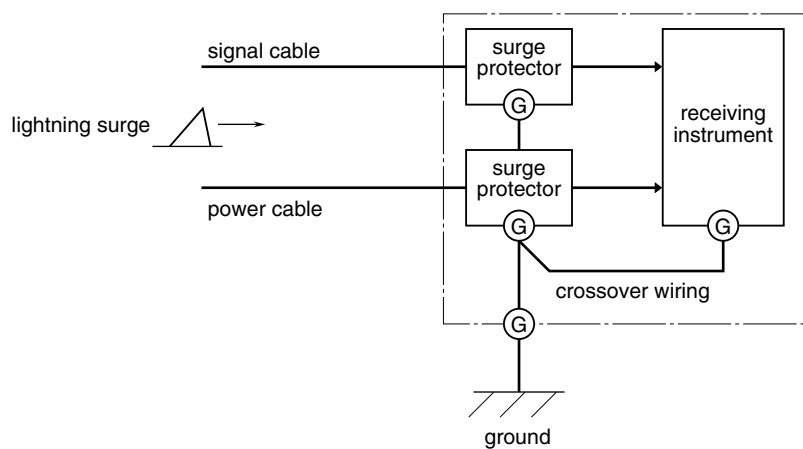
A control room instrument was damaged during a recent lightning strike. Why?

## ANSWER

If possible, determine exactly where the lightning entered the instrument. In all probability, it entered through the input signal line or power supply line.

We would recommend that you use a surge protector on both the signal and power supply lines. Contact your local sales office for specific models for your application.

## DISCUSSION



### Recommended models:

- Model MDP-24-1 (4 – 20mA DC signal lines)
- Model MA-100 (100 – 120V AC, 2A power supply)
- Model MA-200 (200 – 240V AC, 2A power supply)
- Model MAX-100 (100 – 120V AC, 5A power supply)
- Model MAX-200 (200 – 240V AC, 5A power supply)

## QUESTION 4

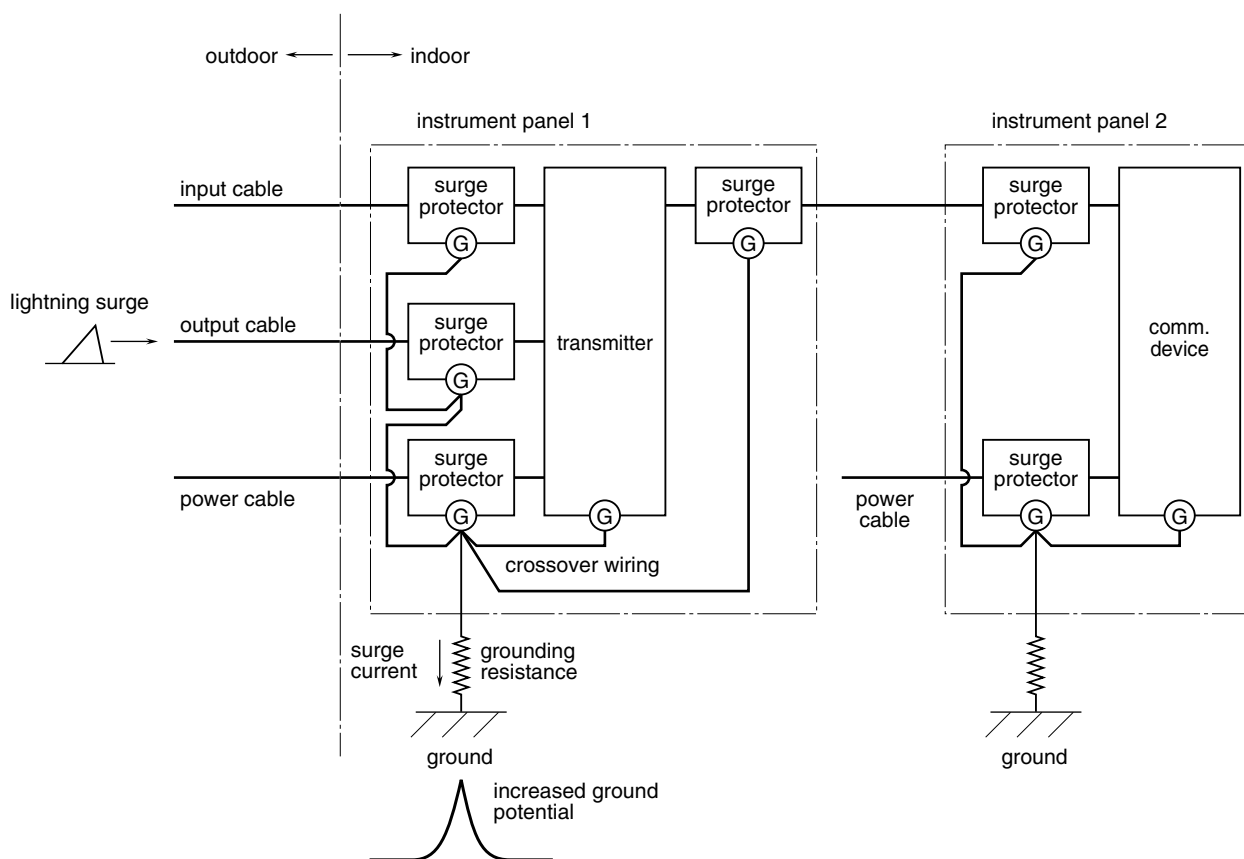
A transmitter that is attached to a panel located indoors was damaged by a recent lightning strike. Can you explain why this occurred?

## ANSWER

Signals and power sources are commonly connected to a transmitter through outdoor cable pits and conduit pipes. It sounds like the lightning surge damaged the transmitter by means of these lines. If the transmitter's output is sent outdoors, then install surge protectors to protect the input, power and output lines.

When a panel 1 located indoors works, ground potential for only panel 1 is elevated and it causes potential difference with the panel 2 which is grounded separately at a different place. When panel 1 and 2 are grounded separately, set a surge protector on the cable to connect panels even when it is wired indoors.

## DISCUSSION



### Recommended models:

- Model MDP-24-1 (4 – 20mA DC signal lines)
- Model MA-100 (100 – 120V AC, 2A power supply)
- Model MA-200 (200 – 240V AC, 2A power supply)
- Model MAX-100 (100 – 120V AC, 5A power supply)
- Model MAX-200 (200 – 240V AC, 5A power supply)

# QUESTION 5

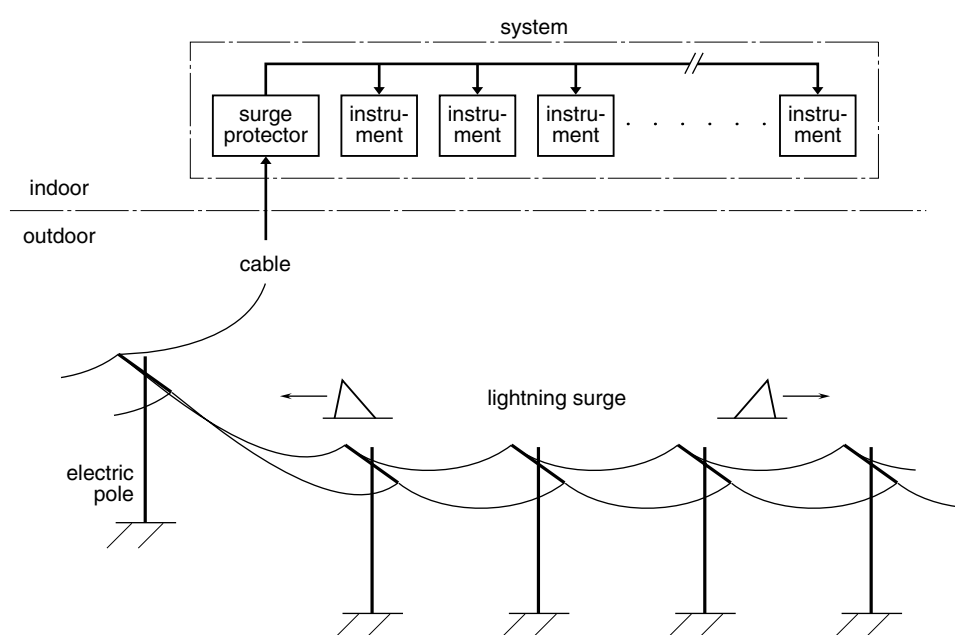
Is a surge protector necessary for a power supply line?

## ANSWER

Yes, spikes and surges often propagate through power lines.

## DISCUSSION

The most likely place for lightning strikes is the power distribution cables. These spread in all directions, like a spider's web, acting similar to an antenna waiting to receive its signal. Please select the appropriate surge protector for your specific application and power requirements.



### Recommended models:

Model	PowerSupply	Load Capacity	Model	PowerSupply	Load Capacity
MA-100	100 – 120V AC	2A	MH-105A	100 – 120V AC	5A
MA-200	200 – 240V AC	2A	MH-110A	100 – 120V AC	10A
MAX-100	100 – 120V AC	5A	MH-130A	100 – 120V AC	30A
MAX-200	200 – 240V AC	5A	MH-205A	200 – 240V AC	5A
MMA-100	100 – 120V AC	10A	MH-210A	200 – 240V AC	10A
MMA-200	200 – 240V AC	10A	MH-230A	200 – 240V AC	30A
			MH-1201	100 – 120V AC	200A
			MH-2201	200 – 240V AC	200A
			MH-2203	200 – 240V AC	200A

## QUESTION 6

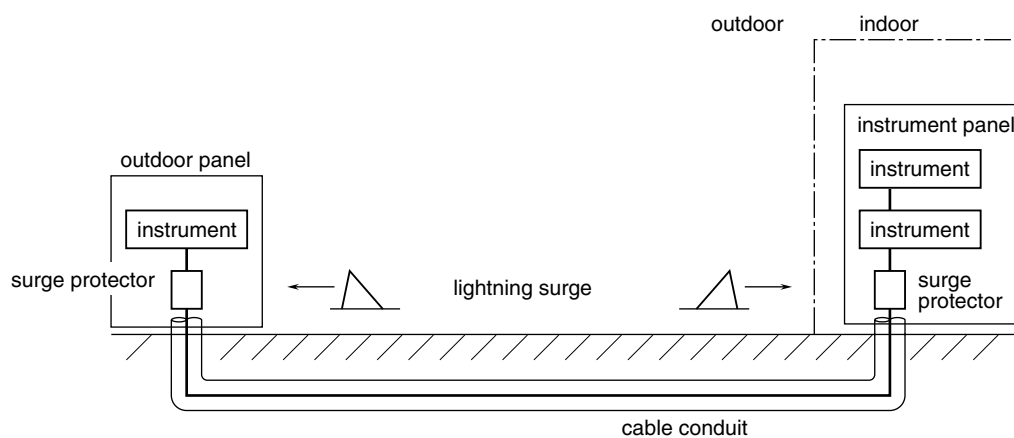
Is it possible for the surge protector which is set at monitoring panel to protect instrument on the outdoor panel?

## ANSWER

No, it can not protect the instrument. Set a surge protector for the outdoor panel.

## DISCUSSION

Surge protector for the cable and for the instrument should be set separately. A surge protector for the instrument can not protect the cable at the same time. Set the same model surge protector for the outdoor panel.



### Recommended models:

- Model MDP-24-1 (4 – 20mA DC signal lines)
- Model MA-100 (100 – 120V AC, 2A power supply)
- Model MA-200 (200 – 240V AC, 2A power supply)
- Model MAX-100 (100 – 120V AC, 5A power supply)
- Model MAX-200 (200 – 240V AC, 5A power supply)

## QUESTION 7

During a recent lightning storm, the power was turned off but some instruments were still damaged. Can you explain this?

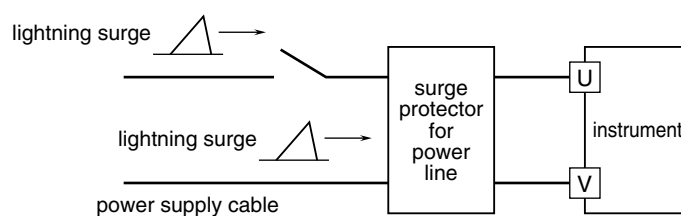
## ANSWER

Lightning jumped across the single-pole switch into the instrumentation.

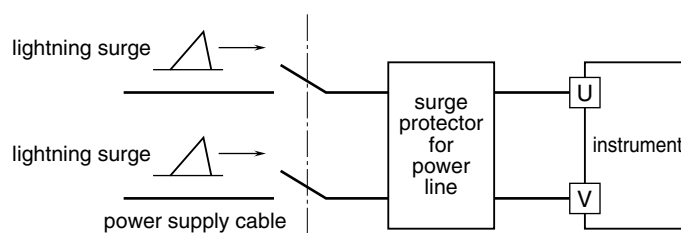
We would recommend to use a double-pole switch. However, this does not insure that a severe lightning surge will not damage. It is depending on the insulation resistance of the switch or the size of the lightening pulse. The only sure solution is to install a surge protector in line with the power source.

## DISCUSSION

### • Single-pole switch



### • Double-pole switch





# QUESTION 8

An instrument was blackened by a lightning strike via a lightning rod. Is there a reason for this?

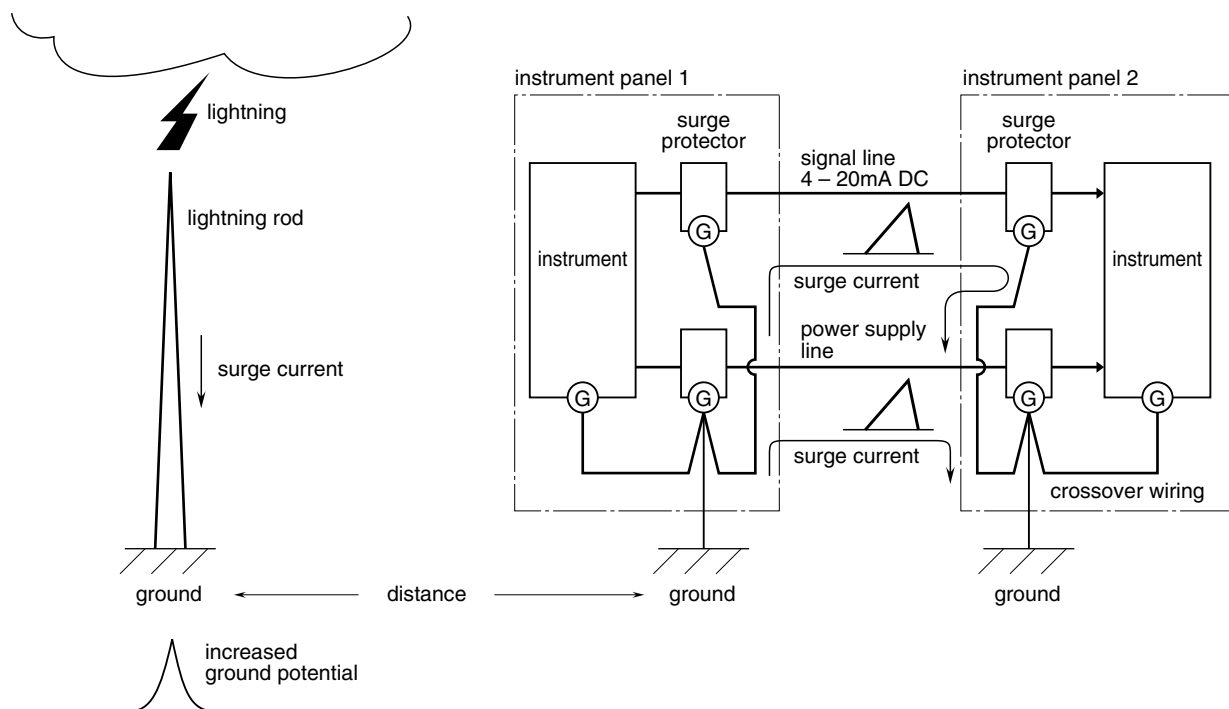
## ANSWER

Because ground potential is elevated, discharge breakdown occurred to the instrument. Set a surge protector. Also, grounding of the lightning rod and surge protector, an instrument, should not be shared but ground individually.

## DISCUSSION

When lightning rod is struck by the lightning, high current flows to the ground and voltage at grounding point rises. When instrument panel 1 is within the shield angle, grounding of instrument panel 1 is near the lightning rod and voltage at the grounding of instrument panel 1 becomes high. Therefore, relative electric potential difference is generated between the instrument panel 1 and the instrument panel 2 which is set away from the lightning rod and ground potential is low. Then, discharge breakdown occurs between enclosure of instrument panel and the circuit.

To prevent this to happen, set surge protectors at both instrument panel 1 and 2 and bypass surge current and absorb relative electric potential difference. If the grounding of surge protector and instrument panel 1 are shared, most of the lightning current possibly flows to the surge protector and exceeds discharge withstand current rating. Be sure to set grounding separately.



### If grounding of surge protectors are shared...

Grounding resistance of surge protector is at least about  $1\Omega$ . When lightning current is 200,000A, voltage generated accordingly is 200,000V. If lightning rod and grounding are shared, this voltage flows backward from G terminal and destroy the instrument. have enough distance separation between them.

#### Recommended models:

- Model MDP-24-1 (4 – 20mA DC signal line)
- Model MA-100 (100 – 120V AC, 2A power supply)
- Model MA-200 (200 – 240V AC, 2A power supply)
- Model MAX-100 (100 – 120V AC, 5A power supply)
- Model MAX-200 (200 – 240V AC, 5A power supply)

## QUESTION 9

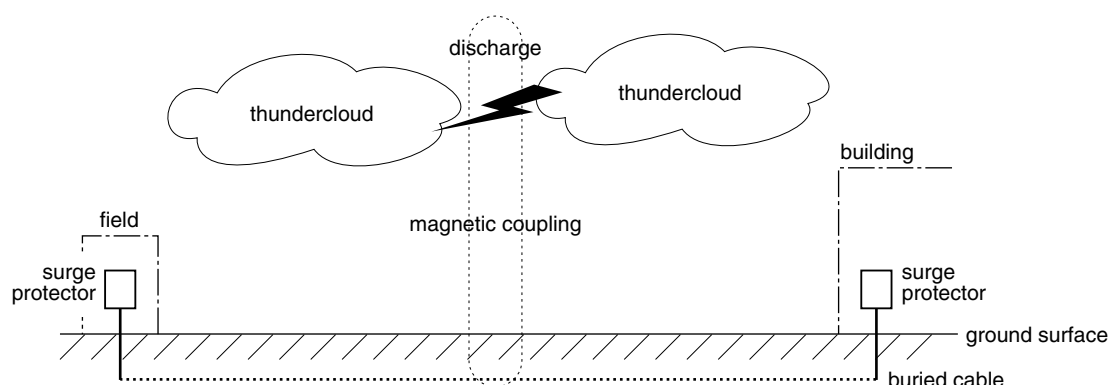
It has been said that if you use buried cables, then that is enough from lightning. Is this a true statement?

## ANSWER

No, because buried cable are also vulnerable to the unpredictable power of lightning.

## DISCUSSION

A buried cable does not have as much protection from induced lightning as one might expect, because underground soil easily transmits an electromagnetic field which occurs during a lightning discharge. Also, the high lightning current that is being discharged to ground by the lightning rod can find its way to the buried cables located in the ground.



### Recommended models:

- Model MDP-24-1 (4 – 20mA DC signal line)
- Model MA-100 (100 – 120V AC, 2A power supply)
- Model MA-200 (200 – 240V AC, 2A power supply)
- Model MAX-100 (100 – 120V AC, 5A power supply)
- Model MAX-200 (200 – 240V AC, 5A power supply)

# QUESTION 10

How much resistance is appropriate when grounding the M-Rester?

## ANSWER

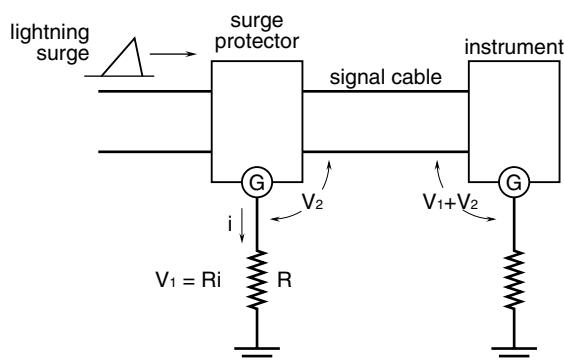
As for lightning protection, any grounding is OK. However, for safety reason, D grounding (100Ω) or more is recommended.

## DISCUSSION

The important thing to remember is that device ground should be connected with a crossover wire. Then ground is at the potential lightning site. As a result, between the signal line and ground terminal (G) of an instrument, discharge voltage ( $V_2$ ) of the surge protector can be added. When appropriate crossover wire is made, instantaneous electric potential is established between the surge protector and the instrument and the volume of the ground resistance does not affect lightning protection function.

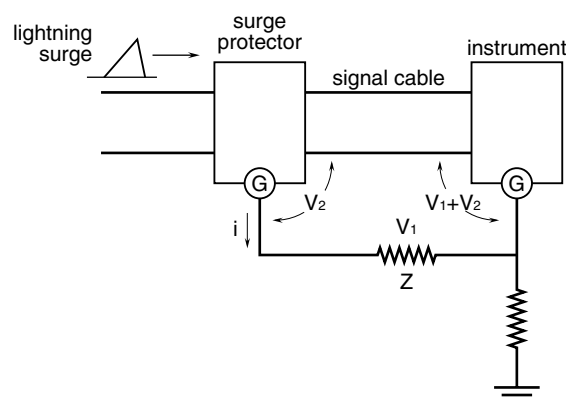
### • Separate wiring

A common-mode voltage  $V_1$ , ground resistance ( $R$ ) (lightning surge current ( $i$ ), is added to discharge voltage  $V_2$  at the surge protector between the signal line and a ground terminal of an instrument. In this case, ground resistance need to be very small (less than several ohms). Otherwise, the surge protector does not protect the instrument from the lightning.



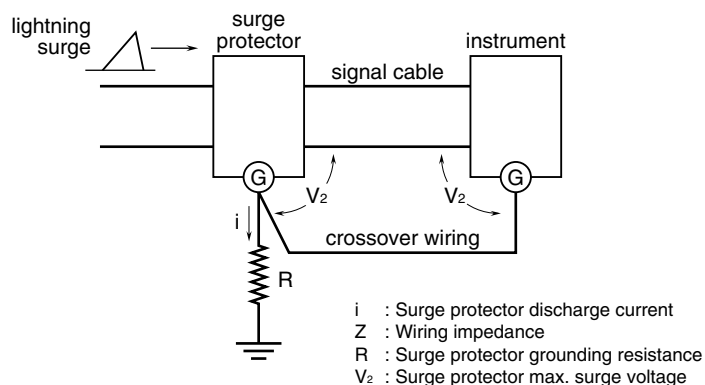
### • Wiring at instrument site

Because lightning surge current flows in crossover wire, voltage ( $V_1$ ) which figure is calculated by wiring impedance ( $Z$ ) (lightning surge current ( $i$ ), join together with clamping voltage ( $V_2$ ) of the surge protector and added to between signal terminal and grounding terminal of the instrument. Lightning protection lessened when crossover wire is long.



### • Crossover wiring

Because lightning surge current does not flow to crossover wire, only clamping voltage ( $V_2$ ) of the surge protector is added between signal terminal and grounding terminal (G) of the instrument. Full lightning protection of the surge protector is performed.



# QUESTION 11

Is power supply line safe if the surge protector for the power source damaged?

## ANSWER

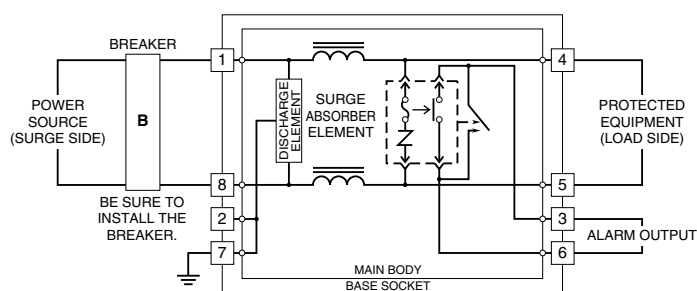
Yes, because the surge protectors have internal protection circuits.

## DISCUSSION

There is a chance that incorporated element of the surge protector has closed-circuit failure when the surge protector receives stress from lightning surge for a long time or handle lightning surge that exceeds discharge withstand current rating. At that time, power source line might have short circuit accident or surge protector might have heat accident.

Therefore, surge protectors have a protection circuit that cut off the element. However, it might not be able to handle when a surge protector receives lightning surge which far exceeds discharge withstand current rating such as a direct lightning strike. Be sure to set an electric current breaker on power source line.

- MAX-100, MAX-200



## QUESTION 12

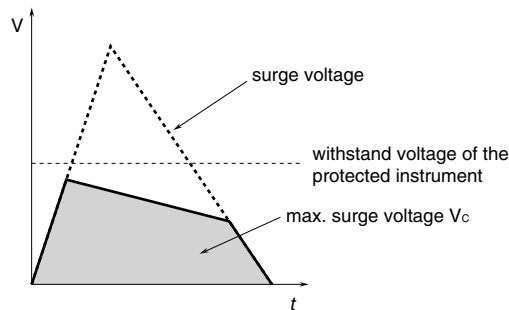
A field transmitter was connected to a surge protector, but it was still damaged by a lightning strike. Can you tell me why?

## ANSWER

The surge protector that was selected could be incorrect for that specific application.

## DISCUSSION

The maximum surge voltage of a surge protector to be used should be below the withstand voltage of the instrument(s) to be protected. This voltage level could be passed through the surge protector to the instrument(s) during a lightning surge. Be sure to confirm this specification before selecting the surge protector. Damage to protected equipment may occur because of this variable.



## QUESTION 13

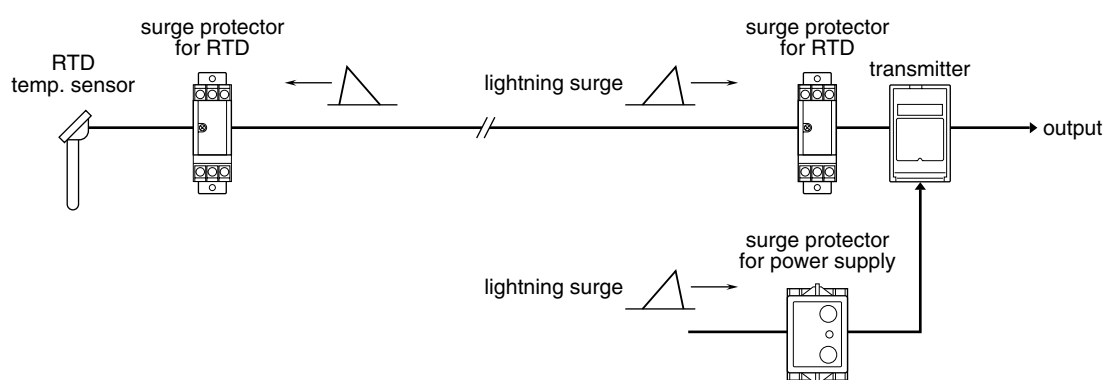
After a lightning storm, there was no input from the remote RTD sensor to the temperature transmitter. There is no detectable damage to the transmitter. What could have happened?

## ANSWER

It seems that the RTD temperature sensor was the only device damaged by the lightning.

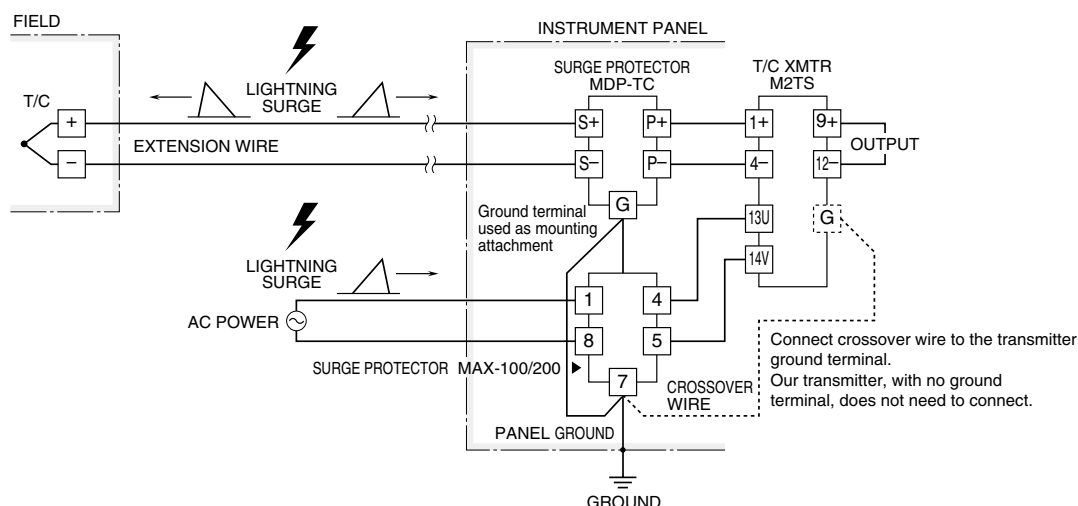
## DISCUSSION

It is recommended that surge protectors be installed on both instrument and RTD to protect RTD sensor. If not, then the temperature transmitter's output signal could go upscale or downscale in this sensor is destroyed by a lightning surge. This means excessive down time for the process that is being monitored and controlled.

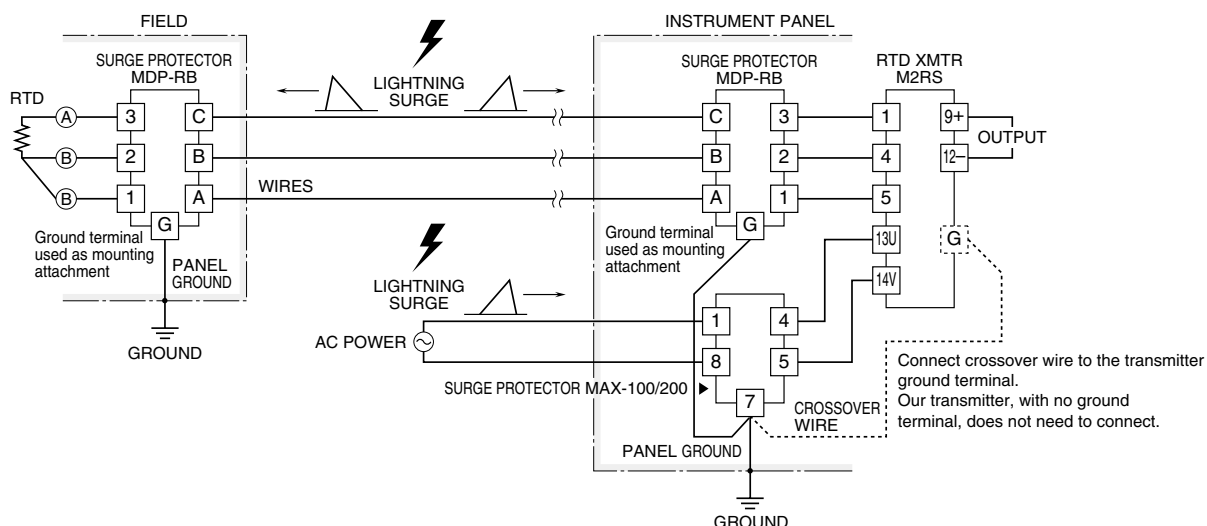


### 3. Connection Examples

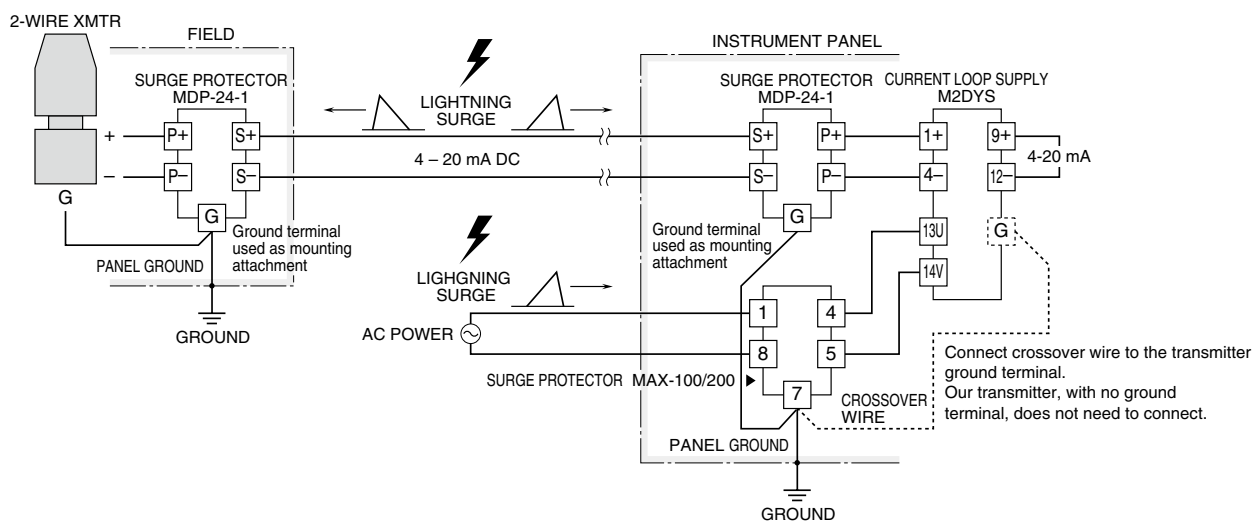
#### ■ THERMOCOUPLE



#### ■ RTD

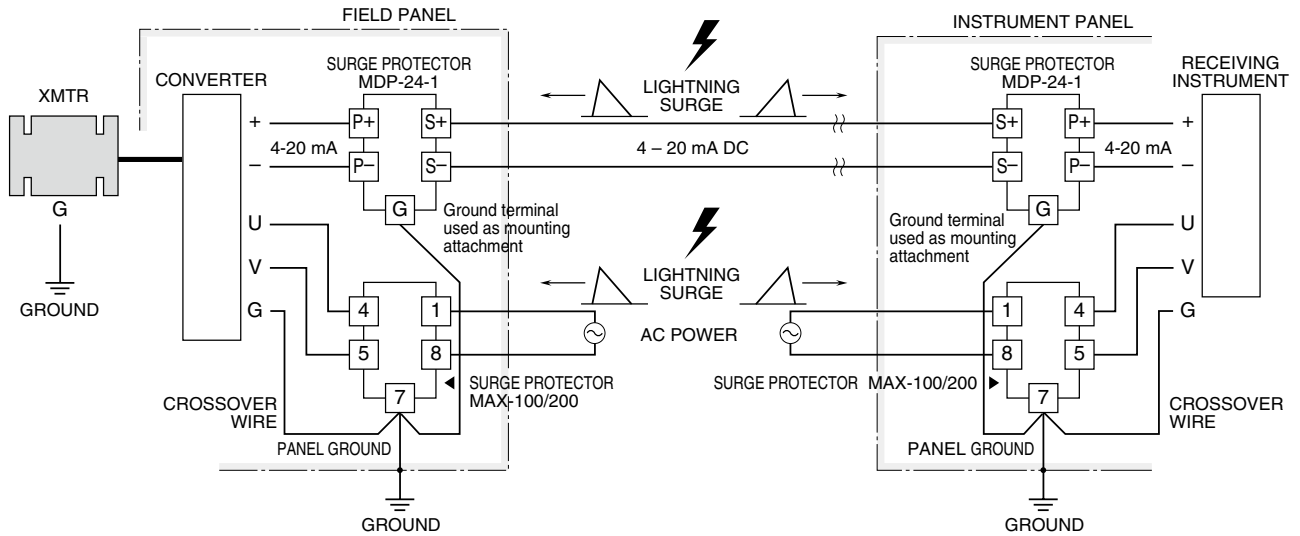


#### ■ 2-WIRE TRANSMITTER



## ■ ELECTRO-MAGNETIC FLOWMETER

### • Transmitter - converter separated



### • Transmitter - converter combined

