Transient Suppression Devices

Transient suppression devices can significantly reduce the amount of energy released as a result of over voltage spikes and surges.

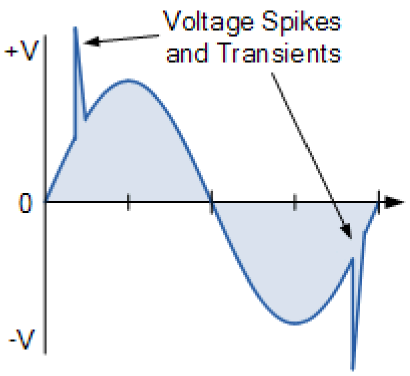
We would like to think that the AC or DC power supplies we use to power our circuits are both clean and well-regulated supplies. However, the switching of AC inductive loads or the switching of DC relay contacts and DC motors as part of a micro-controller project all combine to produce a quality of power supply that is difficult to maintain.

These inductive switching transients occur when some form of inductive or reactive load, such as a motor, a solenoid coil or a relay coil, is suddenly switched off. The rapidly collapsing of its magnetic field induces a transient voltage which becomes superimposed onto the steady-state supply. These inductive switching voltage transients can reach the 1,000's of volts.

Transients are very steep voltage steps that occur in electrical circuits due to the sudden release of a previously stored energy, either inductive or capacitive, which results in a high voltage transient, or surge being created. This sudden release of energy back into the circuit due to some switching action creates a transient voltage spike in the form of a steep impulse of energy which can in theory be of any infinite value.

This high dv/dt transient switching spike can exist either for a very short period of time (milli-seconds or micro-seconds), or they can occur every so often over short periods of time, for example randomly two or three times a day.

We must also realise that voltage transients do not always start at zero volts or at the beginning of a cycle, but can be superimposed onto another voltage level. Either way, transients are bad as they can damage electronic equipment and therefore need to be suppressed and controlled.



Transient suppression devices can take on many forms from arc contacts, to filters, to solid state semiconductor devices. Discrete semiconductor transient suppression devices such as the Metal-oxide Varistor, or MOV, are by far the most common as they are available in a variety of energy absorbing and voltage ratings making it possible to exercise tight control over unwanted and potentially destructive transients or over voltage spikes.

Transient suppression devices can be used in series with the load to either attenuate or reduce the energy value of a transient preventing its propagation through a circuit, or they can be used in parallel with the load to divert the transient away, usually to ground, and so limit or clamp the residual voltage.

Attenuation of a voltage transient is usually accomplished using low-pass filters connected in series with the load circuit. When a voltage transient occurs it is usually a fast moving, high frequency spike so the filter attenuates or blocks this high frequency transient while still allowing the low frequency power or signal component to continue undisturbed. A good example of transient attenuators are mains filtered extension cords.

Diverting a transient is usually accomplished using a voltage-clamping type device or by using what are commonly called a crowbar type device. These parallel connected devices exhibit a nonlinear impedance characteristic as the current flowing through them is not linear to the voltage across their terminals as given by Ohms Law.

A voltage-clamping device such as an MOV, has a variable impedance depending on the current flowing through the device or on the voltage across its terminal. Under normal steady-state operating conditions, the device offers a high impedance and has therefore no effect on the connected circuit.

However, when a voltage transient occurs, the impedance of the device changes increasing the current drawn through the device as the voltage across it rises. The result is an apparent clamping of the transient voltage. The volt-ampere characteristic of a clamping devices is generally time-dependent as the large increase in current results in the device dissipating a lot of energy.

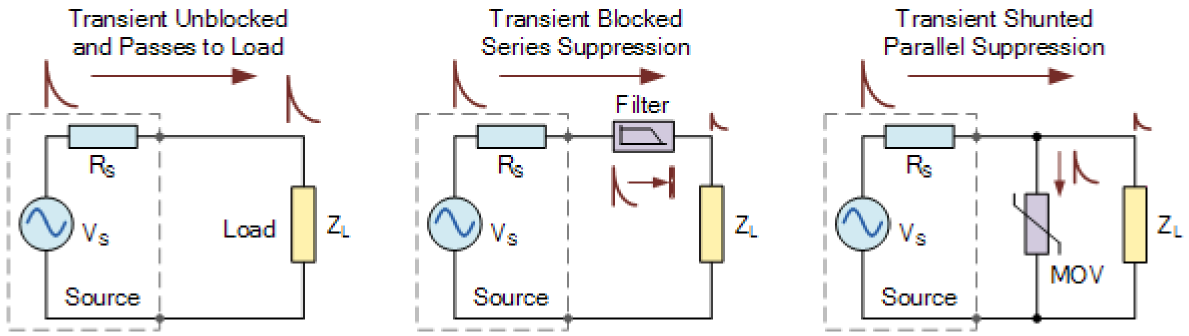
Crowbar devices are another type of transient suppression device which diverts over voltage spikes away from a circuit as a result of a switching type turn-on action. Crowbar devices are similar in operation to a zener diode in that under normal steady-state conditions they have no effect on the circuit. When a transient is detected, they rapidly switch "ON" offering a very low impedance path which diverts the transient away from the parallel-connected load.

Then discrete transient suppression devices can be divided into three basic categories depending on their type of connection and operation.

- Series (blocking) connected Low Pass Filters.
- Parallel (shunting) connected Voltage Clampers and Voltage Clippers.
- Parallel (shunting) connected Crowbar devices.

and this can be shown as:

Transient Suppression Devices



Series Transient Suppression Filters

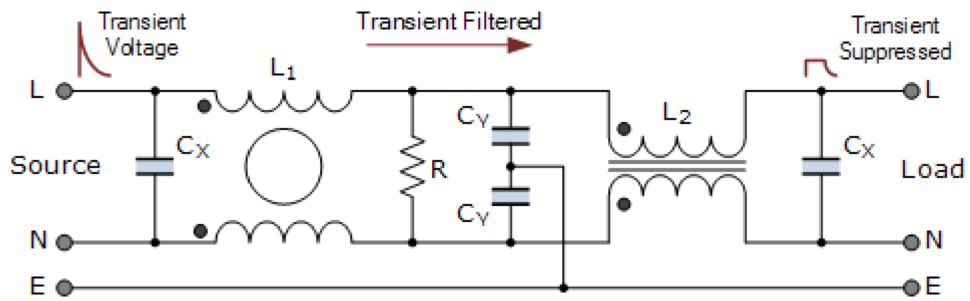
Transients on an AC power line can range from a few volts to over several kilo-volts above the normal mains voltage. Suppression devices which attenuate or block these transient use filter circuits to effectively eliminate these mains born transients by inserting a 100Hz filter in series with the connected load.

The frequency component of a fast switching voltage transient can be much higher than the slow moving fundamental frequency of the AC source. Thus an obvious choice to attenuate and control these unwanted transients is to use a low-pass filter section between the source and the load.

Low pass filters, such as an LC filter, can be used to attenuate any high frequency transients and allow the low-frequency power or signal to pass through undisturbed. The simplest form of transient suppression filter is that of a resistor-capacitor RC filter placed directly across the power line to attenuate any high frequencies transients.

Filters intended for AC power applications generally comprise of inductances and capacitors to form multistage LC filters whose degree of attenuation depends on the number of LC stages in the filter. A typical series connected AC mains transient suppression filter is shown below.

Typical Transient Suppression Filter



This basic two-stage low-pass AC filter provides a high insertion loss between line-to-line and line-to-ground throughout the frequency range offering effective transient voltage protection by stopping any high-frequency transient and noise from reaching the connected load equipment. Also as well as reducing voltage spikes and transients, these mains power filters can help eliminate any radio-frequency interference or emissions given off by the power supply.

Voltage Clamping Transient Suppressors

Voltage clampers are used to limit the amplitude of a transient across a circuit. A voltage clamping device begins conducting when a preset threshold voltage is exceeded, then returns back to a non-conducting mode when the overvoltage drops below its threshold level. Thus overvoltage spikes are clipped off to a safe level by the clamping device.

Voltage clamping devices are generally placed across the supply and in parallel with the load to protect it against any unwanted high dv/dt voltage transients. A voltage clamper can be something as simple as a zener diode across a DC supply, but for bi-directional AC supplies we need to use metal oxide varistor (MOV), suppression diodes or voltage dependent resistor (VDR) for over-voltage protection.

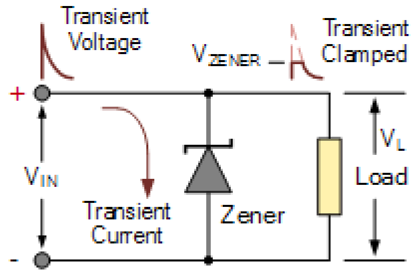
Note that voltage clamping devices divert surge currents, they do not absorb them as with a filter, so care must be taken to ensure that the path used to divert the transient does not produce or create its own problems for the circuit.

Zener Diode Transient Suppressors

Zener diodes are used for protection on DC supplies (unidirectional) as they behave like normal diodes in their forward biased direction, but break down and conduct in their reverse biased direction. Thus a zener diode's reverse breakdown voltage, V_Z can be used as the reference or clamping voltage level.

In the reverse direction and below the their zener breakdown voltage, V_Z zener diodes exhibit high impedance to the supply and conducts very little leakage current. However, when the voltage across the zener is greater than its zener voltage, it starts to breakdown with its conduction increasing gradually as the voltage across it increases exhibiting a very low impedance path to the over voltage transient.

Zener Transient Suppression



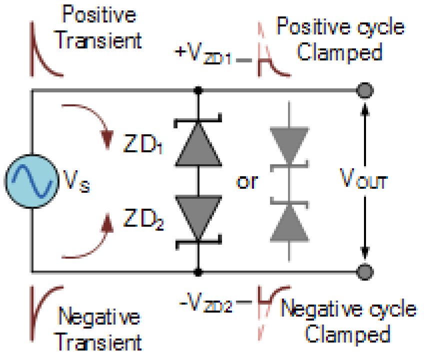
When connected across a supply or across the components being protected, the zener diode is effectively "invisible" until a transient voltage appears as it has a high impedance below its reverse breakdown voltage and a low impedance above its reverse breakdown voltage.

When the zener is in the breakdown mode of operation, that is when suppressing a transient, the diode clamps the over voltage instantly to limit the spike to a safe level and then returns back to normal once the transient voltage is below the zener voltage, V_Z. Then the clamping voltage, V_C is therefore equal to the zener's reverse breakdown voltage. Because of these clamping characteristics, the zener diode is used to suppress transients as it clamps potentially damaging currents away from the protected load.

The surge current and power capability of the zener diode is approximately proportional to its junction area. Most zener diodes are designed to operate at low power and voltage levels. Zener diodes designed to operate at higher voltage levels and absorb higher surge currents without damage are known as *Avalanche Diodes*.

We said earlier that a single zener diode can only be used for transient suppression on steady state DC supplies due to their forward biased diode characteristics. But by connecting two zener diodes "back-to-back" we can use their clamping characteristics across a bidirectional AC supply.

Zener Transient Suppression



By connecting two zener diodes back-to-back we can now protect both the positive half cycle from overvoltage transients with one zener diode and the negative half cycle with the other.

If both the zener diodes are of the same reverse breakdown voltage, then a transient voltage of either polarity will be clamped at the same zener voltage level as one zener diode will be effectively in its reverse bias mode while the other will be in its forward bias mode.

While two back-to-back zener diodes can be used for transient suppression of an AC supply, transient voltage suppressor (TVS) devices are available with opposing junctions built into a single device making them ideal for AC power applications. Bidirectional avalanche diodes are available in a range of voltage and power levels.

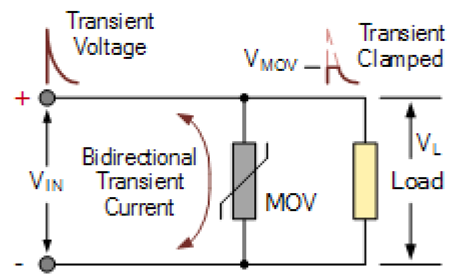
MOV Transient Suppressors

While zener diodes and fast recovery avalanche diodes are fast acting and effective at clamping overvoltages, the most common overvoltage suppression clamping technique is the use of metal oxide varistors, or MOV's. As well as their high voltage ratings, metal oxide varistors are capable of handling much larger surge currents, be it at a slower rate, and can be used in both DC and AC power lines to protect from voltage extremes such as overvoltage transients.

The MOV is a semiconductor voltage-dependent variable resistor which is placed in parallel (shunt) with the load, or component to be protected. MOV's have a high resistance at low voltage and low resistance at high voltage and their non-linear voltage-current characteristics make them useful in guarding against power-line surges and overvoltage transients.

MOV's behave in a similar manner to back-to-back zener diodes as they can be used for bidirectional voltage clamping with the conduction of the transient increasing as the voltage across it increases. These small disk-shaped metal-oxide type of varistors offer high breakdown voltages in both directions and can absorb higher amounts of energy, they are often rated in joules rather than watts.

MOV Transient Suppression



Being a voltage clamping device, metal oxide varistors offer very high resistances when the voltage across its terminals is below its pre-determined breakdown value acting more like a voltage dependent resistor (VDR). When exposed to high transient voltage of either polarity, the electrical characteristics of the device changes and its resistance becomes very small clamping the voltage to a safe level.

Then the main purpose of the metal oxide varistor when used as a transient suppression device is to clamp the voltage appearing across it to a safe level as in most applications, the device is placed in parallel with the circuit or device to be protected.

Crowbar Transient Suppressors

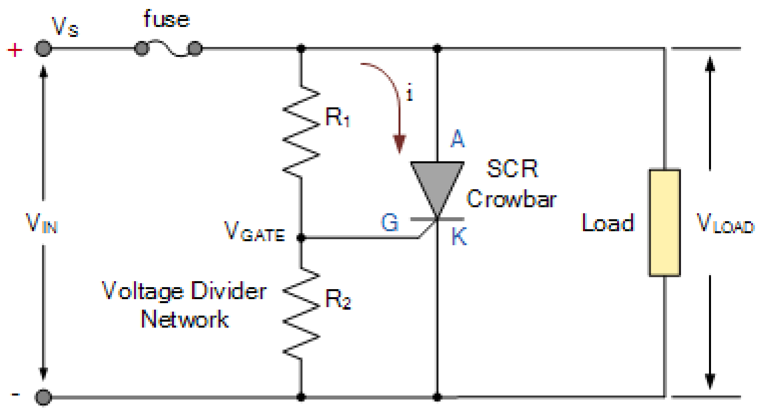
Another type of parallel (shunt) connected transient suppression device is known as *crowbar* protection Electronic crowbar devices conduct when a preset threshold voltage is exceeded by triggering to a conductive on-state resulting in a voltage drop of only a few volts, hence the name crowbar.

Crowbar devices and circuits effectively create a short circuit when a trigger voltage is reached and are commonly found in stabilised power supplies which have been designed to produce a fixed output voltage, for example a constant 12 volts or 5 volts, but can also be used to protect a circuit or load from transient over voltages.

Semiconductor-based active crowbar circuits are placed in parallel (shunt) with the load and are capable of attenuating very large surge currents. Thyristors are generally used in crowbar circuits as they have a low “on-state” voltage and can keep voltage levels well below damaging levels. Once fired they can divert a substantial amount of transient energy to ground through themselves as they act as very low impedance type switch.

The disadvantage here is that this short circuit may cause circuit fuses or circuit breakers to operate if additional commutation circuitry is not provided to turn “OFF” the crowbar clamp once switched “ON” especially in a DC system because the power supply is shorted by the crowbar device and the output voltage will therefore be zero. Consider the simple crowbar clamping circuit below.

Basic Crowbar Clamping Circuit



Here a thyristor or SCR is placed across the supply and the load with the voltage divider circuit set up by resistors R_1 and R_2 set to bias the thyristors gate at a level low enough for it not to be triggered "ON" during normal operation. Then the SCR is cut-off and non-conducting.

However when an over voltage transient occurs and rises above a predetermined level, the voltage drop across resistor R_2 also increases and becomes sufficient to trigger the gate of the SCR into conduction which in turn clamps the voltage transient protecting the load. The problem here is that while the load is protected from the over voltage, it does not protect the power supply thereby blowing the fuse of the power supply. Then the protection of the load from the transient created by short-circuiting the power supply may be greater than the event that triggered it.

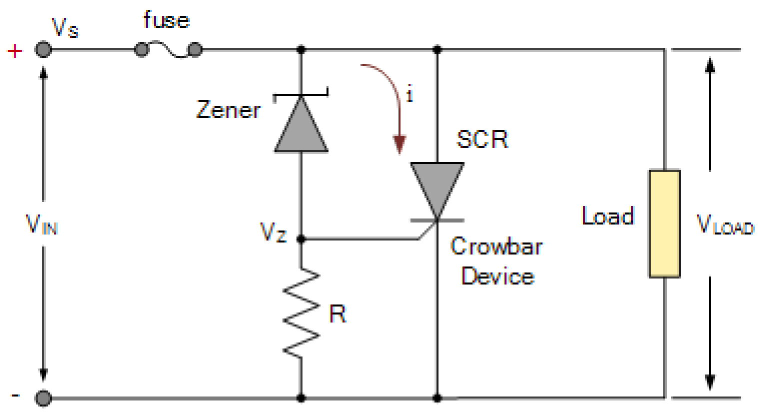
As well as using thyristors, for over voltage protection of AC power supplies, triacs can be used as a crowbar device and triggered into conduction in a similar way. The advantage of using thyristors or triacs for crowbar protection of AC supplies is that they will automatically turn-off at every half-cycle.

So if a short-duration transient of a fraction of a millisecond triggers the crowbar device, the shunting action would only short-circuit the AC power line to which it is connected for at least one half-cycle which may be too fast for the fuse-link to blow.

Zener Crowbar Transient Suppressors

We can improve the transient sensing and performance of the basic crowbar circuit above by using a zener diode to detect an over voltage condition. Here the resistive voltage divider circuit has been replaced by a zener diode as shown.

Zener Crowbar Clamping Circuit



The DC supply voltage, V_S is monitored by the zener diode which is acting like a transient detection component, and whose zener voltage, V_Z rating determines the voltage level at which the SCR turns on. When the DC supply voltage is lower than the reverse bias rating of the zener diode, the zener diode does not conduct so no voltage or current is applied to the gate of the SCR so remains turned "OFF", non-conducting.

If the supply voltage increases above the zener voltage rating as in the case of an overvoltage transient, the zener diode starts to conduct allowing gate current to flow into the SCR turning it "ON" and shorting out the load supply voltage and blowing the fuse. Then the load is protected from transient voltages above the zener voltage, V_Z as the zener diode only carries the gate current for SCR to turn “ON”, as the SCR itself will carry the bulk of the shunt current.

While this zener crowbar circuit is an improvement on the basic voltage divider network, it suffers from a soft turn-on action because the knee at zener breakdown voltage is curved rather than sharp rise. The basic crowbar circuit that can be modified and improved further by adding some voltage gain to the detection and triggering circuit in the form of a single amplifier circuit or op-amp circuit.

To that end, thyristors with an over voltage trigger built in have been designed to crowbar unidirectional or bidirectional transients and voltage surges. Such as the The RCA SK9345 series of IC crowbars which are designed to protect power supplies of 15 volts, the SK9346 which protects 112 volts, and the SK9347 protects which 115 volt supplies.

All use an integrated circuit with a built-in zener diode, transistors, and an SCR. The MC3423 over voltage crowbar sensing circuit is a single IC designed to be used with an external crowbar SCR.

Transient Suppression Devices Summary

As we use more electronic devices in our daily lives, we are becoming more dependent on over voltage protective devices for their role in protecting our equipment from voltage pikes and surges. Transient over voltages are usually caused by inductive or capacitive switching circuits which release sudden, high-voltage spikes.

These voltage spikes and surges can consist of high energy for a short period of time, or intermittently for short periods of time and are superimposed on top of a stead-state value such as an AC mains waveform.

Over voltage protection circuits can take many forms from series connected filters which are designed to pass power-line frequency voltages and currents while rejecting unwanted high frequency harmonics and noise, to parallel connected clamping and crowbar circuits which dissipates the over voltage to ground.

The simplest type of AC power-line filter is a capacitor placed across the voltage source. The impedance of the capacitor changes resulting in attenuation of high-frequency transients. In most applications, the transient suppression device is placed in parallel with the protected load, or in parallel with some component to be protected.

The main purpose of a voltage suppression circuit is to clamp the voltage to a safe level. The most common form of voltage clamping devices are metal oxide varistors, MOV’s and Zener Diodes. MOV’s are best suited for protection on bidirectional AC power supplies, while zener diodes are best suited for smaller low energy DC supplies.

Solid-state crowbar circuits which use an SCR or triac as a “crowbar” rapidly shorts the voltage transient across the power supply to blow the fuse for over-voltage protection. Hybrid transient/surge protectors combine a crowbar with a clamp, or a clamp/crowbar with a filter, in one module and there are many different combinations are possible.

28 Comments

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W

www

Hello! Someone in my Myspace group shared this site with us so I came to check it out. I'm definitely enjoying the information. I'm bookmarking and will be tweeting this to my followers!
Great blog and excellent design.

Posted on February 11th 2021 | 6:19 am

Reply

J

Johnny mullins

Need help where to find a transient voltage protector znr 14k151 s52 or a comparable replacement. To repair a craftsman ac/dc stick welder. I'm novice to internet. If this is not the right place to post this question , please forgive my ignorance and thanks anyway.

Posted on December 23rd 2020 | 3:04 am

Reply

W

Wehibe

It is nice to see various way of protecting loads

Well done!

Thank you for your time

Posted on December 17th 2020 | 2:27 am

Reply

U

Utsav Suthar

Yes

Posted on October 17th 2020 | 8:41 am

Reply

A

Alphonse E. Osowiecki

Can you supply circuit diagrams and parts lists?

Want to design a filter for home use to clean up my output power from a portable power generator.

The rated output is 50 ampere.
Wattage is 13kw.

Posted on October 13th 2020 | 1:17 pm

Reply

F

Francis S. Kutshak,

What an interesting topic of discussion, I will love to know more about MOVs. Thanks for your time, God blessed in Christ Jesus. Amen

Posted on September 29th 2020 | 10:30 pm

Reply

Nick Thrower

I have a question that your article may have answered but I want to confirm. My problem is that I have a variable DC voltage (5v to 14v) & amp (0.5a to 20a) source that can spike at any voltage under certain conditions. Would the Zener Diode (perhaps a series of different voltage ones in parallel) be an answer to control the spikes. The control would need to happen every few 100ths of a second.

Any help appreciated.
Nick

Posted on April 18th 2020 | 1:33 pm

Reply

Wayne Storr

Unidirectional transient voltage suppressors, such as zener diodes (with or without series resistance), large value non-polarised capacitors, or spark gaps can all be used to protect against overvoltage on a DC supply. The breakdown voltage of the protective device, that is the voltage at which it goes into avalanche breakdown as well as its peak-pulse power rating, that is its surge-absorbing capabilies need to be considered. Adding current limiting resistors in series with the load can help reduce the transient current, allowing for smaller power-rated suppressors as the secondary protective device.

Posted on April 19th 2020 | 8:02 am

Reply

DR S C BHARGAVA

What is the best way to protect the distribution board against an over voltage when the phase voltage may rise to L-L voltage in the event of an 'open' neutral due to wire break or otherwise. This kind of unpredictable sudden voltage rise caused irreparable damage to many H/H appliances recently.

Posted on June 27th 2019 | 7:32 am

Reply

Wayne Storr

Your comment of "in the event of an "open" nuetral due to wire break" is a permanent fault condition and will cause the phase voltage to float about, but as there is no return path the voltage on the phase wire will sit there with zero current flow so there will be no "unpredictable sudden voltage rise". The way to protect from open nuetral due to wire break is regular inspection and maintainence of the distribution board.

Posted on June 27th 2019 | 7:20 pm

Reply

B

Boje Breinbjerg

Thank you very much for this fine article.
Still I just miss an explanation in regards to a Transient Diode in series with a high Voltage AC (input) and a Capacitor in parallel with the Diode.
How does this work and what's the best values ?
Thanks in advance !

Posted on May 19th 2019 | 6:22 pm

Reply

Chris

very nice article,
I am using the crowbar overvoltage clamping with scr and zener Diode for my bicycle dynamo hub. I there is overvoltage because of high speed and low load, the scr fires and short circuit the dynamo. As an dynamo is a highly inductive current source, this will not waste any power and when cuurent continues to flow, it does not cause vibrations. for me the best solution. thas to the examples here i did add a resistor at the gate. I us BRX49 a tiny scr with small trigger current.

Posted on February 14th 2019 | 2:43 pm

Reply

W

Wayne Storr

It is assumed that for crowbarring the SCR is placed in parallel with the load and not conducting (cut-off) until the dynamos output voltage rises above some predetermined level established by the zener diode. The issue here is that the output of the dynamo is shorted, and being a DC generator, the SCR may not turn-off again once fired. The SCR must have a high single-pulse I^2*t and di/dt rating.

Also, shorting the output of the dynamo (DC generator) causes an action called "Dynamic Braking" which produces a counter torque and braking action as the kinetic energy of the generator (and the bicycle connected to it) is converted into heat, so the dynamo itself must be protected against long periods of shorted output.

Posted on February 15th 2019 | 8:11 am

Reply

M

Mark Ratcliffe

Followed this post over from pi.org forums (not as technical as the more 'hard core' sites). I thought you were going to tell us why we shouldn't plug our fans into the 5 volt io?

"What does it all mean Basile?" Where do we plug it ?? Click bait ?

Posted on December 03rd 2018 | 11:29 pm

Reply

W

Wayne Storr

Plugging 12 volt fans into 5 volt IO's will damage the port.

Posted on December 04th 2018 | 8:58 am

Reply

G

gobinath

Hello guys , I have a doubt in dual common cathode schottkey diode explain the answer some one

Posted on October 26th 2018 | 1:01 pm

Reply

S

Sam

if you have an input which you want to protect from both small-signal conducted EMI and large transients, typically you would put a ferrite bead in series and mov or transorb in parallel. I'm wondering if anyone has any good rationale for putting the mov/xorb before or after the ferrite. If you put the mov/xorb after the ferrite, can large transients damage the ferrite? If you put it before can high frequency noise couple through the mov/xorb's parasitic capacitance and get into your system?

Posted on July 10th 2018 | 2:03 pm

Reply

R

Roopa

We are facing problem of MOV failure due to over voltage. Is there any circuit which can protect the circuit which is better than MOV.

Posted on March 10th 2018 | 8:43 am

Reply

Wayne Storr

If the MOV fails its protecting the circuit or is under rated

Posted on March 10th 2018 | 9:14 am

Reply

C

Charles West

If the MOV fails, it is over-rated. You need to de-rate (under-rate) a component if you want increased reliability.
I wouldn't employ a plumber if someone told me she was over-rated.

Posted on September 15th 2018 | 5:26 pm

Reply

S

s bhattacharya

Just got the fresh brushing up of the age old basics.

Posted on February 06th 2018 | 10:26 am

Reply

Simon

Excellent article, very informative and clearly explained. Thank you very much.

Posted on February 03rd 2018 | 12:21 am

Reply

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manicjosaeph

oh God this is amazing I really love electronics and I cant another place else to fill my wishes so this has been a great start to learning apart from school keep it up

Posted on March 10th 2017 | 6:39 am

Reply

Alan Jones

I want to switch on a 6ft fluorescent 250 volt tube from a relay. The max relay contact current is 10amp. ac. Do I need an MOV across the contacts to prevent arcing, and if so what spec. (clamping voltage, MOV max. voltage, etc) ?

Posted on February 12th 2017 | 1:50 pm

Reply

manicjoseph

awesome

Posted on March 10th 2017 | 8:10 am

Reply

Wayne Storr

I would assume that the ON/OFF switching of the relay and therefore the fluorescent tube would be infrequent therefore any additional suppression may not be needed. If you decided to use something, either an MOV or RC snubber will help reduce the arcing of the contacts as they open, but the amount of arcing depends also on the load. If you choose to use an MOV for such a low energy load, something like a V275-LA10A, or LA20A or any equivalent would suffice.

Posted on February 12th 2017 | 8:55 pm

Reply

K

Kevin King

Nice article on transient suppression. Very informative

Posted on January 26th 2017 | 8:21 pm

Reply

S

sumon

transistor

Posted on January 04th 2017 | 5:02 pm

Reply