

1. WHAT IS A VARISTOR?

A varistor has the volt-ampere characteristics in which current suddenly starts to flow through the device at a certain voltage, as shown in Figure 1.

The varistors are used to protect semiconductor devices in electronic and electric circuits from overvoltage. As shown in Figure 2, a varistor is inserted in parallel with a circuit to be protected. When an impulse is applied to the circuit, pulse current I_s , which is determined by pulse voltage V_s and pulse impedance Z_s , flows to limit the pulse voltage to the varistor limit voltage V_{clamp} .

The relation can be expressed by the equations as follows:

$$V_s = I_s \times Z_s + V_{clamp} \quad (1)$$

$$V_{clamp} = V_s - I_s \times Z_s \quad (2)$$

The pulse current I_s is easily obtained by the following equation because of $V_s \gg V_{clamp}$.

$$I_s \doteq \frac{V_s}{Z_s} \quad (3)$$

Thus, the circuit can be protected from being damaged by pulse voltages as long as it has withstand voltage larger than the maximum limit voltage.

Owing to the characteristic, the varistors are extremely effective as protecting devices of electronic and electric equipment by absorption of abnormal voltages and lightening pulses.

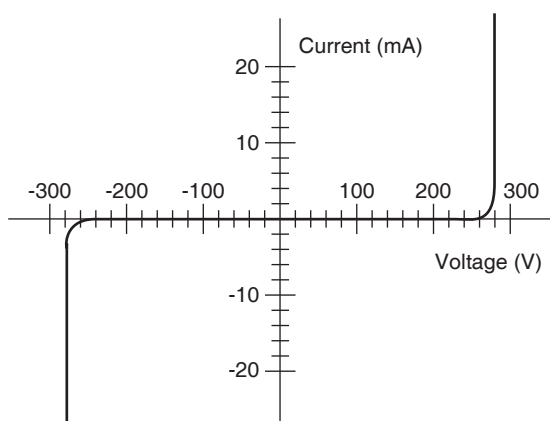


Fig. 1 Volt-ampere characteristics of varistor

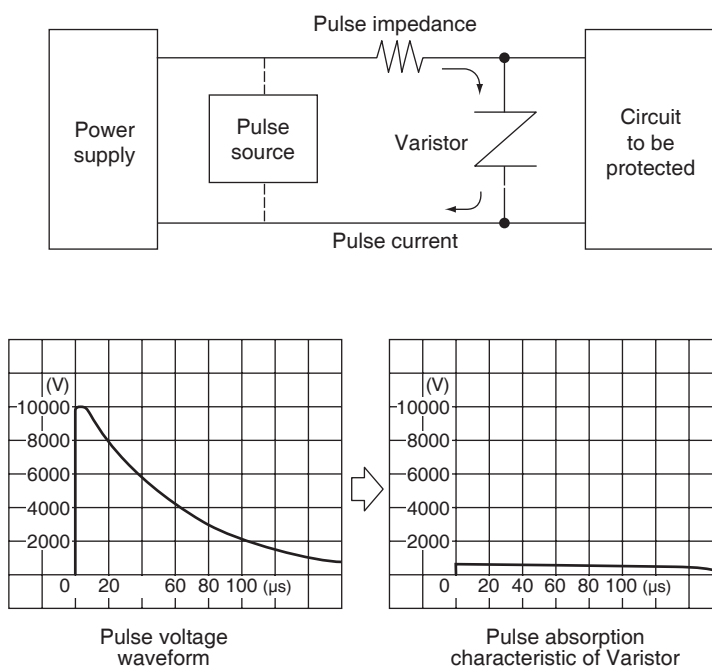


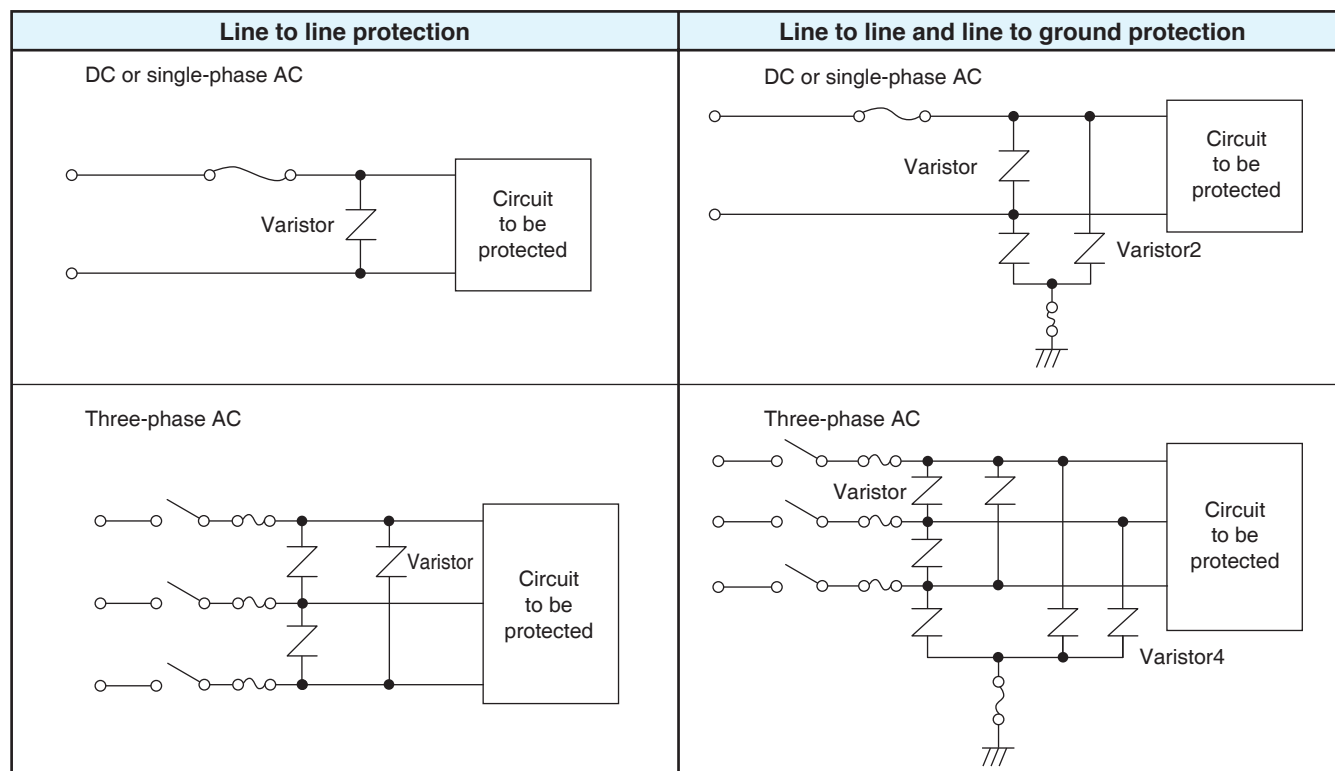
Fig. 2 Pulse absorption by varistor

2. SAMPLE USED AND NOTES ON Varistor

This chapter describes general sample uses and notes on use of Varistors. Take these conditions into consideration when you select Varistors of appropriate ratings.

2-1 PROTECTION FROM POWER PULSE

(1) Examples of wiring



(2) Examples of rating selections

Varistor used for line to line		Varistor used for line to ground	
Power Voltage	Type	Varistor	Type
AC100V	TND□□V-221K	Varistor2	TND□□V-431K
	TND□□V-241K		TND□□V-471K
	TND□□V-271K*		TND□□V-911K≤**
AC200V	TND□□V-391K	Varistor4	TND□□V-182K ***
	TND□□V-431K		TND□□V-431K
	TND□□V-471K*		TND□□V-471K
DC12V	TND□□V-220K		TND□□V-911K≤**
	TND□□V-270K		TND□□V-182K ***
DC24V	TND□□V-330K		
	TND□□V-390K		
	TND□□V-470K		

Notes:

1)If a Varistor is used at power voltage other than the examples above, never make the power voltage increase over the maximum allowable voltage.

2)For individual wiring or capacitive load, the power voltage is temporarily increased by resonance at switch on or off. Thus, use a Varistor of the type with mark * for the power of 100 VAC or 200 VAC.

Notes:

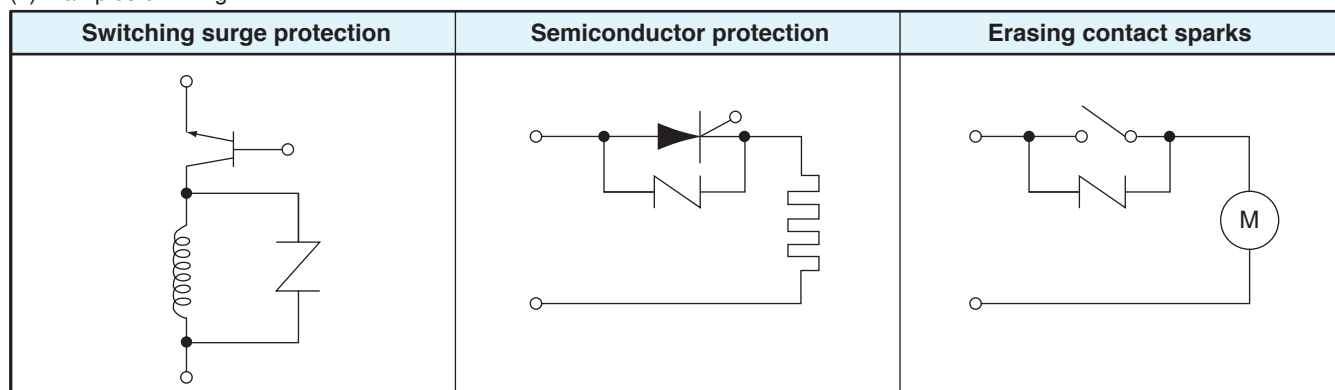
1)In an insulation resistance test (500V mega test) of a unit, it may incorrectly judged to be bad due to its leak current from the Varistor mounted on the unit. Test the unit with the Varistor removed after obtaining approval of the unit user on removing the Varistor. Or use a Varistor with mark ** for the test unit.

2)In a withstand voltage test (1000 VAC test) of a unit, it may incorrectly judged to be bad due to its leakage current from the Varistor mounted on the unit. Test the unit with the Varistor removed after obtaining approval of the unit user on removing the Varistor. Or use a Varistor with mark *** for the test unit.

3)Use a Varistor of 200 VAC type between the 100 VAC power line to ground to prevent the power supply from being damaged by overvoltage such as ground-fault.

2-2 PROTECTION OF SEMICONDUCTORS AND ICs FROM INDUCTIVE ON/OFF PULSES AND ERASE OF CONTACT SPARKS

(1) Examples of wiring



(2) Examples of rating selections

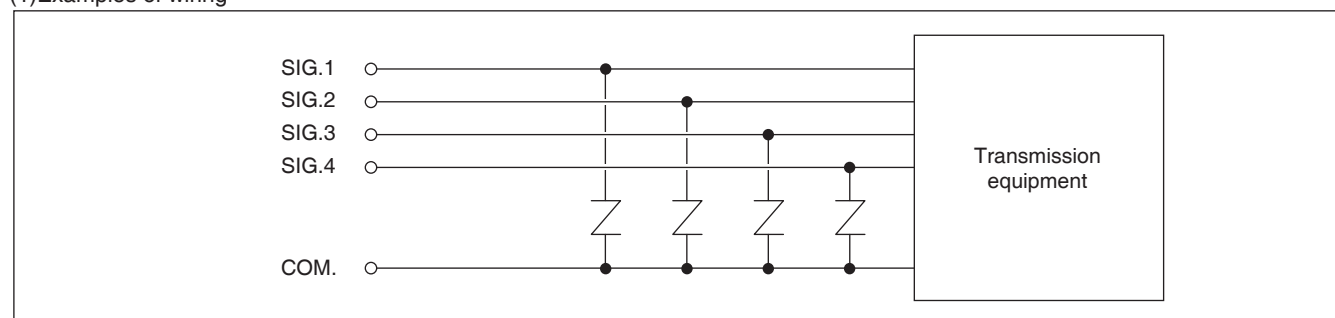
Examples of general selections		
Power Voltage	Type	Notes: 1) If a Varistor is used at power voltage other than the examples to the left, never make the power voltage increase over the maximum allowable voltage. 2) For other than a complete DC voltage, never make the maximum peak voltage increase over the maximum allowable voltage. 3) Take the pulse energy generated in load into account sufficiently to define the maximum peak current, maximum energy, and rated wattage.
DC 12V	TND□□V-220K	
DC 24V	TND□□V-390K	
DC100V	TND□□V-151K	
AC100V	TND□□V-221K TND□□V-241K TND□□V-271K	

(3) Notes on use of Varistor

1. Be careful of the notes described in Section 2-1 "PROTECTION FROM POWER PULSE."
2. Select a proper Varistor satisfying the desired relationship between the number of pulse applications and the Varistor rating, referring to the reduction curve of pulse life time ratings.
3. Select a Varistor having rated wattage larger than averaged pulse wattage to make the Varistor absorb high-frequency pulses.

2-3 REDUCING PULSES ON SIGNAL TRANSMISSION LINES

(1) Examples of wiring



(2) Examples of rating selections

Examples of general selections		
Signal Carrier Voltage	Type	Notes: 1) Any Varistor includes electrostatic capacitor listed in the rating table. Take special note when a Varistor is applied to high-frequency signal. 2) When signal of higher voltage than that of normal signals (such as bell signal) is superimposed on normal signals, select an appropriate Varistor available for the higher voltage. 3) Use a Varistor with a type of varistor voltage 82V or higher if signal is too low to be attenuated.
DC 12V max.	TND□□V-150K TND□□V-220K TND□□V-820K ≤	
DC 24V	TND□□V-390K TND□□V-820K ≤	

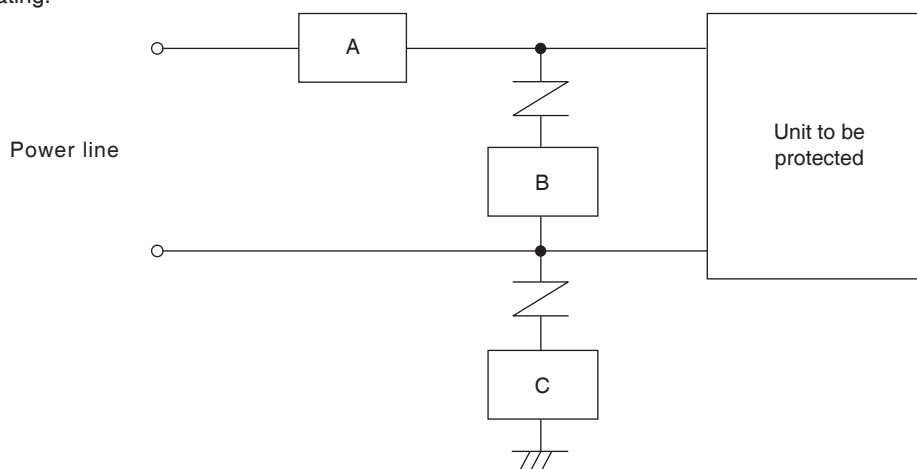
2-4 Examples of selections in fields

Example of general selections			
Use	Location	Type	Notes 1) Each number in the range between 5 to 20 specifies the diameter of a Varistor. The larger the diameter is the greater the maximum peak current of the Varistor is. Select a Varistor of the type covering the expected peak current. 2) Pay sufficient attention to the conditions peculiar to the unit on which the selected Varistor is mounted as well as normal selection examples.
Commercial	Indoor	TND05V-□□□K	
		TND07V-□□□K	
		TND10V-□□□K	
		TND12V-□□□K	
	Outdoor	TND07V-□□□K	
		TND10V-□□□K	
		TND12V-□□□K	
		TND14V-□□□K	
Communication, Measurement, Control	Indoor	TND07V-□□□K	
		TND10V-□□□K	
		TND12V-□□□K	
		TND14V-□□□K	
	Outdoor	TND07V-□□□K	
		TND10V-□□□K	
		TND12V-□□□K	
		TND14V-□□□K	
Industry, Power	Indoor or outdoor	TND14V-□□□K	
		TND20V-□□□K	

2-5 Notes on use

Take the notes for reduction of power pulses into account as well as those explained below.

1. Take the action shown in the figure below because the Varistor may be short-circuited or broken when it absorbs a pulse exceeding its rating.



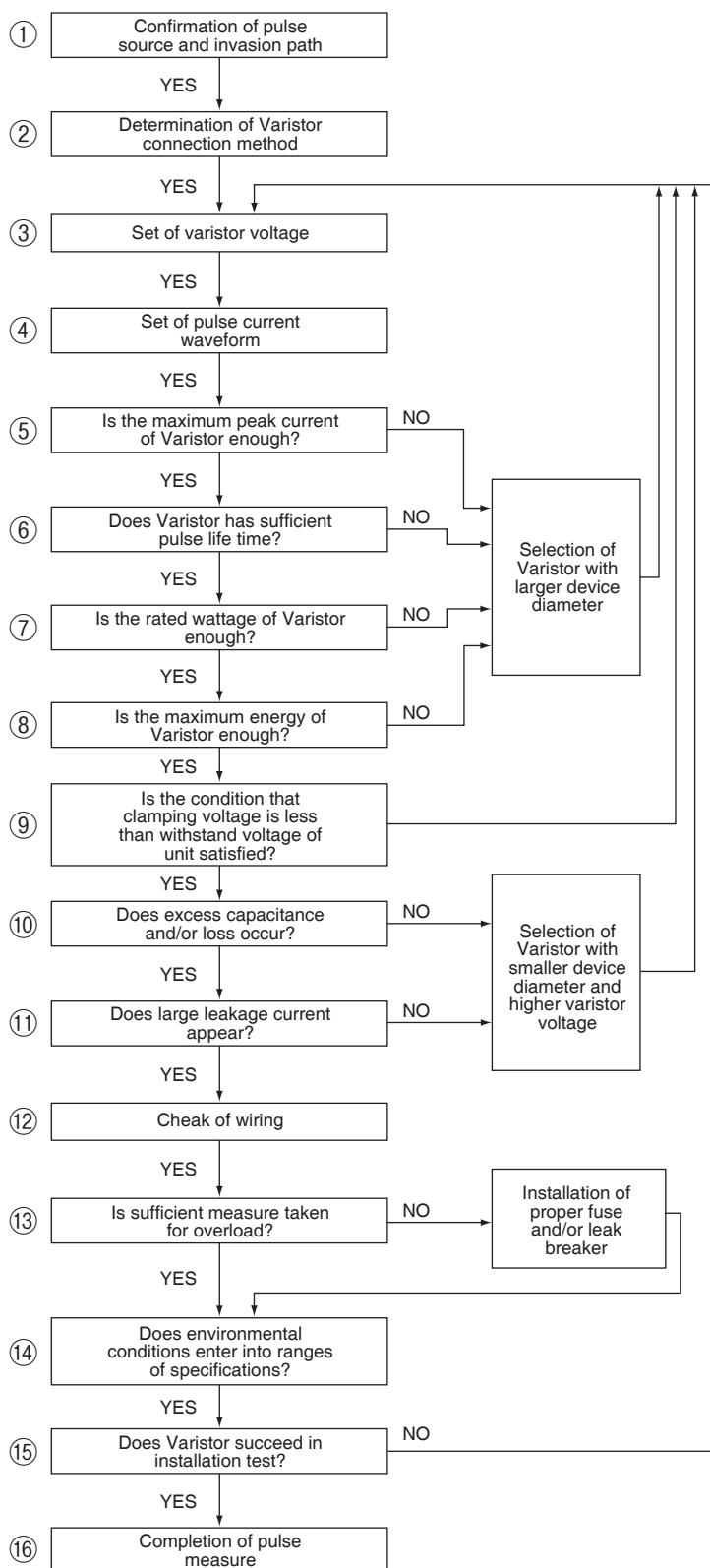
- 1) Mount the Varistor closer to the circuit than the overcurrent protector such as a breaker or fuse to disconnect the Varistor from the power supply immediately at short circuit of the Varistor.
- 2) Mount the overcurrent protector at location B if it cannot be mounted at location A.
- 3) Selection examples of ratings of fuses mounted at location A or B are listed below:

Type (TND-)	05V-□□□K	07V-□□□K	09V-□□□K 10V-□□□K 12V-□□□K	14V-□□□K 20V-□□□K
Fuse rating	3A max.	5A max.	7A max.	10A max.

- 4) Use a leak breaker or at position A or mount a temperature fuse connected thermally to the Varistor at position C if the Varistor inserted between the power line and the earth is grounded to the unit earth. It is also effective to use a Varistor of the GF series which includes a thermal fuse.
2. Check that the Varistor is used within the range of the rating operating temperature if it is exposed to direct sunlight or placed near a heating unit.
3. Make wiring of the Varistor as short as possible. With long wiring, large voltage drop occurring at a rapid rising pulse on the L component of the wiring causes the Varistor not to be effective enough for surge absorption.

3. SELECTION OF Varistor RATING

3-1 RATING SELECTION PROCEDURE

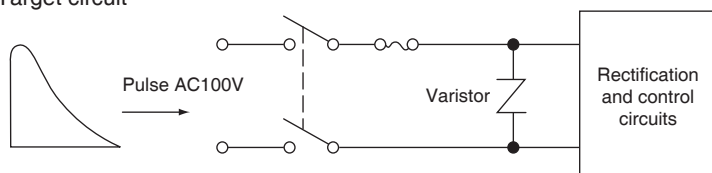


- ① Make clear pulse sources and invasion paths including outer lightning, inner lightning (on/off lightning), line to line portion, line to ground portion, power line, and signal line.
- ② See the Sample uses and notes on Varistor described earlier for the connections of Varistors.
- ③ Set the varistor voltage so that the circuit voltage may not exceed the maximum allowable voltage. Take fully care of the applied voltage in insulating resistance or withstand voltage test if the Varistor is inserted between a line to ground.
- ④ The peak pulse current is almost equal to the value obtained by dividing the expected pulse voltage by the pulse impedance.
- ⑤ Select a Varistor with device diameter for the maximum peak current larger than the peak pulse current if the expected number of pulses are not more than 2.
- ⑥ If many impulses are expected, select a Varistor with device diameter for pulse life time longer than the requested life time, referring to the figure of pulse life time ratings.
- ⑦ Select a Varistor with device diameter for rated wattages larger than the averaged pulse wattage if pulses are applied continuously to the Varistor at a high rate.
- ⑧ Take care of the maximum energy as well if impulses are expected to have high energy.
- ⑨ Select the varistor voltage and diameter of Varistor so that the withstand voltage of the unit to be protected exceeds the maximum clamping voltage. If no Varistor can satisfy the requested characteristics, it may be necessary to make the withstand voltage of the unit higher.
- ⑩ Contact us when you use a high frequency circuit. The capacitance of the Varistor may attenuate high frequency signals and the Varistor may be heated by the loss.
- ⑪ See the maximum leakage current known from the volt-ampere characteristic curve.
- ⑫ Make wiring as short as possible. With long wiring, large voltage drop occurring at a rapid rising pulse on the L component of the wiring and its magnetic joint with other wiring cause the Varistor not to be effective enough for surge absorption.
- ⑬ Connect a fuse before the Varistor. See 2-5 for selection of a fuse.
- ⑭ Take note that the temperature around the Varistor does not become larger than the maximum operating temperature.
- ⑮ Perform installation test as much as possible to confirm the performance of the Varistor.
- ⑯ The action for absorbing pulses by Varistor is now completed.

3-2 EXAMPLES OF Varistor SELECTION

3-2-1 ACTION FOR EXTERNAL LIGHTENING PULSES OF POWER SUPPLY OF CONTROL UNIT

(1) Target circuit



Conditions

- 1) Withstand voltage V_t : 600V
- 2) Pulse impedance Z_s : 50ohm
- 3) Pulse voltage V_s : 12kV at duty cycle of 1.2/50μsec
- 4) Number of pulses: 100 = 10times × 10years
- 5) Pulse interval: 2 minutes or more

(2) Selection of Varistor based on rating selection procedure

1. Confirmation of pulse source and invasion path: Circuit between external lightning pulse and power line. (The unit is not grounded.)
2. Determination of Varistor connection method: Between power lines. (AC power input side of unit to be protected.)
3. Set of varistor voltage
Select the Varistor of 270V type based on the above sample use, because it is inserted between the 100 VAC power lines. Select a proper type of a Varistor if the relationship between the withstand and clamping voltages of the unit to be protected does not satisfy the condition described in item 9.
4. Set of pulse current waveform
 - a) Pulse current peak value (I_p)

$$I_p = \frac{V_s}{Z_s} = \frac{12,000}{50} = 240[A]$$

b) Duration of wave tail of pulse current

The duration of wave tail of pulse current can be shorter than that of pulse voltage. However, set the duration of wave tail of pulse current T to 40μs for safety. (In actual, it is about 25μs if the pulse voltage wave has the duty cycle of 1.2/50μs.)

5. Is the maximum peak current of Varistor enough?
Because the maximum peak current is 240A, it is often considered that a Varistor of 5V type with the maximum peak current of 250A (secured for two pulses) can be available. However, the duration of wave tail of pulse current is not 20μs for a total of 100 pulses. Thus it is necessary to check the pulse life time of the Varistor.
6. Does Varistor have sufficient pulse life time?
The conditions include $I_p = 240A$, $T = 40μA$, total number of pulses = 100, and pulse interval = 2 minutes or more. Collate these four conditions with the pulse life ratings of the Varistor. (Refer to the manual of CAT. No. 1006 for the pulse life time ratings.)

Varistor Type	Number of pulses
5V	2 to 10
7V	10 to 100
10V	100 to 1000
14V	1000 to 10000

Depending on the above specification, a Varistor of the 10V type can be selected. Thus the Varistor of type TND10V-271K is determined as a candidate from the results above together with the result described in Item 3.

7. Is rated wattage of Varistor enough?

The rated wattage of the Varistor should not particularly be taken into account because the pulses are supplied to the unit at a low frequency.

8. Is the maximum energy of Varistor enough?

The maximum energy of the Varistor should not be taken into account because lightening pulses of short duration of wave tail is only applied to the unit.

9. Is the condition that clamping voltage is less than withstand voltage of unit satisfied?

The maximum clamping voltage of TND10V-271K is defined as $V_{25A} = 455V_{max}$ in the rating table. However, since the maximum current flowing through the circuit is 240A, the voltage at 240A should be read from the Varistor volt-ampere characteristics to compare it with the unit withstand voltage of 600V. The relationship is satisfied as follows: $V_{240A} = 510V < 600V$ (See the manual CAT. NO. 1006 for the Varistor volt-ampere characteristics.)

10. Does excess capacitance and/or loss occur?

As the power line of commercial frequency 50 to 60 Hz is low frequency, it does not cause severe problems.

11. Does large leakage current appear?

As the 100 VAC power line produces only a small leakage current of several μA, it does not cause severe problems.

12. Check of wiring

Note that the wiring to the Varistor is not be electrostatically and magnetically coupled with the rectification circuit and control circuit lines. Make the wiring as short as possible to minimize the stray inductance.

13. Is sufficient measure taken for overload?

Attach a fuse of about 5A before the Varistor for occurrence of overvoltage. (See 2-5.)

14. Do environmental conditions enter into ranges of specifications?

Check operating temperature range of the unit unless it is used near heaters such as coils.

15. Does Varistor succeed in installation test?

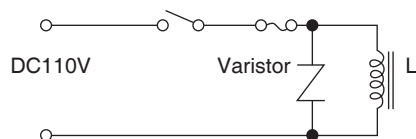
Perform the test with TND10V-271K connected to confirm the performance of the unit.

16. Completion of pulse measure

After insertion of TND10V-271K to the unit as shown in the figure, the action required for absorbing pulses is now completed.

3-2-2 ACTION FOR ON-OFF PULSE FROM RELAY

(1) Target circuit



Conditions

- 1) Coil rating: $I = 0.25\text{ A}$, $L = 1\text{ H}$
- 2) Relay operation: 2 times per sec, 8 hours per day, and 6 days per week
- 3) Life: 5 years
- 4) Number of pulses: $2 \times 3600 \times 8 \times 313 \times 5 = 0.9 \times 10^6$
- 5) Desired suppress voltage: up to 250 V

(2) Selection of Varistor based on rating selection procedure

1. Confirmation of pulse source and invasion path: Wiring between on/off relay line and power line.
2. Determination of Varistor connection method: Between power line (in parallel with coil).
3. Set of varistor voltage

A Varistor will be inserted between the 110 VDC power lines. Because the application is not defined as a typical example, the varistor voltage must be determined from the relationship between the circuit voltage and the maximum allowable voltage. Select the Varistor of type 151K (150V) with the maximum allowable voltage of 121V or more, assuming voltage fluctuation of + 10%.

4. Set of pulse current waveform

a) Pulse peak current (I_p): 0.25A same as load current.

b) Duration of wave tail of pulse current

The duration of wave tail of pulse current can be calculated from the following equation assuming the pulse current wave to be a square wave.

$$E = 1/2 L I_p^2 = 0.5 \times 1 \times 0.25 \times 0.25 = 0.031[\text{J}]$$

$$T = \frac{E}{I_p \cdot V_p} = \frac{0.031 \times 1000}{0.25 \times 220} = 0.56[\text{ms}]$$

where V_p : estimated clamping voltage of Varistor of type 151K at 0.25A read from the Varistor volt-ampere characteristics.

5. Is the maximum peak current of Varistor enough?

Check the pulse life time of the Varistor because pulses occur at a high frequency.

6. Does Varistor have sufficient pulse life time?

The conditions include $I_p = 0.25\text{ A}$, $T = 0.56\text{ msec}$, number of applied pulses = 0.9×10^6 , and applied pulse interval = 0.5 sec. Since the applied pulse interval is shorter than the specification of 10 sec, the equivalent current and the equivalent number of applied pulses should be found with the equivalent interval set to 10 sec.

$$\text{Equivalent current} = 0.25 \times \frac{10}{0.5} = 5[\text{A}]$$

$$\text{Equivalent number of applied pulses} = 0.9 \times 10^6 \times \frac{0.5}{10} = 4.5 \times 10^5$$

In addition, the duration of wave tail of the pulse current T is $0.56\text{ msec} = 560\text{ }\mu\text{sec}$ as known from the result of Item 4. Collate these conditions with the pulse life time rating of the Varistor.

Varistor type	Number of pulses
7V	$10^5 \text{ to } 10^6 < 4.5 \times 10^5$
10V	$> 4.5 \times 10^5$

Depending on the above specification, a Varistor of the 10V type can be selected. Thus, the Varistor of type TND10V-151K is determined as a candidate from the results above together with the result described in Item 3.

7. Is rated wattage of Varistor enough?

The averaged wattage $P_s[\text{W}]$ absorbed by the Varistor is, $P_s = E f_s = 0.031 \times 2 = 0.062[\text{W}]$

where f_s is the repeated pulse frequency [times per sec]. From the viewpoint of the absorbing wattage, a Varistor of 5V type (0.1W) may be available. However, a Varistor of 10V type (0.4W) is better if the pulse life time ratings of the Varistor in Item 6 is also taken into account.

8. Is the maximum energy of Varistor enough?

This is also considered in the pulse life time because many pulses are applied to the Varistor (see Item 6).

9. Is the condition that clamping voltage is less than withstand voltage of unit satisfied?

The maximum clamping voltage of TND10V-151K was assumed to be about 220V in Item 4. By checking it with the Varistor volt-ampere characteristics, we find $V_{0.25\text{ A}} = 210\text{ V} < 250\text{ V}$. Thus this requested characteristic is satisfied.

10. Does excess capacitance and/or loss occur?

As the DC power line does not cause severe problems.

11. Does large leakage current appear?

As the 110 VDC power line produces only a small leakage current of several μA , it does not cause severe problems.

12. Check of wiring

Insert the Varistor near the coil as much as possible to reduce induction to other components.

13. Is sufficient measure taken for overload?

Attach a fuse of 3A to 5A before the Varistor for occurrence of overvoltage.

14. Do environmental conditions enter into ranges of specifications?

Check operating temperature range of the unit and temperature near the coils.

15. Does Varistor succeed in installation test?

Perform the test with TND10V-151K connected to confirm the performance of the unit.

16. Completion of pulse measure

After insertion of TND10V-151K to the unit as shown in the figure, the action required for absorbing pulses is now completed.

4. LOAD REDUCTION CURVE OF Varistor FOR TEMPERATURE

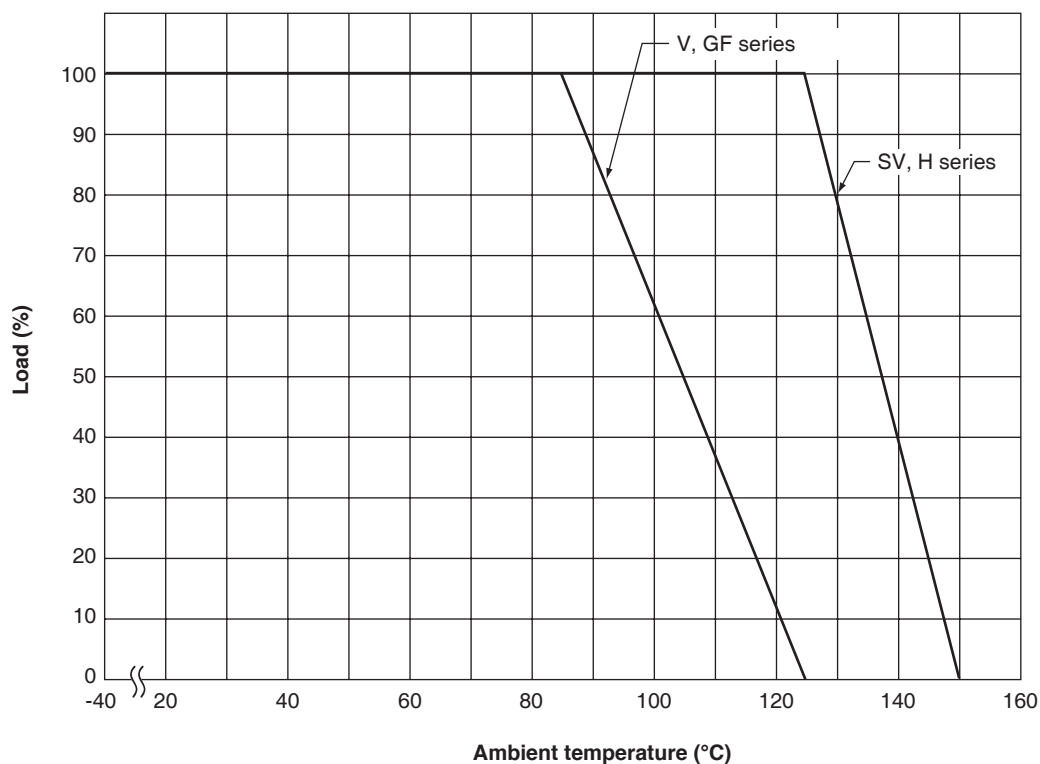


Fig. 3 Load reduction curve

The load includes the rated wattage, maximum allowable voltage, maximum peak current (SV series : Values of 2 times), maximum energy. For example, when TND10V-221K is used at 95°C, the load is found to be 75% from the load reduction curve above. Thus, the parameters can be calculated as follows.

1. Rated wattages	$0.4W \times 0.75 = 0.3W$
2. Maximum allowable voltage	AC : $140V \times 0.75 = 105V$ DC : $180V \times 0.75 = 135V$
3. Maximum peak current	$2500A \times 0.75 = 1875A$
4. Maximum energy	$27.5J \times 0.75 = 20.63J$

5. DETERIORATION OF Varistor

5-1 DETERIORATION OF Varistor

(1) In case where no pulses are applied to Varistor

As known from the relationship between mean life of Varistor and ambient temperature shown in the figure below, a Varistor can have the mean life of longer than 100 years if it is used at ambient temperature and circuit voltage within their maximum ratings. Accordingly it can be said that the Varistor has hardly been deteriorated.

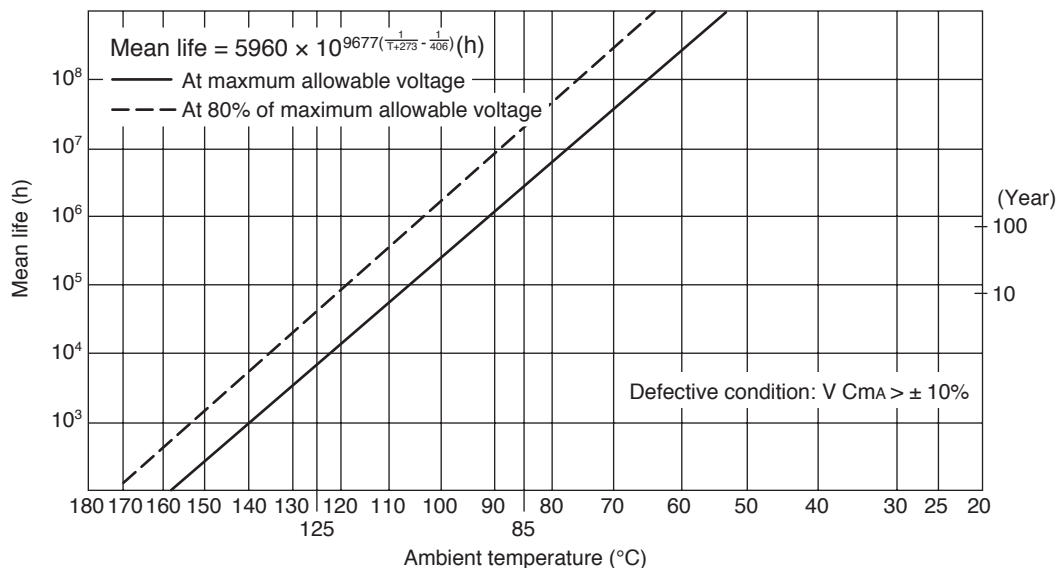


Fig. 4 Relationship between mean life Varistor and ambient temperature

(2) In case where pulses are applied to Varistor

Being a pulse absorption component, the Varistor is deteriorated if it is subject to pulses exceeding its rating.

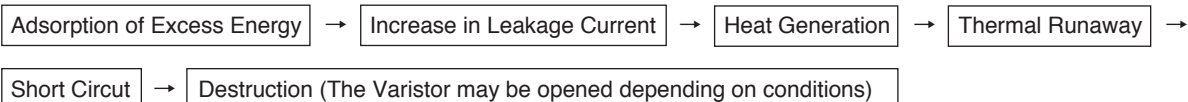
1. With lightning pulses applied to a Varistor, the waveform, energy, and frequency cannot be defined. Thus the period taken until the Varistor is deteriorated cannot also be determined.
2. With on/off pulses applied to a Varistor, the waveform, energy, and frequency can be measured or estimated. Thus the period taken until the Varistor can almost be estimated from the pulse life time ratings.

However, because a Varistor with the rating suited to the requested pulse life time ratings is normally selected, the Varistor will hardly be deteriorated within the life of equipment including the Varistor.

5-2 HOW TO CHECK DETERIORATION OF Varistor AND FREQUENCY OF THE CHECKING

(1) Deterioration of Varistor

The Varistor is deteriorated by overvoltage application caused by overpulses and fluctuation of power voltage.



(2) How to check deterioration of Varistor

As described in (1) of Section 5-2, the deterioration of a Varistor is known by increase in leakage current. Accordingly, how a Varistor is deteriorated can be measured by the leakage current.

The initial value of the leakage current of a Varistor (or leakage current occurring when the DC voltage half of the nominal varistor voltage is applied to the Varistor) is about $1\mu\text{A}$ though the value varies depending on the rating of the Varistor. The leakage current of $10\mu\text{A}$ is a sign that deterioration begins in the Varistor, so the Varistor should be replaced with a new one.

However, the leakage current of $10\mu\text{A}$ causes the Varistor to generate only the minimum heat, which will not lead the thermal runaway immediately. The Varistor has a shorter pulse life than that in the initial state.

6. PULSE RESPONSE CHARACTERISTICS OF Varistor

The Varistor itself has a response time for a pulse as extremely short as 1 nsec. However, it is difficult to measure the time because of a large influence of the inductance of lead wire.

In actual use, the clamping voltage is increased a little with a fast rising pulse even at the same current because of influence of the inductance of lead wire. Figure 5 shows the ratio of clamping voltages at faster pulse rise times to the clamping voltage at application of standard pulse current waveform of 8/20 μ s, which is called overshoot ratio. The figure is an example when pulse current having rising time of 0.5 μ s to 8 μ s and constant peak current of 10A are applied to TND14V-271K. In the figure, the overshoot of about 10% appears at the rising time of 0.5 μ s.

In actual use of Varistor, the rising of pulse voltage is limited by inductance and capacitance on the way to transmit in line. The rise time is almost not less than 1 μ s.

The wiring should be as short as possible because longer wiring make the overshoot higher.

Figures 6 and 7 show pulse absorption characteristics of a Varistor with the wiring lengths of 5mm and 25cm respectively, as extreme examples. In these examples, the clamping voltage with wiring length of 25cm is about 1250V, which is about two times and a half of the clamping voltage of about 500V with wiring length of 5mm.

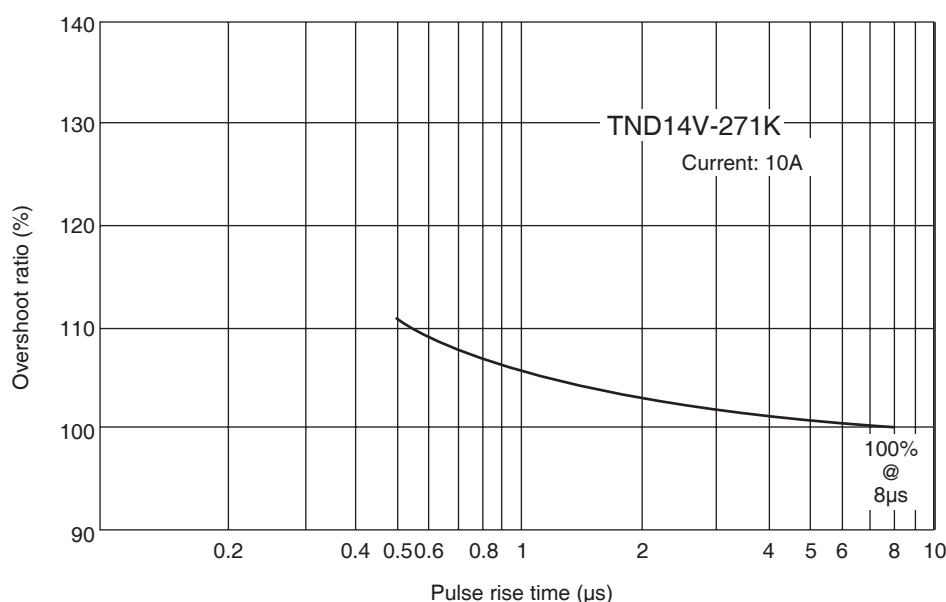


Fig. 5 Relationship between pulse rise time and overshoot ratio

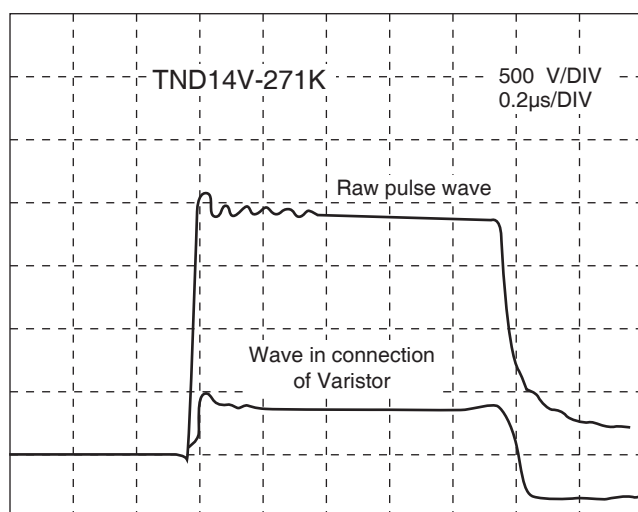


Fig. 6 Pulse absorption characteristic of Varistor (wiring length of 5mm)

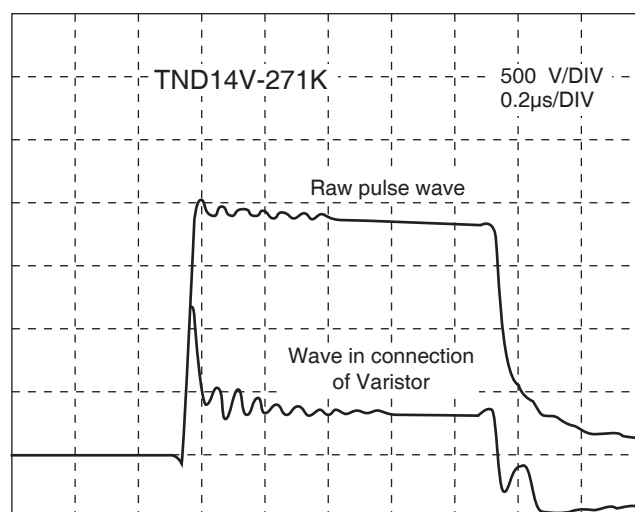
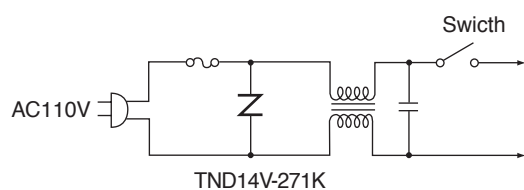
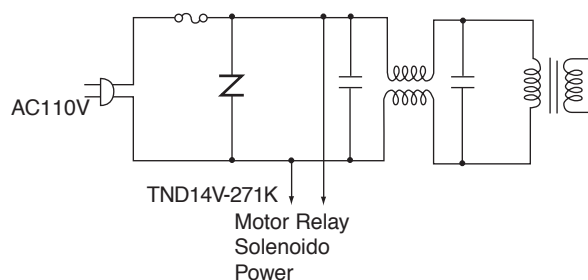


Fig. 7 Pulse absorption characteristic of Varistor (wiring length of 25cm)

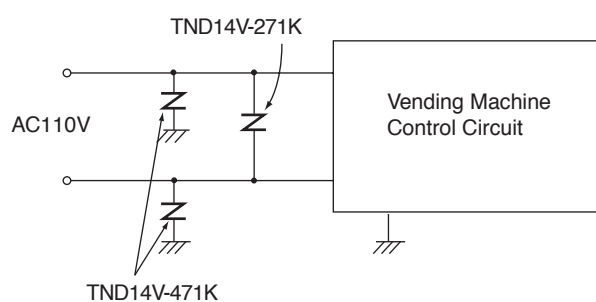
(1) Power Source Circuit



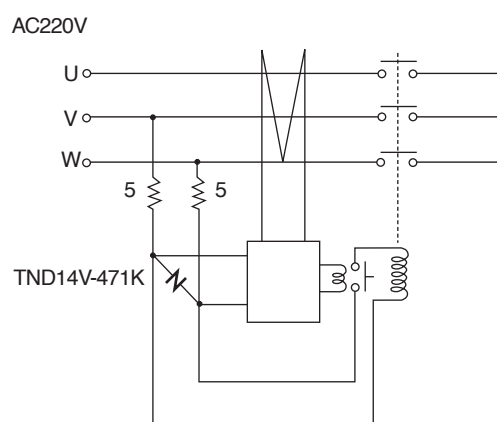
(2) Micro Computer Equipment



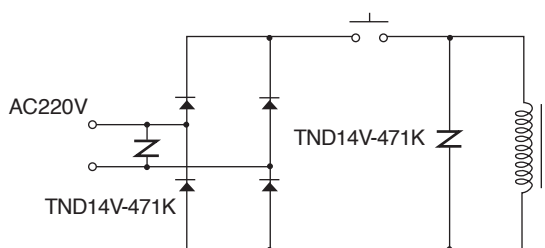
(3) Vending Machine



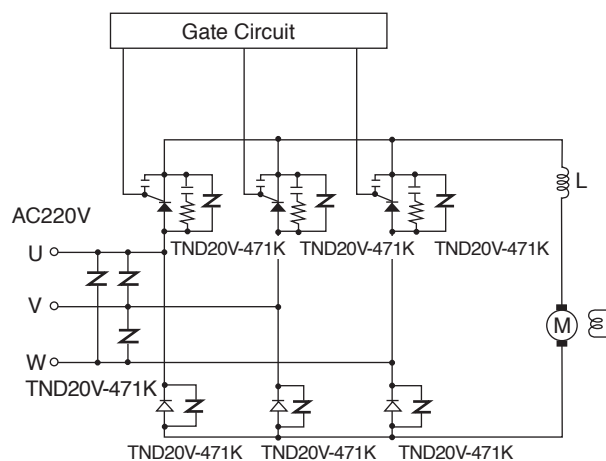
(4) Leakage Current Detector



(5) Magnetic Brake



(6) Control of 20kW DC Motor



(7) Telephone

