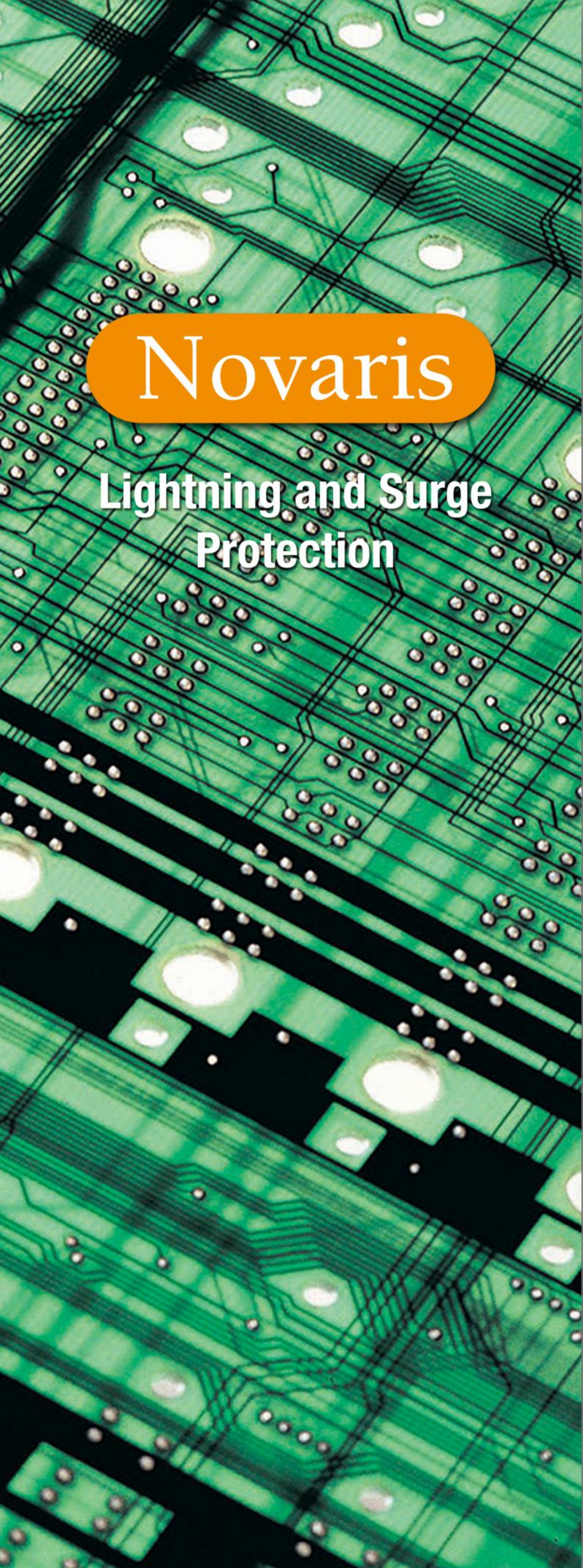

Surge protection for power systems

The application of surge protection for LV power distribution systems

Robert Jordan

Contents

Introduction

The distribution of commercial low voltage power has developed in different ways in countries around the world, often due to the country of origin of the first power system installed.

These differing systems use different electrical parameters and can vary from a single phase of 120 volts at 60Hz up to 440 volts three phase supply with or without neutral operating at 50Hz.

Some countries also have different systems operating in different regions, Japan, USA and the Philippines are examples of this.

All these facts make the application of the correct configuration of surge protection more difficult for the engineer.

This application note explains the differences between the various low voltage distribution systems in use and provides guidance on the selection of the most appropriate type of SPD's.

There essentially two types of surge protection device that are suitable for use on power systems. These are surge diverters (SD) and surge filters (SF).

Surge diverters (SD) are connected in parallel between power conductors or between power conductors and a neutral or earth with the aim of 'shunting or diverting' the surge energy away to neutral or ground. Generally, SDs are a single port device; they most usually just have two connection terminals (more if they are packaged into group modules) and are connected between lines. They are usually constructed using metal oxide varistors (MOV), Gas Discharge Tubes (GDT) or a combination of the two, a hybrid.

Surge Filters (SF) are more complex multistage SPDs that use filtering as well as diverting technology all combined into a single SPD package to provide much improved performance.

SFs are two port devices that are connected in series with the circuits to be protected so that the load or equipment side is separated from the dirty power side by the components contained inside.

The performance of the two types of devices differs greatly and there are some key differences in application.

For more details on the differences between these two families of device please refer to the Novaris Application note number 0015-D39V1.

Power distribution systems

All low voltage distribution schemes in commercial use around the world use alternating current (AC) at either 50 or 60Hz frequency. There are some specialist applications for railway and marine use that operate at different frequencies. If you need to specify surge protection for these systems contact Novaris for specialist engineering support.

DC systems are becoming more common with advent of Solar PV and battery storage but are not covered by this application note.

Distribution systems are either single or three phase; some systems employing a centre tapped secondary on the distribution transformer are known as two phase.

The configuration of the power distribution system and the method of earthing is explained below using the most common nomenclature of two-letter codes.

AS/NZS61439.1 describes three earthing arrangements, using the two-letter codes TN, TT, and IT.

The first letter indicates the connection between earth and the power supply equipment:

(i) T — Direct connection of a point to earth.

(ii) I — No point is connected to earth, or one point connected to earth through a high impedance.

The second letter indicates the connection between earth and the electrical equipment being supplied:

(i) T — Earth connection is by a local direct connection to earth, usually via an earthing system.

(ii) (ii)N — Earth connection is supplied by the electricity supply network, either as a separate protective earth (PE) conductor or combined with the neutral conductor (PEN).

(iii) Subsequent letters, if any – arrangement of neutral and protective conductors:

(iv) S – Protective function provided by a conductor separate from the neutral conductor or from the earth conductor.

(v) C – Neutral and protective functions combined in a single conductor (PEN conductor).

TN-S

The TN-S system has a separate neutral and protective earth conductor run to all customer premises. They are only bonded together at the power system supply point.

At the customer premises neutral terminals are connected to the neutral conductor and all exposed conductive parts are bonded to the protective earth conductor.

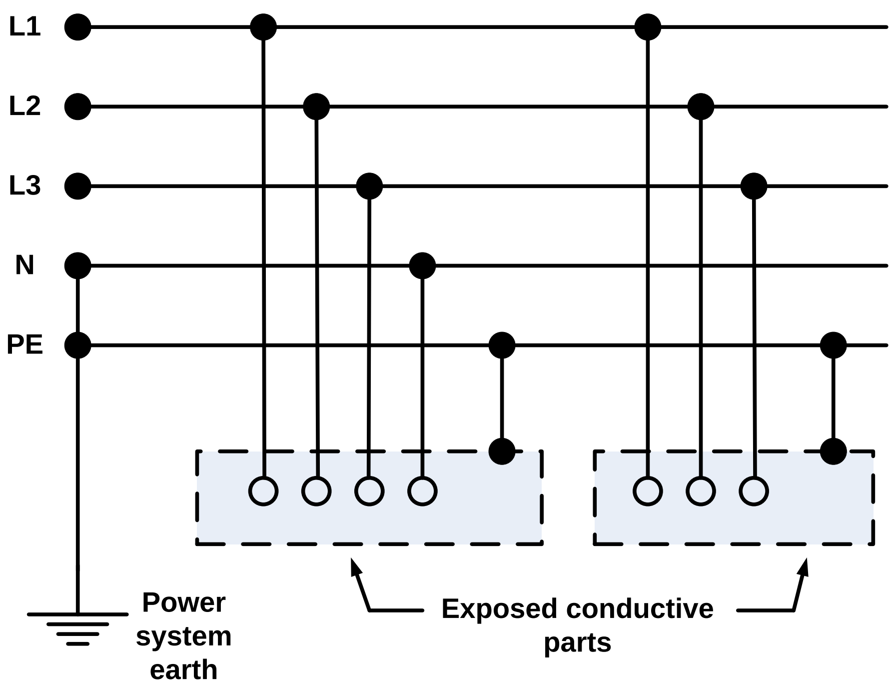

Figure 1. TN-S system schematic

TN-C

The TN-C system has the neutral and protective earth combined into a single conductor called a Protective Earth and Neutral, PEN.

At the customer premises both the neutral terminals of equipment and exposed conductive parts are bonded to the PEN conductor.

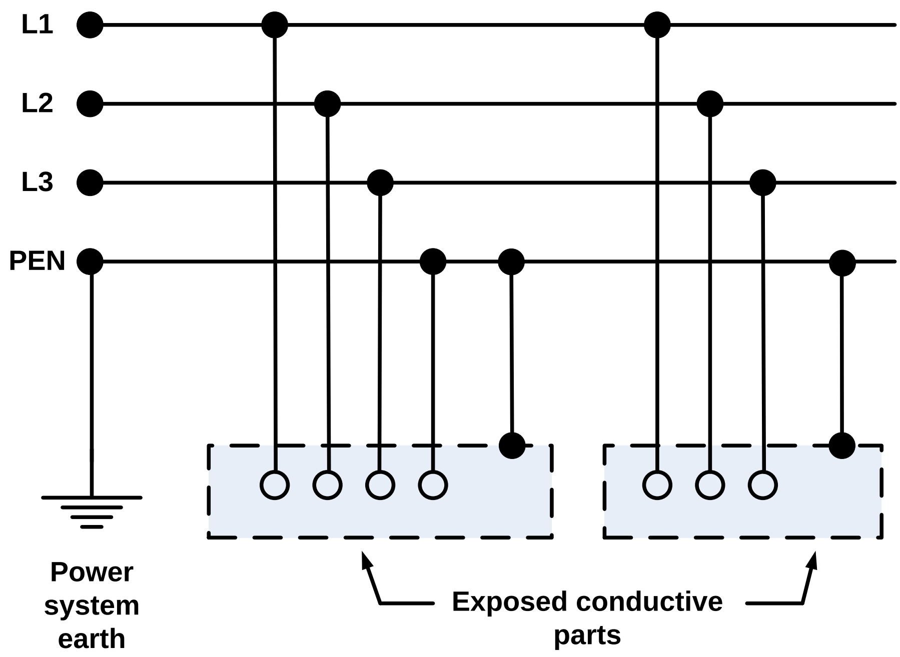

Figure 2. TN-C system schematic

TN-C-S

The TN-C-S system is also known as the Multiple Earthed Neutral (MEN) system and is used in Australia and New Zealand for commercial power distribution.

It differs from the TN-C system in that a local PE conductor is provided at the customer premises for the connection of exposed conductive parts and this is connected to a local earth system. Also, this local PE conductor is bonded to the neutral conductor at the main incoming power board with a single MEN link, but at no other point in the system.

Details of the requirements for this system can be found in AS/NZS 3000, “Wiring Rules”.

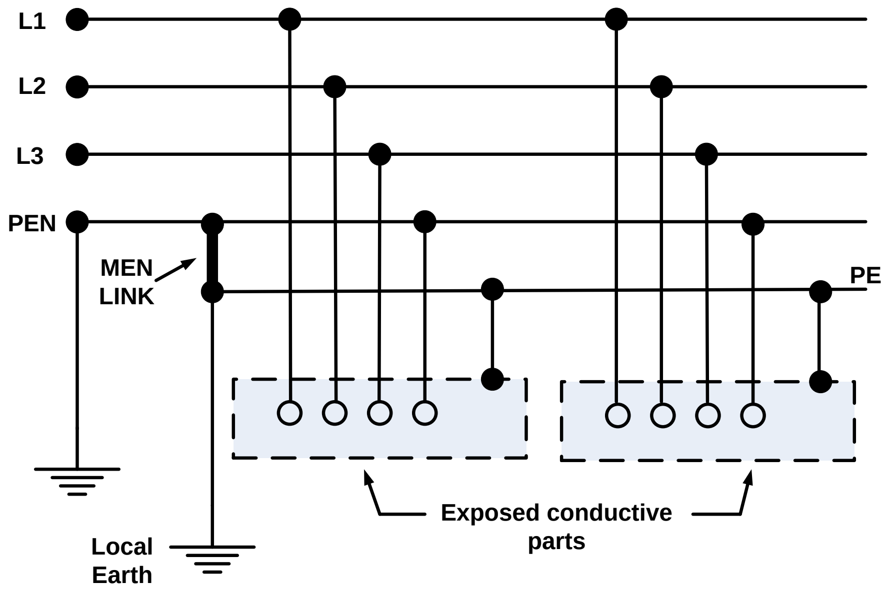

Figure 3. TN-C-S system schematic

TT

The TT system is most used in European and many Asian countries and is characterised by using four conductors, but with the neutral only being earthed at the power system supply side.

Protective earthing for exposed conductive parts at the customers premises relies on only a local earth system for each premise.

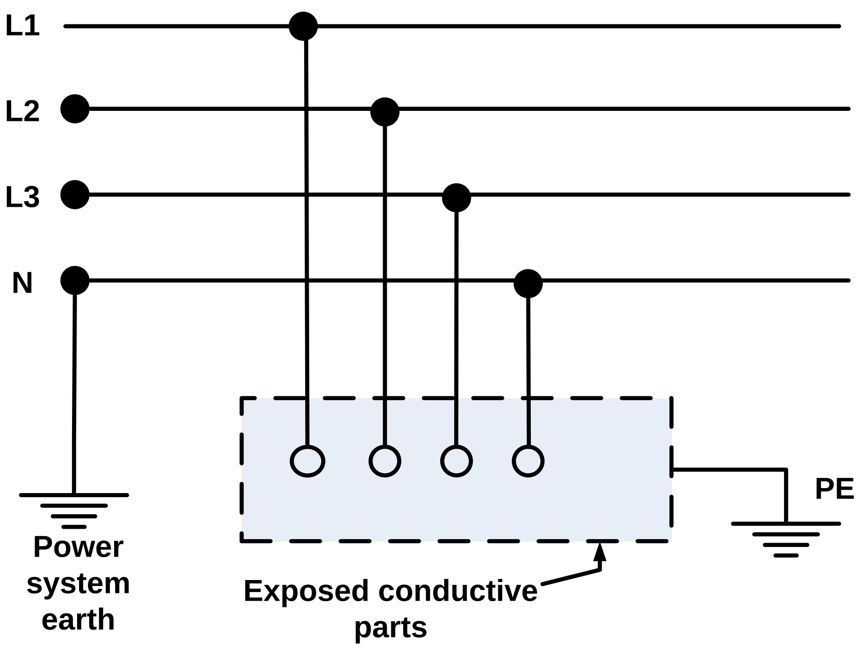

Figure 4. TT system schematic

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IT

The IT system is classified as a floating system where all conductors are not directly earthed. Only three active conductors are used in a three-phase system and the protective earth for the customers premises is provided by a local earth system.

The fact that all the phase conductors have no earth reference means that protection from common mode surges needs special SPDs to be effective.

These IT systems offer the best rejection of interference and offer the lowest cost system for distribution of power over long distances within a customer's system; they are common in railway and industrial power systems.

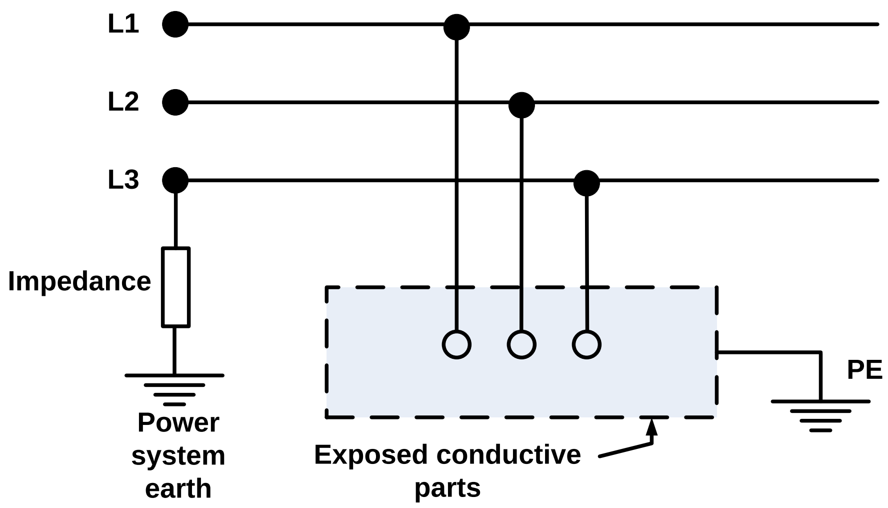

Figure 5. IT system schematic

The table below describes a comparison of the technical and cost features for the systems described and this indicates why some systems are preferred for certain applications.

	TT	IT	TN-S	TN-C	TN-C-S
Earth fault loop impedance	High	Highest	Low	Low	Low
RCD preferred?	Yes	N/A	Optional	No	Optional
Need earth electrode at site?	Yes	Yes	No	No	Optional
PE conductor cost	Low	Low	Highest	Least	High
Risk of broken neutral	No	No	High	Highest	High
Safety	Safe	Less Safe	Safest	Least Safe	Safe
Electromagnetic interference	Least	Least	Low	High	Low
Safety risks	High loop impedance (step voltages)	Double fault, overvoltage	Broken neutral	Broken neutral	Broken neutral
Advantages	Safe and reliable	Continuity of operation, cost	Safest	Cost	Safety and cost

Figure 6. Comparison of power system features

Three phase systems

Three phase systems are used where higher power requirements are needed and for most higher voltage parts of supply and distribution systems. They are used as they are more efficient in supplying power compared to single phase systems when the amount of conductor material is factored in due to the lower phase currents.

There are two popular systems in use in most parts of the world but it common to find both in use in a single country sometimes with transformers to convert between the two types.

Delta connected systems

Delta systems use three conductors to deliver power connected as shown in figure 7.

Each of the phases or lines are separated by 120° and can be rotating at 50 or 60Hz depending on the country. The phase voltage can vary from 110/120 volts in the USA up to 240 volts in Europe and Australia.

There is no neutral connection in this system and it is commonly used for driving rotating machines and other well-balanced loads.

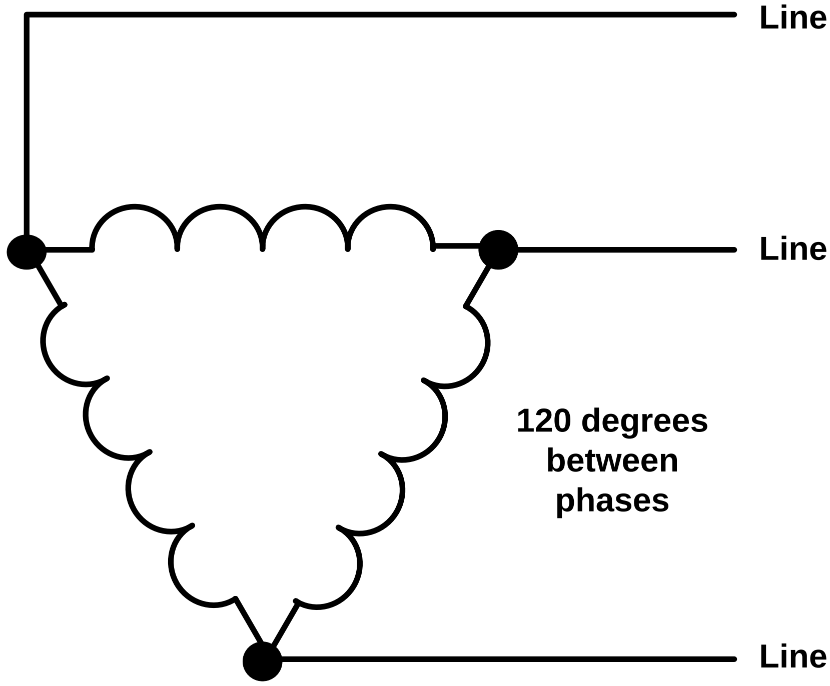

Figure 7. 3-phase Delta connection

Novaris product suggestions 3 phase Delta

The table below provides basic guidance on suggested products in both one and two port SPD's for these applications. For more detailed advice regarding surge ratings please refer to the Novaris Product Handbook and also AS 1768.

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Product Type	Ports	Low exposure	Med. exposure	High Exposure
Surge Filter	2	IFD3-x-50-D220	IFD3-x-100-D220	IFD3-x-200-D220
Surge Diverter	1	IDD3-50-D220	IDD3-100-D220	IDD3-200-D220

Star or wye connected systems

Star or Wye connected systems have the three phases connected at a common point thus making the phase to phase (line) voltages larger than in the Delta connected system.

There are two variations of the Star system, a four wire with neutral as shown in figure 8 and a three wire with no neutral as shown in Figure 9.

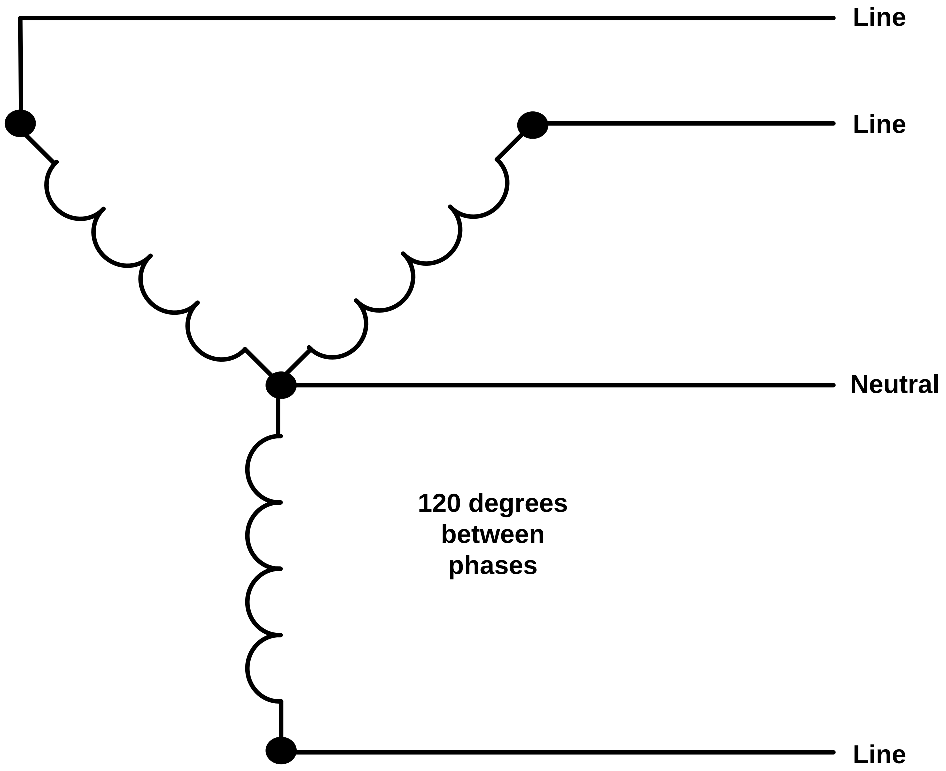

Figure 8. 4 wire star connection with neutral conductor

Novaris product suggestions 3 phase Star 4 wire

The table below provides basic guidance on suggested products in both one and two port SPD's for these applications. For more detailed advice regarding surge ratings please refer to the Novaris Product Handbook and also AS 1768.

Product Type	Ports	Low exposure	Med. exposure	High Exposure
Surge Filter	2	SFD3-x-50-275	SF(M,H)3-x-200-275	SF(M,H)3-x-200-275
Hybrid Surge Filter	2	HSF3-x-100-275	HSF3-x-100-275	HSF3-x-100-275
Hybrid Spark Gap	1	N/A	HSG3-100-480	HSG3-200-480
Surge Diverter	1	SDD3-50-275	SD3-100-275N	SD3-200-275N

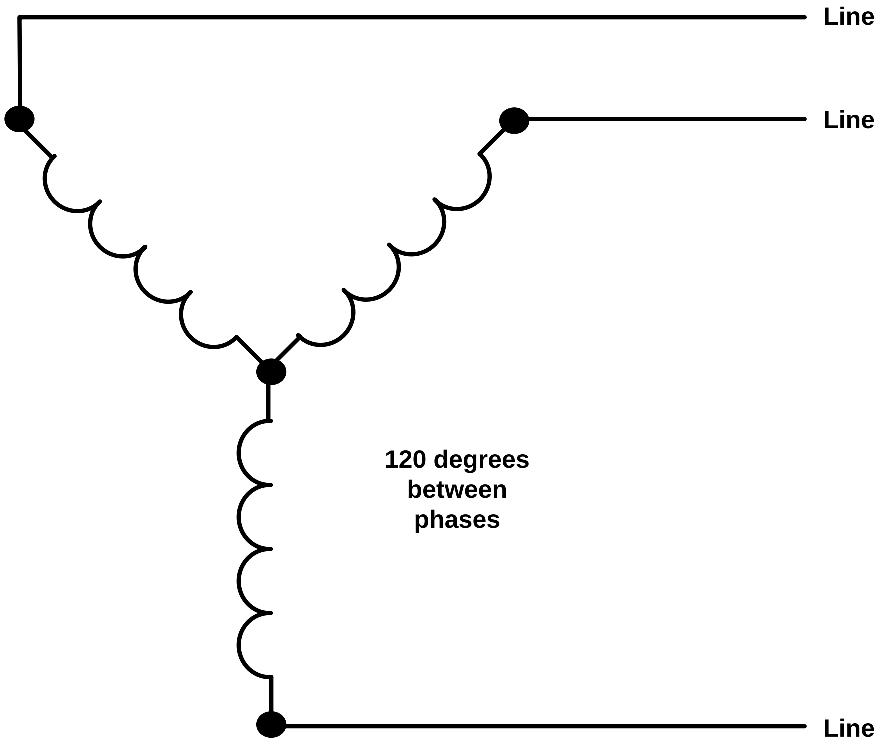

Figure 9. Star connection with 3 wires

Novaris product suggestions 3 phase Star 3 wire

The table below provides basic guidance on suggested products in both one and two port SPD's for these applications. For more detailed advice regarding surge ratings please refer to the Novaris Product Handbook and also AS 1768.

Product Type	Ports	Low exposure	Med. exposure	High Exposure
Surge Filter	2	IFD3-x-50-D220	IFD3-x-100-D220	IFD3-x-200-D220
Surge Diverter	1	IDD3-50-D220	IDD3-100-D220	IDD3-200-D220

Other systems

There are other systems in use around the world that are not as common as the main systems but will be mentioned here in case the need arises for specification of SPDs.

Hi-Leg Delta

Also known as the Wild, Stinger or Red leg Delta. This is a system mainly used in the USA and some parts of Philippines, Central America and Japan to derive a single phase supply from a 3 phase delta system.

It uses a centre tap connection to a local earth on one phase (usually the B phase) of the delta to provide a 2 phase connection relative to the earth.

Connection between L1 or L2 and N will give a single phase of 110 volts. Connection between L1 and L2 will give a 2 phase connection of 220 volts.

Figure 10 below details this arrangement.

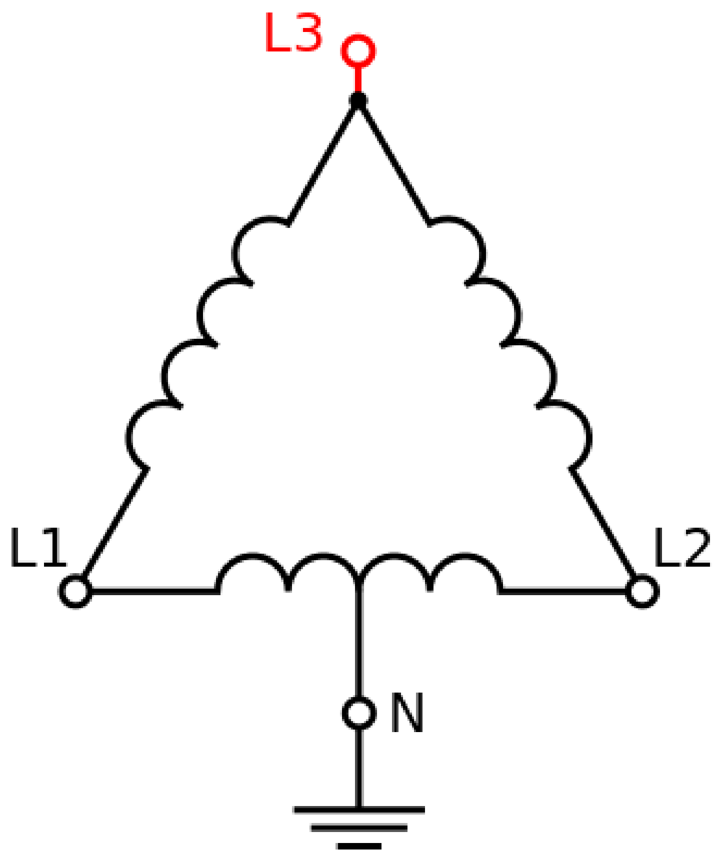

Figure 10. Hi-Leg delta connection diagram showing 2-phase connections via L1 and L2

Two-phase systems

These two phase systems to the premises are used in central America, Philippines and parts of Japan. Depending on the country this centre tap earth arrangement can have a nominal voltage L1 to N (Earth) of 110 or 120 volts giving a phase to phase voltage of 220 or 240 volts.
The connection diagram is shown below in Figure 11;

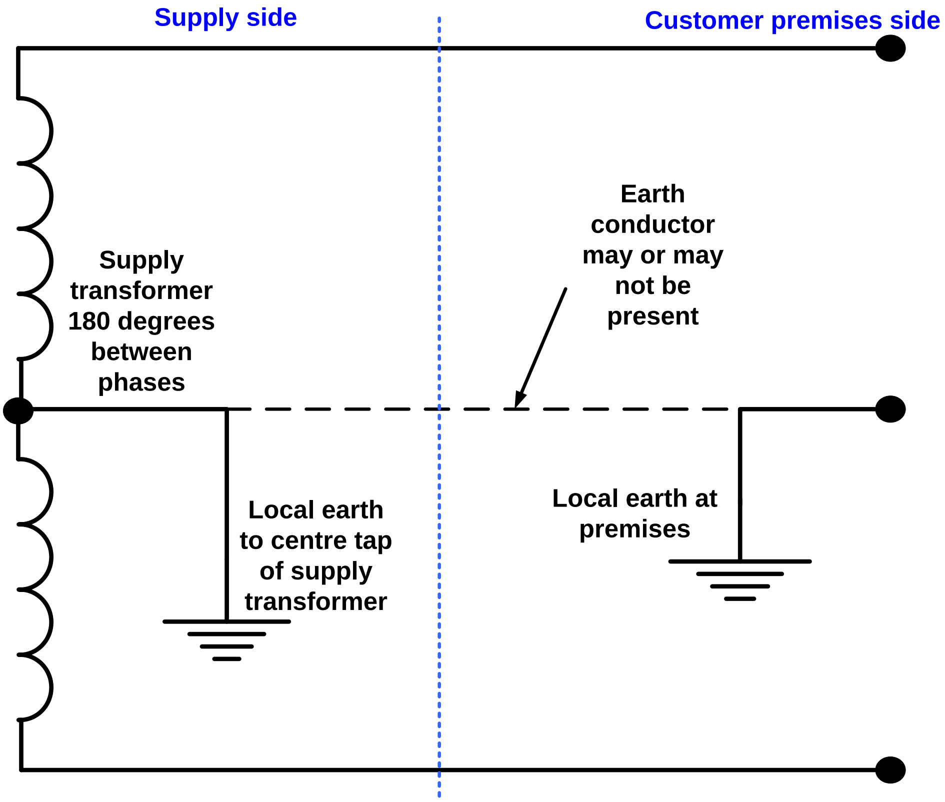

Figure 11. Two-Phase supply connection diagram

In some countries the N or Earth connection at the feeding transformer is not brought into the premises as a conductor. In some cases, like the USA, where a conductor is utilised it is often uninsulated.

To determine without doubt which system is in use a measurement at the premises is recommended. Measure from L1 and L2 to the local earth and record the two voltages. If they are equal, or close to equal, then this is a true two phase system. If one measurement is close to the normal supply voltage and the other close to zero then this is a single phase system where the Neutral conductor has an earth connection at some point.

It is important to understand exactly what the system in question is as the surge protectors required to give effective protection are different.

Novaris product suggestions 2 phase

The table below provides basic guidance on suggested products in both one and two port SPD's for these applications. For more detailed advice regarding surge ratings please refer to the Novaris Product Handbook and also AS 1768.

Product Type	Ports	Low exposure	Med. exposure	High Exposure
Surge Filter	2	IFD2-x-50-D220	IFD2-x-100-D220	IFD2-x-200-D220
Surge Diverter	1	IDD2-50-D220	IDD2-100-D220	IDD2-200-D220

Single phase systems

Single phase systems are the most common for domestic and light commercial customers where the power demand is not large. They can vary in voltage from 100 volts to 260 volts and can be delivered at 50 or 60Hz. There can be a wide tolerance on the voltage supplied to the customers premises and this can be as much as +/- 10%. In some countries due to poor regulation and overloading of the grid these voltages can go up to even greater levels during times of low loading.

Many developing countries have poor power system regulation. When specifying surge protection for countries that have poor power system regulation knowledge should be sought as to the maximum sustained voltages that the SPDs will be exposed to so a suitable device Uc can be selected.

For some specialist applications single phase supplies, often the IT type, are used at much higher voltages and different frequencies. Some examples are:

- railway signalling, where up to 1000 volts single phase is used for IT distribution systems
- medical systems
- marine on-vessel power distribution, 400Hz is used in some cases

For more information on Railway Signalling surge protection please refer to the Novaris application note 0015-D63V1.

Novaris product suggestions 1 phase

The table below provides basic guidance on suggested products in both one and two port SPD's for these applications. For more detailed advice regarding surge ratings please refer to the Novaris Product Handbook and also AS 1768.

Product Type	Ports	Low exposure	Med. exposure	High Exposure
Surge Filter	2	SFD1-x-50-275	SFD1-x-100-275	SF(M,H)1-x-200-275
Hybrid Surge Filter	2	HSF1-x-100-275	HSF1-x-100-275	HSF1-x-100-275
Hybrid Spark Gap	1	N/A	HSG1-200-480	HSG1-200-480
Surge Diverter	1	SDD1-50-275	SD1-100-275	SD1-200-275

Surge modes

Electrical surges can present themselves at equipment in one of two ways:

- **Transverse Mode**, when individual conductors in a circuit rise in voltage relative to one and other. This is commonly seen on paired or multi-phase circuits where one line rises relative to another causing damage to the controlling equipment on one individual circuit - A damage to one phase for example.

- **Common Mode**, when all, or a group, of conductors in a circuit rise in voltage relative to a common point, most often a chassis, neutral or earth connection. This is commonly seen where circuits coming from outdoors all have a common mode voltage that exceeds the break-down or insulation voltage of a piece of connected equipment and a component break down occurs often destroying the whole piece of equipment. Common mode faults cause more than 90% of damage seen to power equipment.

For distribution systems this common mode surge can present itself between all conductors and a local earth or between all conductors and the neutral/earth connection, all these need to be considered to select the appropriate configuration of SPD.

It is important for the designer/engineer to understand which type of system is in use and where the closest earth connection point might be located. Significant common mode voltages can exist between conductors and a neutral and/or earth if they are not close to the installation point of the SPD. In a TN-C-S system the MEN link will actually turn an incoming common mode surge into a transverse mode surge beyond the MEN point. It is for this reason that the use of all mode surge protection is important.

SPD selection

The selection of a suitable SPD for a power system must take notice of several key parameters:

1. Single phase, 2 phase or three phase?
2. If two or three phase, what is the connection system?
3. How many conductors coming into the premises?
4. Is there a neutral conductor?
5. Is the earth local or distant?
6. Is the neutral earthed locally?
7. What is the maximum phase voltage that can be applied for an extended period?
8. What is the maximum full load current draw (for series connected SPD's only)
9. What level of surge current is required for the exposure level?

Note: All Novaris power SPD's will operate at 50 and 60Hz power frequencies.

Device parameters

The following parameters are used on Novaris data sheets and should be used to select the most appropriate SPD's for any given application.

- U_o Normal operating voltage
- U_c Maximum continuous Voltage
- I_L Maximum load current (series connected devices like SFD and SSP
- I_{max} Maximum discharge current (surge current with 8/20µs waveform)
- In Nominal discharge current (15 times with 8/20 µs waveform)
- U_p Voltage protection level

Standards

There several standards that are helpful in providing additional information and guidance to this subject.

1. AS1768 the Australian/New Zealand standard for lightning protection has a section (Appendix F) detailing how SPD's should be installed to the various power system configurations and how they are protected with over current protection devices (OCPD) and/or earth leakage devices.
2. AS/NZS 61439.1 Low-voltage switchgear and control gear assemblies, general rules. This document provides a description of the various power distribution systems as well as rules for insulation and protection schemes

3. AS/NZS 3000, wiring rules. Appendix F1 provides details on the application of SPD's.

Over current protection for SPD's

SPDs require over current protection to prevent overheating and fires in the case of component overload or failure.
Novaris power SPDs have metallic enclosures and are fitted with internal over-current and thermal protection mechanisms to minimise these risks.

Protection can be achieved using upstream overcurrent protective devices (OCPDs) such as fuses and circuit breakers, AS/NZS 1768 details the application of these OCPDs. The sizing of these OCPDs must comply with the relevant wiring standards such as AS/NZS 3000 and must be coordinated with upstream OCPDs and importantly supply fuses or circuit breakers.

The rating of these OCPDs can be remarkably different when they are subjected to surge related currents and it is possible that nuisance tripping of the OCPD can occur when a surge is conducted by the SPD. Careful selection of fuse types and the use of delayed action type circuit breakers can minimise this.

To overcome these problems Novaris manufactures a device called a Surge Circuit Breaker (SCB) which is installed in series with parallel single port SPDs, namely surge diverters.

They provide over current protection at the power frequency of only 3 amps, fully protecting against damaging SPDs from overheating or rupture whilst also allowing high surge currents to pass without tripping.

See Novaris data sheets SCB1-3-80 and SCB1-3-25 for details.

Basic rules for power surge protection

The following basic guidelines should be used in the selection and installation of electrical surge protection equipment for power distribution systems

1. Ensure the distribution system type is known
2. Ensure the maximum continuous voltages the system can attain are known and are below the Uc of the SPD selected
3. Use surge filters if possible, see Novaris application note 0015-D39V1
4. Rate the SPD's as per AS1768
5. Consider common mode and transverse mode surges
6. Apply protection at all points of entry to buildings
7. Keep wiring as short and straight as possible
8. Mount the surge protection as close to the equipment as possible
9. Protect sensitive electronic circuits first
10. Use the mounting rails as the ground connection and bond all rails in a matrix

Other voltage and protocol protection

Novaris manufactures a full range of products for the protection of other voltages and protocols not mentioned in this application note.

For the complete range of Novaris products please see our Web site www.novaris.com.au or contact us at sales@novaris.com.au

Bibliography

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He is a career railway signalling and electrical engineer with over 34 years of experience mostly in Mass Rapid Transit systems and product development.

He is a full member of the Institute of Railway Signalling Engineers and in 1998 he won the Institute of Engineers Australia, Railway Engineering Award for pioneering work on the development of failsafe surge protection for computer based interlocking equipment.