Top 10 Considerations for RF and Facility Power Line Filters

ETS·LINDGREN®
An ESCO Technologies Company

TOP 10 FILTER CONSIDERATIONS FOR EMC, EMI, HEMP, AND EMP APPLICATIONS

ETS-Lindgren Filters are designed and produced at our manufacturing facility in Cedar Park, Texas, USA.

Following is our Top 10 list of the most important things you need to consider when selecting power, signal, data, and/or control line filters for protection of Points of Entry (POE) on secure environments. This may include RF shielded enclosures, computer racks, and mobile shelters for data centers, utilities, financial institutions, power transformers, and communication shelters, as a few examples. Filters protect against adverse effects, such as electromagnetic interference (EMI) or electromagnetic pulse (EMP), that may enter a secure environment through power, signal, data, and/or control lines. While the cost of filters is often a minor part of an overall project, filters play a key role in the overall success of any project. A poorly designed or mismatched filter for an application, for example, can compromise the RF shielding integrity of the facility thereby eliminating the protection of the secure environment. In other cases, the safety of personnel and equipment may be jeopardized.

After decades of experience in the design and manufacture of standard and custom power, signal, data, and control line filters, ETS-Lindgren's veteran engineering team has assembled the Top 10 considerations for the selection of filters for your next project. As an industry leader in the design and manufacture of RF shielded enclosures, ETS-Lindgren has the unique advantage of first-hand experience earned with over 25,000 installations – all requiring filters for each POE. While these installations are worldwide, ETS-Lindgren's filter engineering, R&D, and manufacturing team is solely located at the company headquarters in Cedar Park, Texas, USA.

You'll find ETS-Lindgren's expertise evident in this quick and concise guide created to ensure the success of your next project.

1. Filters should perform in both symmetric and asymmetric mode. That is, they should remove differential AND common mode noise.

Some manufacturers offer comparatively smaller filters, but only offer asymmetric performance. Asymmetric filters fail to remove differential noise.* Noise that appears differently on conductors will not be removed in an asymmetric filter. Only symmetric filters can remove BOTH differential and common mode noise.

In large filtering systems such as a 3-phase 4-wire panel, symmetric filters offer another advantage in being able to remove one filter element at a time without removing the entire filter panel. For asymmetric filters, the entire panel would need to be removed. This stems from the fact that all asymmetric filters, regardless of how many lines, must fit into one box. The reason is that all lines must share a common mode inductor. Whereas in a symmetric filter, individual lines do not share a common mode inductor and thus can often be packaged as individual filter elements within a cabinet. In the event of a filter failure, this affords the convenience of replacing just the one damaged line without having to dismount the entire filter cabinet. In filters where the penetration is welded to the shield enclosure, a symmetric filter is the only alternative that makes sense. In an asymmetric filter, the welded penetration would need to be cut in order to replace the filter and then re-welded after replacement.

Asymmetric filters are also more prone to develop audio noise issues or problems. If the system is not perfectly balanced, an audible noise can disrupt the surrounding environment, similar to a “buzzing” fluorescent light bulb.

It is important to note that asymmetric filters are not ideal for higher current filter requirements where it is necessary to place several filters in parallel in order to achieve a higher ampere rating. For example, this may occur when lower current filters are placed in parallel to achieve 800 Amps or higher. In this case, the asymmetric filter design may overheat which will lead to filter failure. In addition, the physical mounting of parallel asymmetric filters is cumbersome. Asymmetric filters require an installation where the filters are placed one on top of the other to minimize the possibility of over-heating due to the additional, convoluted cabling required. In contrast, symmetric filters may be installed side-by-side on a wall with less cabling required, which reduces the risk of overheating and the filter not performing as intended.

** For further reading on this topic, please see “Facility Power Filters: Symmetric vs. Asymmetric Performance” by Sergio Longoria with ETS-Lindgren, IN Compliance Magazine, September 2013. Available on the ETS-Lindgren website.*

2. Filters should be rated for the appropriate maximum Line-to-Ground or Line-to-Line voltage for a 3-phase system.

This eliminates the uncertainty of whether a filter will work at circuit voltages lower than the maximum filter rating. There are many voltage systems in the world and often even within the same country. In Europe, 250/440 VAC systems are common. In Asia, 220/380 VAC systems are the norm. In the United States, there are 120/208 VAC or 277/480 VAC and other voltage rating systems. Thus, power line filter voltage ratings should typically be specified at the maximum voltage rating so that any voltages used below the maximum rating will be within the safe operation of the filter. For example, in the United States a filter specification may state it operates from 0 – 277/480 VAC. This indicates that from Line-to-Ground (phase-to-ground), the filter may operate at any voltage between 0 - 277 VAC. In addition, from Line-to-Line (phase-to-phase), the filter would operate safely at any voltage between 0 - 480 VAC. This is one of the most commonly asked questions of filter application engineers.

3. Filters should be rated for the appropriate circuit current and be able to withstand an overload of 140% of the rated current for at least 15 minutes.

This ensures the survival of the filter under overload conditions, such as unexpected power surges or equipment failures that affect the power line performance. The current rating of a filter, measured in amperes, should also be a maximum rating. Thus, a 30 Ampere (30 Amp) filter would operate safely at any current at or below 30 Amp. This filter could be used in a circuit that is below the rating of the filter itself. For example, a 30 Amp filter may be placed in a 20 Amp circuit, but not the other way around. In addition, while a 60 Amp filter could also be placed in a 20 Amp circuit, considerations of cost, space, and leakage current should be considered. Ultimately, it is not cost effective to use a higher ampere, larger filter for a lower ampere circuit capacity. In addition, most properly designed and manufactured filters can withstand circuit overloads of 140% of rated current for at least 15 minutes, if not more, without permanent damage. This follows the overload percentage rating and length of time specified in the standard MIL-F-15733 and applies to power, signal, data, and control line filters.

4. To ensure safety and optimal performance, filters should be rated for low temperature rise in order to increase their durability and reliability.

The greatest enemy of all electrical and electronic equipment is heat. Filters are essentially comprised of capacitors and inductors in a steel case. Heat causes capacitors to dry out while inductor cores and insulation will deteriorate. Over time, these conditions can lead to a shortening of the life of the filter and in some cases to premature failures or combustion. Filter heat dissipation typically occurs through the metallic surfaces of the filters themselves. Temperature rise is related to the heat dissipation of the components and not just to the environmental temperature conditions around the filter.

Most filters are designed not to exceed 25 or 30 degrees Celsius (77 or 86 degrees Fahrenheit) of temperature rise in the working environmental temperatures provided by the manufacturer. For example, a filter manufacturer states their filter performs as specified in environments rated for 30 degrees Celsius (86 degrees Fahrenheit). The filter will be safe and perform as intended when operating at 55-60 degrees Celsius (131-140 degrees Fahrenheit). Since filters are typically used in controlled interior environments, it is usually advantageous that no additional need for cooling is required.

As long as the proper temperature rise is maintained, there is no need for additional cooling. While temperature rise has been addressed by industry, it is not currently specified in a standard. Therefore, confirmation of the temperature rise of a filter is recommended to ensure it is rated appropriately for its intended installation.

5. Power filters should be listed by a Nationally Recognized Testing Laboratory (NRTL).

As defined by the US Department of Labor, an NRTL is an independent third-party laboratory recognized by the United States Occupational Safety and Health Administration (OSHA) to test and certify products to applicable product safety standards. OSHA recognizes private sector organizations to perform certification of certain products to ensure that they meet the requirements of both the construction and general industry OSHA electrical standards.

Each NRTL has a scope of test standards for which they test products for conformance. Further, each NRTL uses its own unique registered certification mark(s) to designate product conformance to the applicable product safety test standard. After certifying a product, the NRTL authorizes the manufacturer to apply a registered certification mark to its product. If the certification is accomplished under the NRTL program, this mark signifies that the NRTL independently tested and certified the product, and that the product complies with the requirements of one or more appropriate product safety test standards. This assures the user that the manufacturer's filter meets the industry safety standards, such as those specified in UL 1283.

As a result of the UL 1283 standard, the most important safety test that should be done while the filter is being manufactured is the DC dielectric withstand test (hi-pot). Every filter and every filter line should be tested for conformance with hi-pot requirements in the manufacturer's production line. In order for filters to be "listed" to the safety standard UL 1283, for example, manufacturers must submit a sample filter to an NRTL, such as Intertek, MET Laboratories, NTS, TÜV SUD, TÜV Rheinland, UL, and others, for a battery of safety tests. These tests address DC dielectric withstand voltage, discharge rate, endurance, arc fault, insulation resistance, current overload, and other safety parameters.

Obtaining an NTRL approval mark or "listing" certifying a filter meets OSHA safety and performance verification standards requires a considerable investment of time and money by the filter manufacturer. Further, every new filter design - or variation of an original design - must be submitted for the independent third-party NTRL approval on that particular filter. Since the filters themselves may be an expensive investment by the purchaser, having an NRTL third-party listing documents the filters will perform as specified and reduces the risk in placing the purchase order. You can check the NTRL website to view the listings provided to a filter manufacturer.

Keep in mind that there are rare occasions, however, where non-listed filters may be used. While not formally listed by an NTRL, the filters are still built to safety standards and factory tested by the manufacturer. For example, this may involve custom filter designs and those outside the scope of UL 1283. Notably, all signal line filters and 400 Hz power line filters are outside the scope of UL 1283.

For "mission critical" applications that require filters for High-Altitude Electromagnetic Pulse (HEMP) and Electromagnetic Pulse (EMP) protection, a specialty independent third-party test lab may be preferred to perform the high current, high voltage testing required per MIL-STD-188-125, for example. In his case, test labs such as the Little Mountain Test Facility operated by Boeing at Hill Air Force Base, in Ogden, Utah and other similar labs should be considered. Since mission critical applications have zero tolerance for filter failure, filter manufacturers should provide the NTRL file number to verify that the filter has passed the robust electrical safety performance testing required for your HEMP/EMP application.

6. Protection performance for HEMP/EMP filters should be provided according to industry standards MIL-STD-188-125 or IEC 61000-4-24, as well as newer DTRA requirements.

These are the preeminent standards used today for designing conducted Point of Entry (POE) protection. MIL-STD-188-125 was originally intended for mission critical installations such as defense applications; however, it is now often used for other commercial applications as well including those that require hardening for EMP protection, such as data centers, utility control centers, and other facilities where security and downtime may be compromised, leading to extreme financial and service implications.

Note that MIL-STD-188-125-1A, released by the Defense Threat Reduction Agency (DTRA) in July 2021, supersedes MIL-STD-188-125-1, released in 1998. The MIL-STD-188-125-1A standard specifies test methods as well as updates passing criteria for POE, such as filters, to secure environments including SCIF and TEMPEST shielded enclosures. The new edition of MIL-STD-188-125-1A raises the quality standard for RF power line filter installations. Be aware that the appropriate filters to comply with MIL-STD-188-125-1A require a larger space for installation than standard sized EMP/HEMP filters.

61000-4-24 is also available to define hardening for EMP protection of POE. This standard includes several levels of severity, one of which is very similar to MIL-STD-188-125; however, other levels are included that are based on the application and degree of tolerance against an EMP event. For example, if your facility can tolerate a certain period of downtime or failure, you may look for guidance in this standard.

Keep in mind that for HEMP/EMP filters, ALL points of entry must be protected. This includes filters for power lines, signal and data lines, as well as communication lines.

When in doubt, check to ensure your power line filters are designed to meet the POE requirements of MIL-STD-188-125-1, -1A, and -2 for short and intermediate pulses as well as robust insertion loss performance for SCIF, TEMPEST, and other military and commercial applications.

It is recommended that HEMP/EMP filter performance be verified to meet the requirements specified in MIL-STD-188-125, or the applicable severity level of IEC 61000-4-24, by an independent third-party such as an NRTL discussed on page 6. Since there is no margin for error following an EMP event, the filter manufacturer should provide certified test reports that document compliance with the requirements of the applicable industry standard.

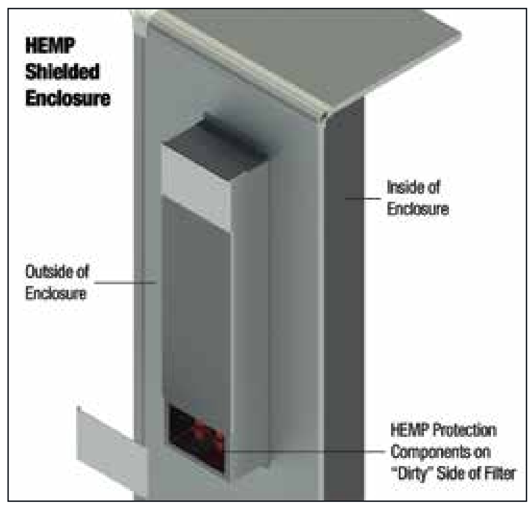
7. When securing a facility against an HEMP/EMP event, it is crucial - prior to order placement - to indicate if the filters will be installed inside OR outside the protective RF shielded enclosure.

Only one side of the filter has the protective elements needed to ensure HEMP/EMP protection. The protection side must be that which is directly exposed to the threat. The protection elements are composed of an electronic surge arrestor and an input inductor which are then followed by the filter components. In a typical filter installation in an RF shielded enclosure, the filter is typically located directly on the exterior shielded room wall. In this configuration, i.e. the MOV-Inductor-Filter, the MOV is located on the dirty side of the filter. However, for installations where the filters need to be installed on the interior wall of the enclosure, the MOV-Inductor-Filter is located on the clean side—now becoming the line side. When power enters the filter, it is best for the power to enter via the MOV in order to ensure EMP protection. See the images below for a pictorial representation of the recommended interior/exterior installation of HEMP/EMP filters on an RF shielded enclosure.

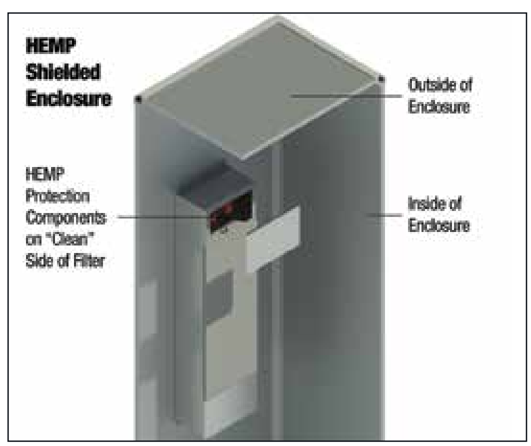
It is critical that the filter installation location of inside the RF shield or outside the RF shield is confirmed in advance to ensure optimal HEMP/EMP protection. The MOV-Inductor-Filter series is then manufactured for the selected interior or exterior installation. If the filter installation location changes mid-project from inside to outside the RF shield, or vice versa, significant project completion delays and increased costs may be incurred as the orientation of the filter will need to change. This change requires new filters/elements to match the new filter installation location.

Keep in mind that when replacing MOVs on a filter, they should match the same rating as the replacement MOV. New MOVs should have a clamping current at or above 40 kAmps for power line filters. Whereas signal, control, and data line filters should have MOVs rated at or above 3 kAmps.

Standard Installation with HEMP Protection Filter Mounted on Outside of HEMP Protected Environment (MOVs are shown in red on the dirty side of filter)



Reverse Installation with HEMP Protection Filter Mounted on Inside of HEMP Protected Environment (MOVs are shown in red on the clean side of filter)



8. For 400 Hz power applications, power line filters should also use Power Factor Correction Coils.

This will ensure that high reactive currents at 400 Hz are compensated. Avionics applications typically use 400 Hz power, for example.

All power filters generate reactive currents due to the capacitance in the filter. This is known as “leakage current” in the power line filter industry. Typically, the leakage current is about 10% or less of the rated current of the power line filter. Leakage current is also dependent upon the voltage applied and the power frequency applied. The 10% rule applies to filters used for 50/60 Hz applications. At 400 Hz, the leakage current is typically close to 170% of the rated current of the power line filter. In most applications, this is unacceptable operation. To compensate, it is necessary to counteract the high leakage current with the use of a Power Factor Correction Coil (PFCC). This is especially true for single-phase power systems and highly recommended in three-phase systems where balancing the power between the three lines may be difficult.

It is critical to match the power factor correction with the total capacitance of the line that is being compensated. Therefore, since this information is not readily available, a filter application engineer should provide guidance to ensure a proper match between the filter and the PFCC.

A few important notes:

- In a three-phase, four-wire system, a power factor correction coil is not required on the neutral line.
- While power factor correction coils have an amperage rating, this rating is not related to the amperage rating of the filter to which it is connected. This information is provided on the label of a PFCC so the electrician can size the cabling correctly for the PFCC installation.

9. When using electronic power sources connected to filters, the source should have a transformer in its output circuitry.

This will minimize unwanted interaction with filters. Electronic power sources include uninterruptable power supplies (UPS), power generators, and frequency converters, as an example. These devices have largely replaced motor/generator power sets by using high power semi-conductors, which have a wave-shaping network on their output. This network consists of capacitors and inductors. When these are connected directly to power line filters on an RF shielded enclosure, the interaction between the output of these devices and the power line filter may destabilize their operation of the electronic power source. In this case, the electronic power source may shut down or produce an unacceptable waveform on the output, maintain consistent voltage, or exhibit other undesirable reactions.

For installation on an RF shielded enclosure, it is recommended to use a well-designed electronic power source that includes an isolation transformer on its output. This configuration is generally less susceptible to the additional presence of a power line filter on its output.

10. Do’s and Don’ts for higher current filters placed in parallel.

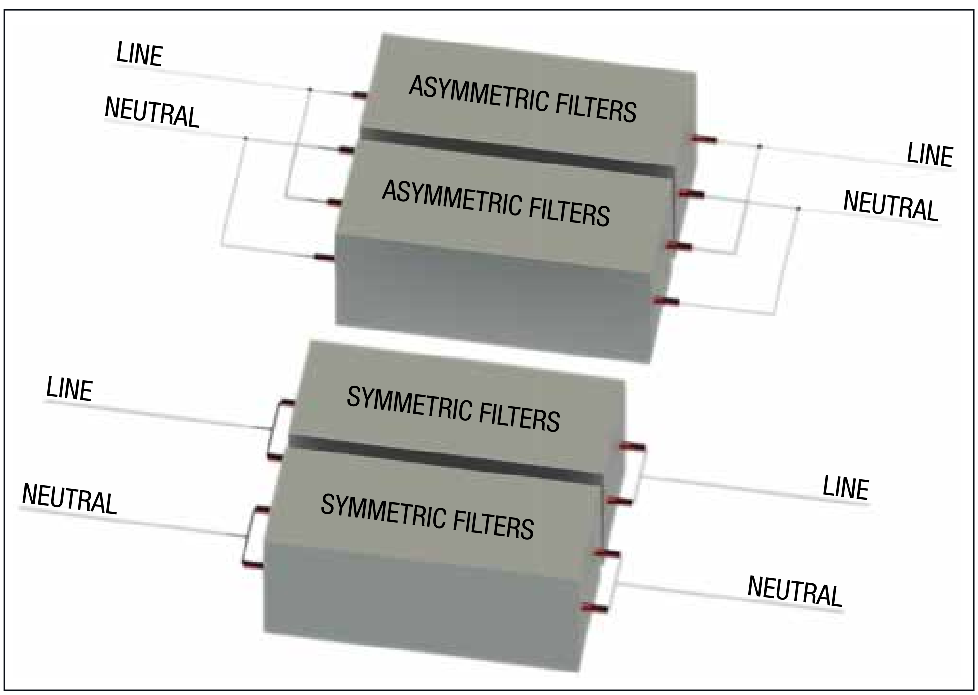
Due to the delicate nature of placing one or more filters in parallel, the less cabling required the better. Cable, as any conductor, has resistance. When paralleling two filters, care must be taken to ensure that the filter elements are within 5% of their respective resistances in order to avoid a current imbalance between the paralleled elements. With the addition of parallel cabling, this adds resistance to the circuit, which increases the chances of introducing a resistance imbalance.

Thus, in an optimal configuration, no cabling is added and the paralleling is accomplished at the filter terminals using bus bars. This guarantees that the paralleling of filters has not added undesirable resistance to each line causing an imbalance. The typical configuration would be to have filters side by side with a short bus bar across each terminal to provide paralleling.

Note that this works effectively for symmetric filters where each filter line is independent of the other and the lines do not share a core. With an asymmetric filter, placing the filters side by side would require the addition of cables in order to parallel two lines. This topology, however, would necessarily create a line resistance imbalance and increase current flow on one of the lines. The diagram shown on page 11 provides an example of the difference between paralleling asymmetric versus symmetric filters.

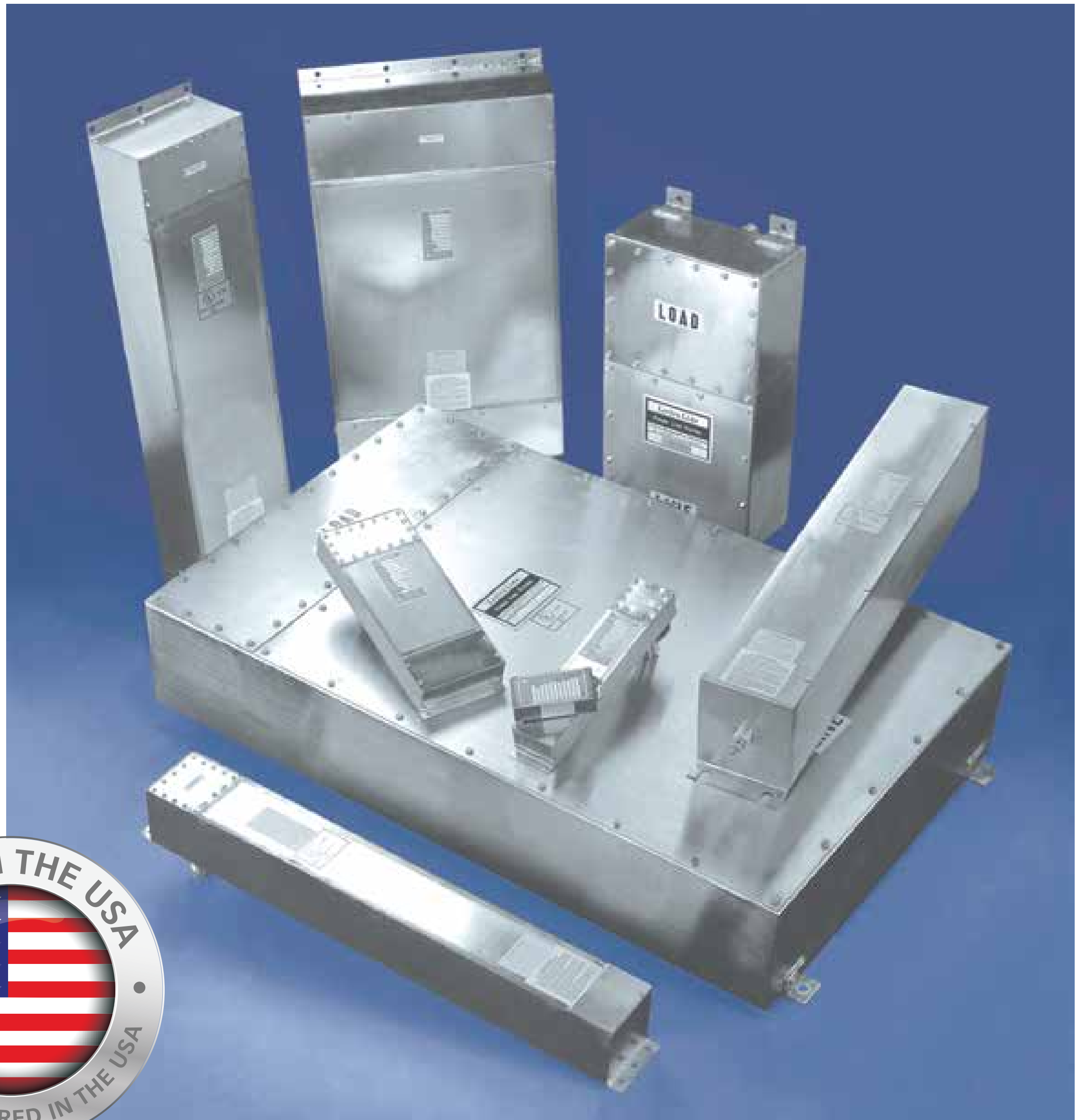
Keep in mind that power line filters rated above 200 Amps should have an option to be provided in a floor-standing panel. This will ensure that most of the weight rests on the floor, rather than on the shielded wall. When filters are placed in parallel to achieve higher current ratings, floor-standing panels are ideal to accommodate the increased weight of these filters.

The above photo shows an example of several three phase, plus neutral, floor standing panels. Each panel contains four symmetric single circuit power line filters rated for 1200 Amps per filter. While these filters run relatively cool, the honeycomb air vent panel shown helps passively dissipate the heat generated by high current filters and ensures that no additional cooling measures are required. In general, it is best to select single circuit filters for higher ampere rating requirements. When this is not possible, the optimal solution is to use the highest ampere rated single circuit symmetric power line filter available placed in parallel to achieve the higher ampere rating.



This diagram shows an example of the difference between paralleling asymmetric versus symmetric filters.

Note with an asymmetric filter, placing the filters side by side requires the addition of cables in order to parallel two power lines. This topology creates a line resistance imbalance and increases current flow on one of the power lines that could lead to filter failure. With the symmetric filters, however, note that no cabling is added and the paralleling of power lines is accomplished at the filter terminals using bus bars. The bus bars work effectively with symmetric filters as each power line filter is independent of the other and the power line filters do not share a core. This optimal topology guarantees that there is no undesirable resistance and resulting imbalance. Filters will have a longer life with less risk of failure using this topology.



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ETS-Lindgren produces a wide selection of general requirement, special application, and custom powerline filters in a broad range of configurations, performances, and power levels. All filters may be ordered with transient suppressors for improved protection against voltage transients. If you need assistance in choosing filters for your applications, ETS-Lindgren can help! Contact your local ETS-Lindgren representative, phone us at +1.512.531.6400, or visit our website at www.ets-lindgren.com.

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