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The Metal-Enclosed Advantage

Power capacitor banks and harmonic filter banks can be specified and purchased in two different configurations: "Open-Rack" or "Metal-Enclosed". This technical note presents background information on these configuration options and provides compelling reasons why the metal-enclosed configuration is a better choice.

Introduction

Engineers and purchasing agents have two configuration options to choose from when specifying and purchasing medium-voltage power capacitor banks and harmonic filter banks: the older, open-rack configuration, and a newer advanced configuration, now being employed in all industries: the metal-enclosed configuration.

Both configurations provide power factor correction, var support, harmonic filtering, and voltage control. Their physical design, appearance, and operational features, however, are dramatically different.

This technical note provides key decision-making information, and illustrates why the **metal-enclosed configuration offers significant value over the open-rack configuration.**

Open-Rack Configuration

Figure 1 shows a typical open-rack (sometimes referred to as "stack-rack") harmonic filter bank and associated components. Key components of this design include:

Elevating Structure (shown as #2 in Figure 1): The elevating structure is provided for equipment protection and personnel safety by raising the live parts approximately 9 feet up (3 meters) and is required by the NEC and NESC standards. For 15kV, 25kV, and 35kV class capacitor banks and harmonic filter banks, total capacitor bank height can reach 25 to 40 feet (7.5 meters to 12.5 meters). Therefore, maintenance and installation requires special elevating equipment such as bucket trucks, scissor lifts, cranes, and/or forklifts. The open-rack configuration normally consists of multiple elevating structures, one for each of the following components: capacitor rack, switching device, high-pass resistor (for high-pass filter systems), air-core reactor (for all harmonic filter systems), and disconnect/ground switch. Each of these elevating structures require their own engineered foundation/footing. In high seismic zones, significant design consideration needs to be given to the foundation and the elevating structure.

Controls and Protection (4): The controls and protection package is typically located within a substation's E-House and consists of circuit breaker control switches, lockout relays, overcurrent relays, over-voltage relays, indicators, blown fuse detection relays, HMI, remote communication devices, meters, and meter relays. There is a significant amount of wiring required between the open-rack components and the remote protection and control system.

Separately Mounted Switching Device (7): This device provides the switching function for the bank. It is typically a vacuum or SF6 breaker or switch. Its purpose is to make and break the capacitive load current of the harmonic filter bank or power capacitor bank. It may be located local to the bank on a separate pedestal (as shown here) or it may be located in the E-House as metal-clad switchgear. Switch/breaker control wiring must be wired back to the bank's control and protection system.

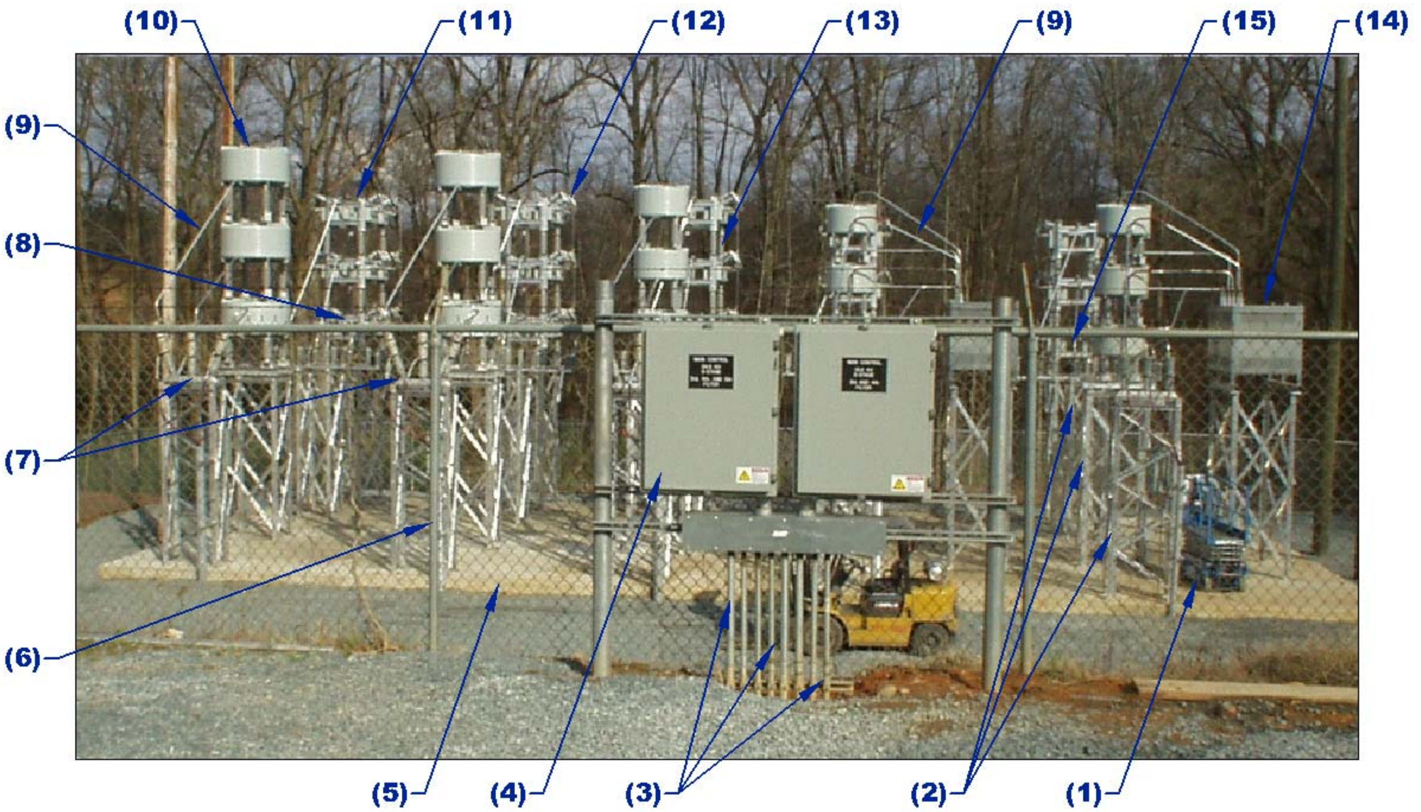

Figure 1—*Typical Open-Rack Harmonic Filter Bank Configuration Showing Medium Voltage Switches, Current Transformer, Filter Reactor, and Open-Rack Power Capacitor Bank. Note the space requirements, number of footings, and the height of the bank.*

Figure 1—Legend

1) Scissor Truck	2) Elevating Structures
3) Wiring to Filter Bank CT's, PT's, and Switching Devices	4) Remote Control and Protection System
5) Foundation (Either 1 Large Pad, or many small footings for each pedestal/elevating structure	6) Barbed Wire Protection Fence
7) Capacitor Switching Device	8) Ground and Disconnect Switch
9) Complex Interconnecting Bus Work	10) Harmonic Filter Reactor
11) Capacitor Rack	12) Expulsion Fuses
13) Insulators	14) Filter Resistors

Separately or Integrally Mounted 3 or 4 pole Ground Switch and Visible Disconnecting Device (8): The disconnecting switch and ground switch is typically a rotary handle operated knife switch and is operated from the base of the rack. These switches provide a visible break and ground for the capacitor bank to allow for safe maintenance of the bank.

Capacitor Rack (11): The capacitor rack consists of the capacitors and bus-mounted expulsion type capacitor fuses. For banks at 35kV and below (the range for metal-enclosed designs), the rack consists of single series group of parallel connected shunt capacitors. Three capacitor racks, one per phase, containing the capacitors and the expulsion fuses are stacked on the elevating structure with insulators mounted between the phases.

Bus-Mounted Expulsion Type Capacitor Fuses (12): Bus-mounted expulsion type capacitor fuses are typically supplied with open-rack capacitor banks to interrupt failed capacitors. These fuses have a low kA interrupting rating, require increased can-to-can spacing due to expulsion by-products during operation (increasing footprint size) and provide no current limiting action.

Phase-Phase and Phase-Ground Insulators (13): Since the rack is normally energized to phase potential, insulators are typically mounted between the capacitor racks, and between the elevating structure and the first capacitor rack for phase-ground isolation. For high seismic zones, insulator strength is a major concern.

Separately Mounted Filter Reactors and High-Pass Resistors (10, 14): These components provide the tuning and dampening function for the capacitor bank when it is installed as a harmonic filter bank. The reactors and the resistors both need their own elevating structure with insulators mounted between the phases and between phase and ground. Aluminum bus must be used to interconnect the reactors, resistors, capacitors, isolation/ground switch, and switching device. This bus is custom cut, bent, and installed onsite after all key components have been installed on their elevating structures. This is typically done in the field by the installing contractor on a bucket truck or scissor truck and is labor-intensive, specialized work.

Current Transformers and Potential Transformers (15): These devices provide the necessary protection and control signal requirements for the capacitor/harmonic filter bank control and protection system. Secondary wiring from these components must be interconnected to the remote protection and control system in separate conduit.

The open-rack bank does not come completely assembled. Field assembly of the racks and elevating structure is required by the installing contractor. In addition, enhanced control and protection features are not usually provided by the manufacturer. Rather, they must designed/engineered separately and remotely located in an E-House.

Metal-Enclosed Configuration

Figure 2 shows a typical one-line diagram and picture of a multi-tuned, multi-stage, metal-enclosed harmonic filter system. With this type of configuration, all key issues that were previously noted in the open-rack configuration are simply addressed: preassembled and interconnected within a free-standing 11-gauge compartmentalized outdoor metal enclosure. The metal-enclosed configuration comes fully assembled, tested, and ready for interconnection with the customer's power system. A crane places the finished equipment onto a concrete pad (see picture on page 6). Banks longer than 40 feet are shipped in sections for simple joining on the jobsite. As many stages/branches as required can be easily placed into a single enclosure on a single concrete pad.

All protection and control is provided in an isolated compartment within the metal-enclosed bank or externally mounted enclosure for placement in the E-House. Wiring is minimized by use of remote I/O that uses TCP/IP for communication of all status points.

All conceivable controls, protections, or equipment features are available in this configuration. Metal-enclosed designs are installed, tested, and commissioned within a few of days of arriving on a jobsite.

The Metal-Enclosed Advantage
Construction, Procurement and Engineering Firms Take Note

$ Lower civil/mechanical engineering expense: One simple pad-layout for a multi-stage/bank system	$ Significantly lower installation cost: Equipment comes fully assembled, tested and ready for interconnection
$ Significantly less risk associated with site-preparation and excavation	$ 20% or less the foot-print requirement as compared to open rack
$ Less interface engineering as the entire metal-enclosed package, including protection and control system, is engineered by NEPSI.	$ Less shipping cost due to compactness

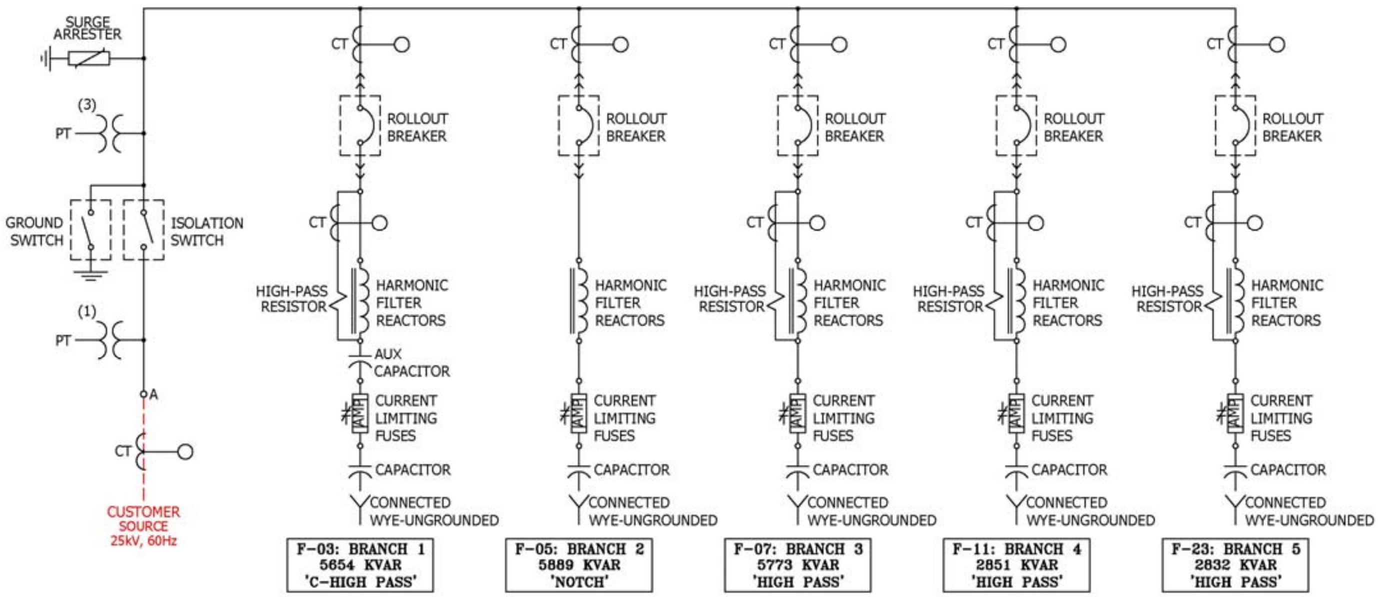

Figure 2—Top, *typical one-line diagram for a multi-tuned metal-enclosed harmonic filter system. All protection, disconnecting, switching and controls come preassembled, tested and ready for operation in a compact design from NEPSI. Picture is of harmonic filter system corresponding to one-line diagram.*

The Metal-Enclosed Advantage

When deciding on which configuration to use, **consider the following key points:**

- **A metal-enclosed bank comes fully assembled, tested, and ready for interconnection.** Open-rack banks require field assembly and testing by qualified contractors. Therefore installation time and costs associated with open-rack designs are higher. This is especially important where qualified personnel are not readily available, field labor costs are high, site location, altitude, and/or weather conditions are harsh, and construction is on a compressed schedule.

- **Maintenance costs associated with open-rack bank designs are higher** for the following reasons:

1. A bucket truck with a qualified operator is required when performing maintenance on open-rack bank designs, which can be as tall as 25 to 40 feet (7.5 meters to 12.5 meters).
2. OSHA fall protection requirements (or similar standards) add difficulty and ultimately time and costs to the installation and maintenance of open-rack banks.
3. Qualified personnel are required, as operation, grounding, and human contact with exposed live parts are not controlled by a key interlock system or prevented by metal enclosure barriers. In-house plant electricians can maintain metal-enclosed bank designs with minimal training.

- **Metal-enclosed banks come standard with a main disconnecting device, a requirement of the National Electric Code** (NEC). Open-rack configurations do not. The costs associated with the purchase and installation of this main disconnecting device must be considered when comparing an open-rack bank design to a metal-enclosed design.

- **A metal-enclosed bank design significantly reduces the risk and associated liability of trespassing or tampering from unauthorized persons and untrained employees.** With metal-enclosed banks, all live parts are contained in a grounded, key-interlocked enclosure and no live parts are accessible.

- **Open-rack bank designs must be placed in a fenced-in substation.** Fence cost and future substation space requirements must be considered. Metal-enclosed banks can be put in areas of general public access. NEPSI's banks can be designed in accordance with ANSI Standard C57.12.28-1988, *Pad-Mounted Equipment Enclosure Integrity*.

- **Metal-enclosed bank designs have a much smaller foot print versus open-rack designs (less than 1/5 the area).** Civil costs can be considerable with an open-rack configuration.

- **Open-rack designs are more easily affected by wildlife and air-born settlements** which can cause faults due to bushing and insulator tracking. NEPSI's **metal-enclosed banks protect against wildlife and air-born settlements** as all live parts are housed in the metal enclosure.

- **Open-rack designs are more susceptible to corrosion** as all of the electrical components are exposed to the elements. The structure is typically composed of unpainted Galvanized steel or Aluminum. NEPSI's metal-enclosed banks protect the electrical components with an 11 gauge Galvaneal enclosure that is painted with a marine epoxy-based paint. The paint system provides excellent chemical resistance to splash, spillage, fumes, and weather for acidic, alkaline, salt solutions, fresh water, solvents, and petroleum product environments.

- **Metal-enclosed banks are more aesthetically pleasing**. They are compact and can be provided with a paint finish that will match the environment or surrounding architecture.

- **Metal-enclosed banks come with advanced control and protection schemes**. These schemes are designed, installed, and tested by NEPSI's experienced engineers and technicians. Third party vendors are not required.

- Open-rack banks typically utilize expulsion fuses. **Metal-enclosed banks utilize current limiting fuses that dramatically reduce damage associated with faults.** Current limiting fuses also **provide better coordination with upstream protective devices and reduce the possibility of a system-wide power outage.**

- **Metal-enclosed banks come with drip trays** installed under the capacitors to contain any fluid leakage providing **superior environmental protection**.

- **Metal-enclosed banks are mounted on a pad at ground level and are not subject to the same seismic forces** as open-rack bank designs. Foundation and elevating structure cost associated with the open rack are complex and significant in high seismic areas.

- **Metal-enclosed harmonic filter banks are less expensive in material costs** when compared to open-rack filters and together with their installation labor savings **offer a significant savings over open-rack filters installed costs**.

Conclusion

Metal-enclosed bank designs offer many advantages over stack-rack bank designs. When all factors are considered, including site preparation, installation, maintenance, and liability, the metal-enclosed bank design becomes the favorable choice. Use the bid comparison worksheet on the last page of this tech-note to assist in a thorough evaluation and comparison of total system costs.

SMALL FOOTPRINT, EASY INSTALLATION, READY FOR INTERCONNECTION AND OPERATION

Quality Wind, Tumbler Ridge, B.C. Canada

NEPSI metal-enclosed filter banks and capacitor banks are shipped fully assembled, tested, and ready for operation

Cost Comparison Worksheet

Item		Description	Bank Configuration: Open-Rack	Bank Configuration: Metal Enclosed
1		**Main Breaker**		Included
	1a	Elevating structure and foundation		Included
	1b	Installation/Rigging		Included
	1c	Relay (over-voltage, over-current, lock-out)		Included
	1d	Current transformers		Included
	1e	Controls, control switches, indicators		Included
	1f	Labor and material for bus connections or cable connections to capacitor bank		Included
2		**Main disconnecting device**		Included
	2a	Elevating structure and foundation		Included
	2b	Installation/Rigging		Included
	2c	Labor and materials for bus connections to capacitor bank		Included
3		**Ground switch**		Included
	3a	Elevating structure and foundation		Included
	3b	Installation/Rigging		Included
	3c	Labor and materials for bus Connections to capacitor bank and installation of ground switch		Included
4		**Control power transformer**		Included
	4a	Elevating structure and foundation		Included
	4b	Installation/Rigging		Included
	4c	Labor and materials for primary connections to main bus and secondary connections to capacitor bank control and protection system		Included
5		**Lightning arresters**		Included
	5a	Elevating structure and foundation		Included
	5b	Installation/Rigging		Included
	5c	Labor and materials for primary connection of lightning arresters		Included
6		**Current transformers**		Included
	6a	Elevating structure and foundation		Included
	6b	Installation/Rigging		Included
	6c	Labor and materials for primary and secondary connections to capacitor bank control and protection system.		Included

Cost Comparison Worksheet - cont.

		Bank Configuration	
Item	**Description**	**Open-Rack**	**Metal Enclosed**
7	**Switches/Breakers for switching capacitor stages**		Included
7a	Elevating Structure and foundation		Included
7b	Installation/Rigging		Included
7c	Labor and material for primary connections to capacitor/filter bank and secondary conductors to control and protection system		Included
8	**Filter Reactors/Transient Inrush Reactor**		Included
8a	Elevating structure and foundation		Included
8b	Installation/Rigging		Included
8c	Labor and materials for primary connections to capacitor bank and main breaker		Included
9	**Filter Resistors**		Included
9a	Elevating structure and foundation		Included
9b	Installation/Rigging		Included
9c	Labor and materials for primary connections		Included
10	**Capacitors**		Included
10a	Elevating structure and foundation		Included
10b	Installation/Rigging		Included
10c	Labor and materials for primary connections		Included
11	**Control & Protection System**		Included
11a	PLC and PLC programming		Included
11b	Automatic PF/Voltage/Var controller		Included
11c	HMI		Included
11d	Breaker & capacitor switch control switches		Included
11e	Lockout relays		Included
11f	Over-current relays		Included
11g	Over-voltage relays		Included
11h	Harmonic management relays		Included
12	**Site Preparation**		
12a	Excavation Cost		
12b	Fence Cost		
12c	Ground Pad Cost		
13	**Seismic Certification (Typical)**		$10,000
	Total Bid Comparison		
	Pad Cost for Metal-Enclosed Capacitor Bank	-	
	Installation/Rigging Cost - Metal Enclosed Bank Design	-	
	Total Bid Cost (Add above lines in each column)		