Convection vs. Forced-Air Cooling of Chargers and Inverters

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Abstract

Project specifications sometimes require SCI to provide Convection Cooled Chargers and Inverters, or taking another approach, the project specification may forbid the use of forced-air cooling. The prohibition against the use of forced-air cooling is usually interpreted to mean that Convection Cooling must be provided.

The intent of the specification requirements above, regardless of the actual wording, is to reduce the possibility of sudden charger or Inverter shutdown caused by a cooling fan failure. Many engineers believe that all rotating equipment is inherently unreliable, thus the MTBF (Mean-Time-Between-Failures) of the Charger or Inverter should not depend on the continuous operation of cooling fans.

In older Power Generation plants, the engineers may worry that coal dust might be drawn inside forced-air cooled equipment. Similarly, Cement plant engineers worry about the ingress of cement dust through the forced-air cooling supply air inlets.

Solidstate Controls Inc. (SCI) understands why specifying engineers might wish to have purely Convection Cooled equipment, but as we shall see, Convection Cooling is not always possible in larger power capacities.

Additionally, we shall also discuss the difficulty created by the common specification requirements for screening on the equipment air inlets. The requirement for fine mesh inlet screening make Convection Cooling extremely difficult or even impossible.

In this paper, SCI will show that SCI's cooling philosophy which uses redundant, top-mounted, low-velocity fans is often the best compromise for meeting the intent of all sections of the specifications for Chargers and Inverters.

Finally, we shall describe the overall requirements of IEC-529: Degrees of Enclosure Protection which classifies equipment enclosures and the effects of these requirements on cooling and long term reliability.

Please refer to **Figure 1**, which is a sketch of a typical SCI Convection Cooled Charger with a IEC IP-21 cabinet. The Charger's cooling path is shown by the large arrows. The Inlet air first passes through a screen with a 12 mm. mesh size. The air inside the Charger cabinet is heated by the energy lost in the AC-DC conversion. The heated air rises out the top of the cabinet. The rising air creates a partial vacuum which induces cooling air to flow into the bottom of the enclosure. (Convection Cooling is sometimes referred to as Natural Cooling).

The inlet air heated by the Charger's input transformer also passes over the cooling fins of the heat sinks of the SCR's (Silicon Controlled Rectifiers) in the Bridge circuit. In a Convection Cooled design, the air velocity is quite low which makes heat transfer from the center of the Charger Transformer and from the SCR heat-sink assemblies inefficient.

The heat transfer inefficiency of low velocity, convection driven air can be partially overcome by widening the coil spacing of the transformer windings and by using larger cooling fins on the SCR heat-sinks. These design modifications work well up to a power loss level of about 4, 600 watts, which is the heat rejection of a 270 VDC, 400 Ampere Charger. At higher power levels, the heat transfer inefficiency becomes too large and Convection-Aiding fans must be used inside the Charger cabinet.

If the Charger specification also calls for the 2.5 mm. mesh screening found in IEC-529, such as required for IP-31), the free air inlet area is made smaller which then may reduce the cooling air flow to unacceptable levels. Please refer to **Figure 4** which shows the theoretical free flow area reduction with various mesh and wire size screening.

The actual air flow reduction may become much worse than shown in the chart if dust and dirt begin to collect on the screen opening areas.

The IEC-529, IP-31 classification requires all cabinet openings to be covered with 2.5 mm. mesh screening. The more stringent IP-41 classification requires an extremely fine 1 mm. Screening on all openings. **Figure 4**, shows clearly the inlet area reduction caused by the use of 1mm. mesh screens could range between 18-33% depending on the wire gage of the screening used.

SCI's 35 year experience building Chargers has shown us that Convection Cooling works best when the Inlet air path is not restricted with fine mesh screening . In general, when we must build to meet IP-31, we recommend the use of Convection-boosting fans.

Our long experience with Chargers has demonstrated that the reliability is better when the inlet air path is unrestricted in both Convection and Convection-aided designs. The accumulation of dry dust inside our Chargers has been less of a problem that the complete blockage of the screened air inlet due to gradual accumulation of job-site dirt.

In the case of SCI's Static Inverters, the practical Output Power limitation of pure Convection Cooling is about 30 kilowatts (30,000 watts) at 40°C.

Please refer to **Figure 2** which is a sketch of a typical SCI Convection Cooled Inverter .

Unlike the Linear Transformer used in a Charger, the SCI Inverter uses a proprietary Non-linear, magnetic technology called Ferroresonant. The Ferroresonant Transformer windings are constructed much differently that a linear transformer. The secondary winding is designed to operate normally in a saturated state. The heat density of the Ferroresonant Transformer is much higher than a Linear Transformer, thus the power output limit of 30 kilowatts with pure Convection Cooling is much lower than the 90 kilowatt limit for Convection Cooled Chargers.

The power output capacity limit on our Inverters can be increased to 120 kW by the addition of Convection Boosting fans, as shown in **Figure 3**.

It should be noted that in both the SCI fan cooled Chargers and fan cooled Inverters, the fans are always installed as pairs. The loss of one cooling fan in the pair will not cause the Charger or Inverter to shut down. The SCI fans have a MTBF exceeding 30,000 hours, but since we strive for a system MTBF exceeding 150,000 hours, our cooling fans are installed in redundant pairs.

The last item, **Figure 5** is a explanation of the enclosure requirements of IEC-529. SCI's standard cabinets are rated for IP-20 and the classification can be increased to IP-21 with the addition of a drip shield.

To meet the IEC-529 enclosure classification of IP-31, SCI adds both drip shields and 2.5 mm. screening over all openings including the drip shield exhaust areas.

It is important to note that SCI usually takes strong exception to the enclosure requirements of IP-4X because of the 1 mm. mesh screening requirement. It is our experience that fine screen quickly becomes loaded with dirt which restricts proper cooling air flow.

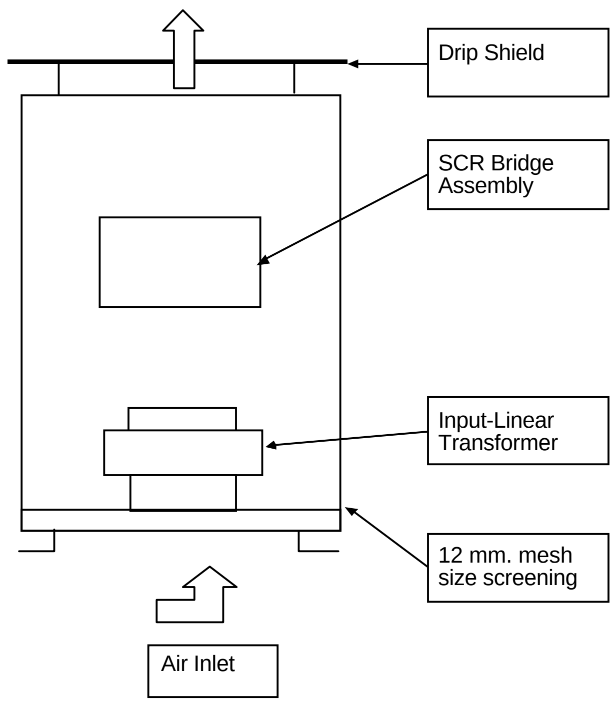


Figure 1
Convection-Cooled Battery Charger, IP-21

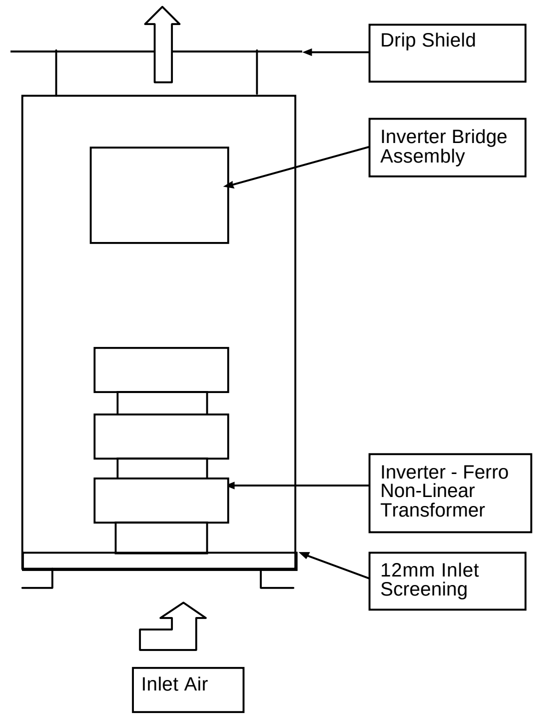


Figure 2
Convection-Cooled Ferroresonant Inverter, IP-21

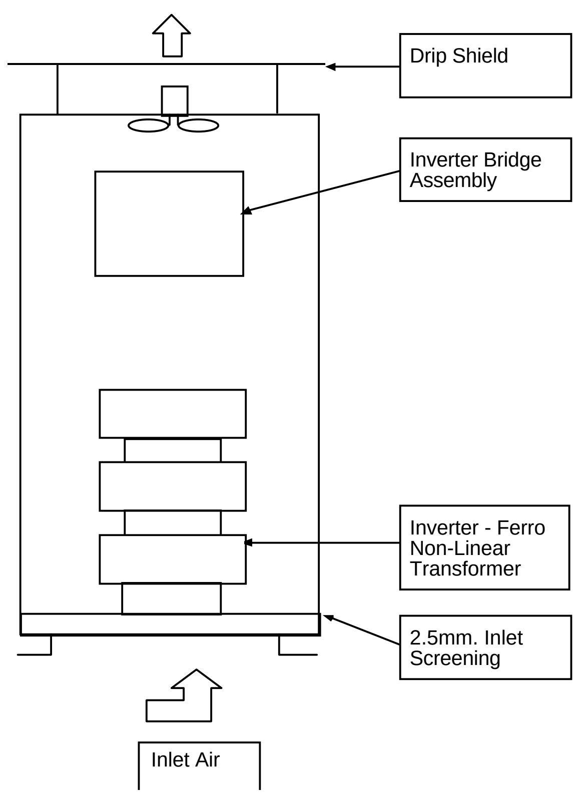
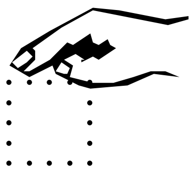
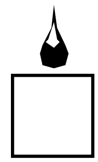
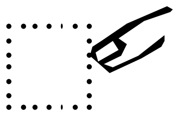
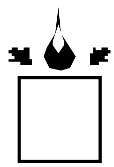
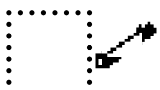
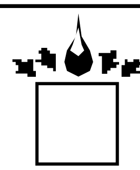
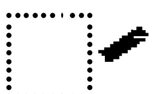
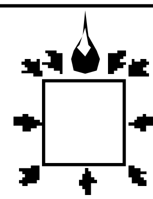
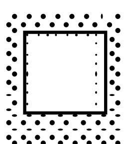
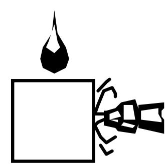
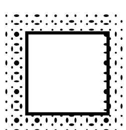
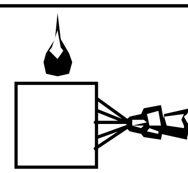


Figure 3 Convection-Aided Ferroresonant Inverter, IP-31

Mesh Wire Dia. Gage	Mesh Wire Dia. inches	Mesh Wire Spacing	Wire Blocking Area	Free flow Area sq. in.	Free Flow Reduction	Wire Dia. mm.	Mesh Space mm.
16	0.065	0.472	2.8	97.2	**3%**	1.65	12
16	0.065	0.236	5.5	94.5	6%	1.65	6
16	0.065	0.098	13.2	86.8	13%	1.65	2.5
16	0.065	0.039	33.1	66.9	33%	1.65	1.0
18	0.049	0.472	2.1	97.9	2%	1.24	12.0
18	0.049	0.236	4.2	95.8	4%	1.24	6.0
18	0.049	0.098	10.0	90.0	10%	1.24	2.5
18	0.049	0.039	24.9	75.1	25%	1.24	1.0
20	0.035	0.472	1.5	98.5	1%	0.89	12.0
20	0.035	0.236	3.0	97.0	3%	0.89	6.0
20	0.035	0.098	7.1	92.9	7%	0.89	2.5
20	0.035	0.039	17.8	82.2	18%	0.89	1.0

Figure 4 Screenin Data: Sizes & Free Area Percentage vs. Mesh Size

I E C - 5 2 9 D e g r e e o

First Numeral IP		Tests	Second Numeral IP		Tests
0		No protection	0		No protection
1		Protected against solid objects up to 50mm, e.g. acidental touch by hands.	1		Protected against vertically falling drops of water, e.g. condensation
2		Protected against solid objects up to 12mm, e.g. fingers	2		Protected against direct sprays of water up to 15” from vertical
3		Protected against solid objects over 2.5mm	3		Protected against sprays to 60” from vertical
4		Protected against solid objects over 1mm	4		Protected against water sprayed from all directions (limited ingress permitted)
5		Protected against dust (limited ingress, no harmful deposit)	5		Protected against low pressure jets of water from all directions (limited ingress permtted)
6		Totally protected against dust	6		Protected against strong jets of water

Specification IP 2 3

Characteristic letters
1st characteristic numeral (Protection against solid objects) → 2
2nd characteristic numeral (Protection against liquids) → 3

An enclosure with this designation is protected against the penetration of solid objects greater than 12 mm and against spraying water.

Figure 5 Enclosure Protection Classification Method