STEEL TUBE INSTITUTE

Steel Conduit

TECH TALKS

STEEL CONDUIT AND EMT: PROVEN TO MEET THE NEC® REQUIREMENTS FOR EQUIPMENT GROUNDING

Technical information about steel conduit and electrical metallic tubing

In addition to system grounding, electrical systems require equipment grounding and bonding to safeguard personnel. Properly sized and bonded equipment grounding conductors ensure that all metal parts of electrical equipment are at the same electrical potential as the earth to prevent electric shock and provide a low impedance path to facilitate the operation of the circuit protective devices.

The National Electrical Code® (NEC®) recognizes several types of conductors that are permitted to be used as equipment grounding conductors in Section 250.118. Rigid metal conduit, intermediate metal conduit and electrical metallic tubing are permitted in 250.118(2), (3) and (4) respectively, followed by other restricted uses of metal raceways, metal cable trays, and metal cables.

Steel conduit and EMT are widely used in secondary power distribution systems, indoors and outdoors. Systems are designed in such a way that the steel conduit or EMT does not carry any appreciable electric current under normal operating conditions. Under certain fault conditions, the steel conduit or EMT, acting as an equipment grounding conductor, will carry most of the return fault current, or, in some cases, it will be the only return path of the fault current to the source.

NEC REQUIREMENTS

NEC Article 250 contains the general requirements for grounding and bonding of electrical installations as well as other specific requirements. According to the 2008 NEC Handbook, *"Sections 250.4(A) and (B) 'General Requirements for Grounding and Bonding' set forth in detail what must be accomplished by the grounding and bonding of metal parts of the electrical system. The metal parts must form an effective low impedance path to ground in order to safely conduct any fault current and facilitate the operation of overcurrent devices protecting the enclosed circuit conductors."*

Part VI of Article 250 specifically covers equipment grounding. Part VI includes the list of allowable equipment grounding conductors in Section 250.118, as noted above.

In order for steel conduit and EMT to perform effectively as equipment grounding conductors, it is crucial that they are installed properly with tight joints. If a fault occurs, this helps ensure a continuous, low impedance path back to the overcurrent protective device. If the joints are not made up tight or if there is a break in the ground fault current path under fault conditions, there is a possibility of electric shock for anyone who comes in contact with the conduit. The NEC requires in Section 300.10 (Electrical Continuity) and in 300.12 (Mechanical Continuity) that "metal raceways, cable armor, and other metal enclosures for conductors shall be metallically joined together into a continuous electrical conductor and shall be connected to all boxes, fittings, and cabinets so as to provide effective electrical continuity."

"Equipment Grounding Conductor Installation" the NEC requires that all connections, joints and fittings *"shall be made tight using suitable tools."*

Section 250.122 covers the sizing of equipment grounding conductors and includes Table 250.122, *Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment*. This section makes it clear that the conductor sizes in Table 250.122 may not be adequate to comply with 250.4(A)(5), *Effective Ground-Fault Current Path* (Grounded Systems), and 250.4(B)(4), *Path for Fault Current* (Ungrounded Systems), and may have to be evaluated to ensure that they can provide the effective ground path.

The SOARES BOOK ON GROUNDING, published by IAEI, states that the "*NEC does not dictate any particular size of conduit or tubing to serve as the equipment grounding conductor for an upstream overcurrent device. It is felt that the metallic raceway that is sized properly for the conductor fill will provide an adequate equipment ground fault return path."*

In 1966, Eustace C. Soares, one of the most renowned experts in the area of grounding electrical systems, had published the first edition of his book, *Grounding Electrical Distribution Systems for Safety*, which included tables showing acceptable lengths of steel conduit and EMT for equipment grounding, based on his calculations. If field tests were performed, no evidence of it was ever discovered.

In the early 1990s, U.S. steel conduit producers decided to undertake a research project in order to confirm the Soares Tables, to provide scientific proof that steel conduit and EMT do provide an adequate equipment ground fault return path, and to provide software that would help engineers determine the appropriate run lengths of steel conduit and EMT when used for equipment grounding.

GEORGIA INSTITUTE OF TECHNOLOGY GROUNDING RESEARCH

One of the top experts in the field of grounding, Dr. Sakis Meliopoulos, professor of electrical and computer engineering at Georgia Tech, headed the grounding research that was completed in 1994. This research represented the first update on the impedance and permeability of steel conduit in over 40 years.

The first phase of the grounding research at Georgia Tech consisted of resistance and permeability testing of various steel raceways that were purchased from local distributors. Based on this information, Dr. Meliopoulos and his team developed a computer model and validated the results through actual field testing. The next step was to develop a computer software program that allowed the user to calculate the appropriate length of steel conduit or EMT runs necessary to meet NEC requirements.

A few years later, Georgia Tech conducted research on steel conduit to show how steel conduit reduces electromagnetic fields. This research was added to the grounding research and was ultimately rolled into the GEMI (**G**rounding and **E**lectro**M**agnetic **I**nterference) software analysis program, now available for free downloading at www.steeltubeinstitute.org.

SUMMARY OF KEY FINDINGS IN GEORGIA TECH GROUNDING RESEARCH

The GEMI research project and resulting software analysis program proved that listed steel conduit and EMT clearly exceed the minimum equipment grounding requirements of the NEC. In addition, the GEMI research on grounding verified the following:

- Comparably sized steel rigid conduit, IMC and EMT allow the flow of higher fault current than an aluminum or copper equipment grounding conductor as listed in NEC 250.118.
- Steel rigid conduit, IMC and EMT provide a low impedance path to ground and facilitate the operation of the overcurrent devices in runs not exceeding the maximum allowable lengths detailed in the research report.
- Where lengths do not exceed the maximum allowable computed by the GEMI software, supplemental grounding conductors in secondary power systems enclosed in steel EMT, IMC or rigid conduit do not add to safety in a phase to neutral fault. The use of supplementary equipment grounding conductors, when participating in the fault circuit, reduce the overall impedance and may or may not increase the allowable length of the run, depending on the size and system design.
- The maximum allowable length for a specific system depends on conductor size, steel conduit size and fault type. In many cases, the maximum allowable length for a phase to neutral fault is shorter than the maximum allowable length for a phase to steel conduit fault. Thus, in most cases, the steel conduit is not the limiting factor in a conductor to neutral fault.

FREE DOWNLOADS OF GEMI SOFTWARE

The GEMI software is available for free downloading at www.steeltubeinstitute.org. Click on “Resources” then “GEMI Analysis Research,” where you will also find copies of the two Georgia Tech research reports on grounding and on shielding against electromagnetic fields.

Maximum length of steel conduit/EMT that may safely be used as an equipment-grounding circuit conductor. Based on a ground-fault current of 400% of the overcurrent device rating. Circuit 120 volts to ground; 40 volts drop at the point of fault. Ambient temperature 25°C.

Copper Equipment Grounding Conductor AWG Size***	Copper Circuit AWG Conductors	Maximum Length of Run (in feet) using Copper Equipment Ground Conductor	Aluminum Equipment Grounding Conductor AWG Size***	Aluminum Circuit AWG Conductors	Maximum Length of Run (in feet) using Aluminum Equipment Grounding Conductor	For Copper and Aluminum: Overcurrent Device Rating Amperes 75°C**	For Copper and Aluminum: Fault Clearing Current 400% O.C. Device Rating Amperes
14	14	253	12	12	244	15	60
12	12	300	10	12	226	20	80
10	10	319	8	8	310	30	120
10	8	294	8	8	232	40	160
10	6	228	8	4	221	60	240
8	3	229	6	1	222	100	400
6	3/0	201	4	250 kcm	195	200	800
4	350 kcm	210	2	500 kcm	204	300	1200
3	600 kcm	195	1	900 kcm	192	400	1600
2	2-4/0	160	1/0	2-400 kcm	163	500	2000
1	2-300 kcm	160	2/0	2-500 kcm	161	600	2400
1/0	3-300 kcm	134	3/0	3-400 kcm	131	800	3200
2/0	4-250 kcm	114	4/0	4-400 kcm	115	1000	4000
3/0	4-300 kcm	106	250 kcm	4-500 kcm	107	1200	4800
4/0	4-600 kcm	93	350 kcm	4-900 kcm	97	1600	6400
250 kcm	5-600 kcm	78	400 kcm	5-800 kcm	79	2000	8,000
350 kcm	6-600 kcm	*	600 kcm	6-900 kcm	*	2500	10,000
400 kcm	8-500 kcm	*	600 kcm	8-750 kcm	*	3000	15,000
500 kcm	8-1000 kcm	*	800 kcm	8-1500 kcm	*	4000	16,000
700 kcm	10-1000 kcm	*	1200 kcm	10-1500 kcm	*	5000	20,000
800 kcm	12-1000 kcm	*	1200 kcm	12-1500 kcm	*	6000	24,000

*Calculations necessary
** 60°C for 20- and 30-ampere devices
*** Based on NEC Chapter 9, Table 8

This table shows examples of calculations from the GEMI (Grounding and ElectroMagnetic Interference) analysis software program.

Maximum length of steel conduit/EMT that may safely be used as an equipment-grounding circuit conductor. Based on a ground-fault current of 400% of the overcurrent device rating. Circuit 120 volts to ground; 40 volts drop at the point of fault. Ambient temperature 25°C.						
Trade Size	Conductors AWG	Overcurrent Device Rating Amperes 75°C*	Fault Clearing Current 400% O.C. Device Rating Amperes	Maximum Length of Rigid Run in feet	Maximum Length of IMC Run in feet	Maximum Length of EMT Run in feet
½ (16)	3-12	20	80	384	398	395
	4-10	30	120	364	383	358
¾ (21)	4-10	30	120	386	399	404
	4-8	50	200	334	350	332
1 (27)	4-8	50	200	350	362	370
	3-4	85	340	357	382	365
1 ¼ (35)	3-2	115	460	365	392	391
1 ½ (41)	3-1	130	520	377	402	407
	3-2/0	175	700	348	377	364
2 (53)	3-3/0	200	800	363	389	390
	3-4/0	230	920	347	375	367
2 ½ (63)	3-250 kcm	255	1020	356	368	406
3 (78)	3-350 kcm	310	1240	355	367	404
	3-500 kcm	380	1520	327	338	370
	3-600 kcm	420	1680	314	325	353
4 (103)	3-900 kcm	520	2080	310	320	353
	3-1000 kcm	545	2180	304	314	347

* 60°C for 30- and 30-ampere devices

This table shows examples of calculations from the GEMI (Grounding and ElectroMagnetic Interference) analysis software program.

Derived from *Soares Book on Bonding and Grounding*, 10th edition, by permission of International Association of Electrical Inspectors.