

Square D® I-Line® Plug-On Connections

Introduction

Good electrical connections are essential for proper performance of all electrical equipment whether in residential, commercial, light industrial, large industrial, or utility applications. A critical requirement of any electrical connection is that it maintains a low-resistance current path to avoid overheating. Clean contact surfaces and the proper amount of pressure are essential for a good electrical connection. Maintaining a low resistance current path can be especially challenging in environments with vibration and thermal cycling.

The I-Line® plug-on connection design reduces or eliminates the inherent connection problems in conventional bolted connections. The I-Line design not only provides excellent performance, it also minimizes installation and maintenance time.

Figure 1: I-Line Plug-on Jaw with Multiple Fingers



Plug-on Verses Bolted Connections

In order to fully appreciate the advantages of the I-Line plug-on connection, it is helpful to have a general understanding of the common issues associated with bolted connections.

- Prior to making bolted connections, each connecting part requires the removal of surface films and oxides if the bus bar is tin or silver plated. When the surfaces of connecting parts are not properly prepared, high-resistance connections are often the result.
- Each bolted connection is made by assembling multiple loose parts including nuts, bolts, and Belleville washers. Properly assembling each connection can be difficult and time consuming.
- Many bolted connections are made by driving a thread forming screw or bolt into an aluminum or copper bus bar. Proper care must be taken during assembly to assure the screw or bolt is not cross threaded or stripped. If either occurs, it may result in a loose connection.
- Even when properly installed, annual inspection and retightening of bolted connections is necessary due to the loosening effects of vibration and thermal cycling.

Plug-on Connections

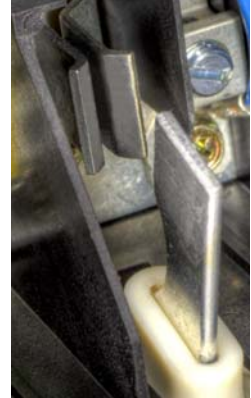
Plug-on connections are used extensively in residential, commercial, and industrial applications. They can be found in many everyday electrical devices such as shown in Figure 2.

The design of the plug-on connection is relatively simple. A conductor is inserted between hardened metal jaws and the spring force from the jaws maintains the proper contact pressure for good connections. The plug-on design resists many common connectivity problems, including those due to vibration and thermal cycling.

Figure 2: Common Plug-on Connections



Miniature Circuit Breakers



Safety Switches



Fuses



Switchgear



I-Line® Busway Bus Plug

Advantages of the I-Line® Plug-on Design

By understanding the challenges of creating good electrical connections in panelboards and switchboards and the limitations of bolted connections, it is easier to appreciate the advantages of plug-on connections and the value of the I-Line® connection system.

Some design challenges for making good electrical connections include:

- Limiting the number of parts required to make the connection
- Simplifying the installation process, thus decreasing installation and replacement time
- Minimizing the potential for improper installation
- Minimizing or removing blow-apart concerns under fault currents
- Dealing with vibrations and the effects of thermal cycling
- Dealing with corrosion and non-conductive surface layers

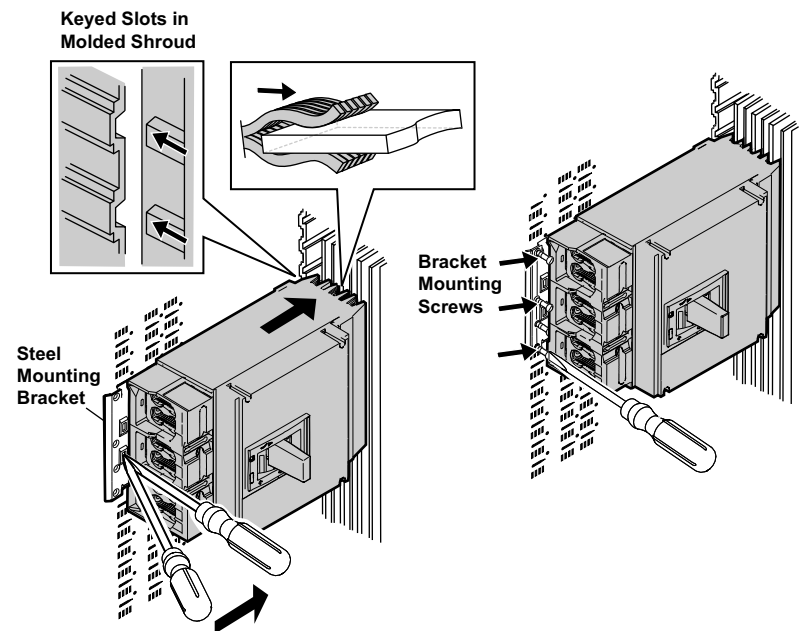
Quick Installation and Removal

I-Line devices can be installed anywhere in an I-Line switchboard or panelboard bus stack and do not require special tools, additional mounting assemblies, or mounting hardware such as connecting bars, straps, nuts, bolts and washers. All connection components for I-Line applications are permanently contained (factory-installed) within the I-Line device. Likewise, removing or changing out I-Line devices is simplified because there are no special tools needed to disassemble or reassemble mounting hardware.

I-Line devices are installed using a simple process. A steel mounting bracket is levered to push the multiple plug-on fingers onto the bus stack. Bracket mounting screws are used to secure the circuit breaker in place.

Keyed slots in the molded shroud surrounding the insulators helps to ensure proper alignment and helps support the device during installation and removal.

Figure 3: Quick Installation



Surface Preparation during Installation

Non-conducting surface films and oxides pose significant challenges to creating good connections. Conventional bolted connections require special on-site surface preparation and tightening tools to achieve proper connection pressure.

Unlike bolted connections, I-Line® plug-on connections do not require connector preparation to ensure good long-term electrical connectivity.

During installation, the connector force from the I-Line plug-on jaws and beveled fingers wipe the non-conducting surface films from the bus bar and jaw surface. This “in-line” wiping action develops a line of electrical contact spots to maximize the connection’s electrical performance.

Line contact spots actually produce lower resistance connections than circular contact spots of the same area.

Figure 4: Beveled Jaw Fingers

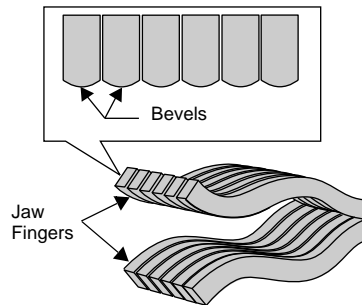


Figure 5: Wipe Tracks on Bus Bar

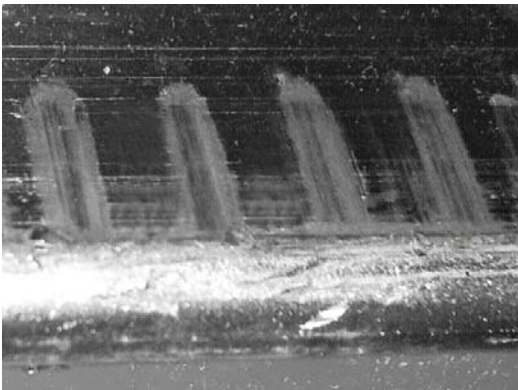
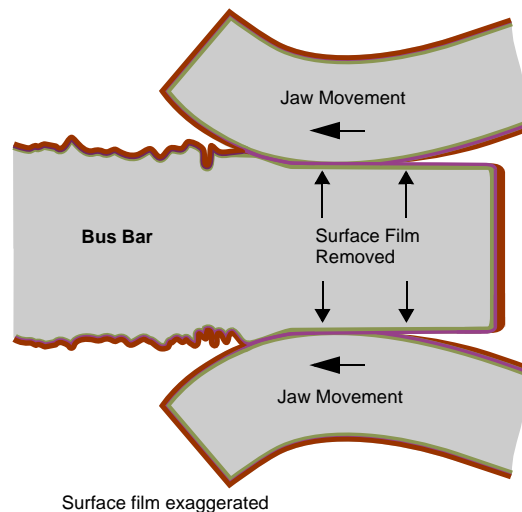


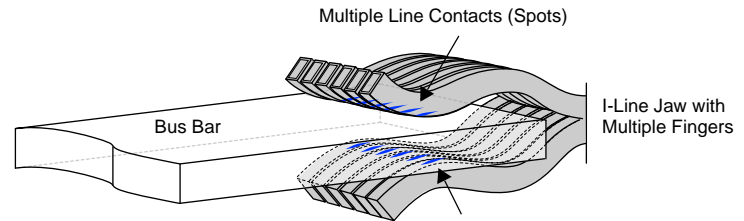
Figure 6: Surface Film Removal during Installation



Multiple Current Paths with I-Line Connections

A significant advantage of the I-Line plug-on connection is that it creates multiple current paths on each side of the bus bar. Each of the fingers on a plug-on jaw provide an individual current path with an equal contact area. Devices with higher current carrying capacity are designed with more contact fingers to minimize electrical resistance.

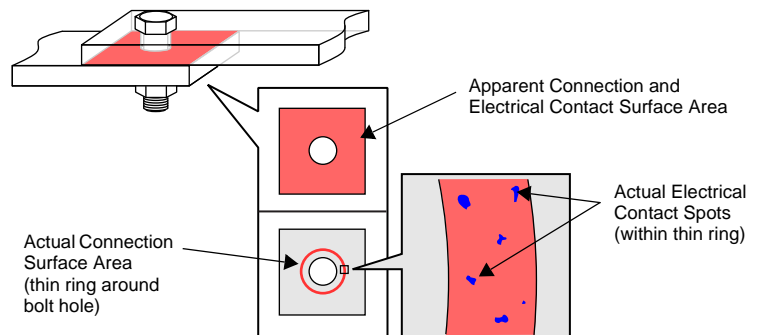
Figure 7: Multiple Line Contacts and Current Paths



Apparent Contact Area with Bolted Connections

In contrast, the electrical resistance values in bolted connections often measure much higher than expected when considering the apparent connection surface area. The actual electrical contact spots are only within the thin ring around the bolt hole (Figure 8).

Figure 8: Apparent vs. Actual Contact Area of Bolted Connections

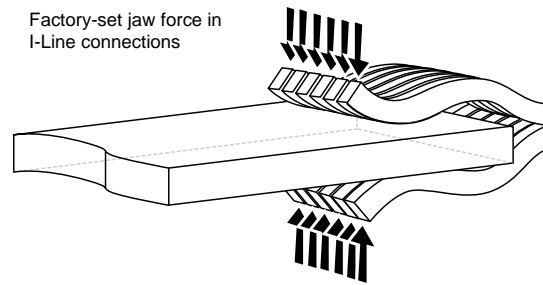


Making good bolted connections with sufficient low-resistance contact spots requires the use of calibrated tightening tools, careful preparation of the contact surfaces, correct assembly of the connection pieces, followed by applying the appropriate amount of torque according to tightening recommendations. Inadequate preparation and installation reduces the number of contact spots, increases current constriction, and can result in overheating at the connection.

Proper Contact Force

I-Line® jaw spring forces determine the “contact force” or the amount of pressure that is applied between the device jaws and the bus bar. Unlike bolted connections, the contact force for all I-Line plug-on connections is carefully designed, factory set, and checked to ensure correct contact force. In addition to saving installation time, this design reduces the potential for incorrect connection forces due to installation errors.

Figure 9: Preset Jaw Force



Resistance to Effects of Vibration and Thermal Cycling

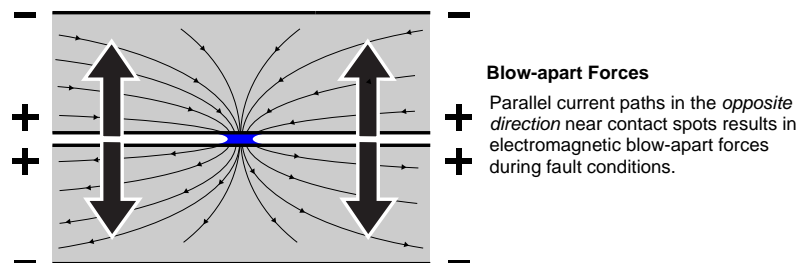
All connections experience thermal cycling due to changes in the level of current flowing through the connection as well as fluctuations in ambient temperature. Electrical connections that cannot withstand the expansion and contraction of the mating parts typically require annual maintenance or retightening to avoid overheating due to loose connections.

I-Line plug-on connections, with their jaw spring action, do not require such maintenance to accommodate the effects of expansion and contraction.

Fault Current Forces

Electrical connections must be designed to carry the high levels of current that occur for short periods of time during electrical faults. However, with conventional bolt-on connections, there is a tendency for electrical connections to blow-apart at the contact spots due to electromagnetic repulsion (Figure 10).

Figure 10: Bolt-on Connections



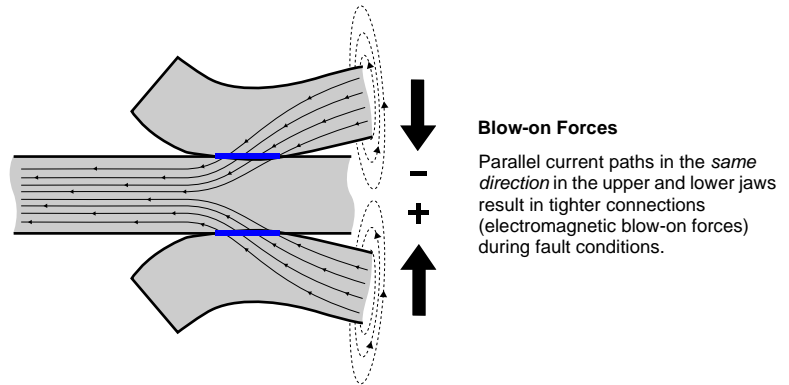
By design, I-Line connections eliminate the problem of blow-apart forces. Multiple contact fingers provide independently suspended current paths for more contact spots. The in-line contact spots are distributed both above and below the bus bar. The parallel current paths created by the multiple jaw fingers actually create blow-on forces during fault conditions (Figure 11).

Parallel currents in the same direction attract each other with the same proportionality to current magnitude squared. The parallel current paths of I-Line jaws attract each other and grip the bus bar under fault conditions.

In fact, theoretical calculations on I-Line jaws indicate the blow-on forces dominate the blow-apart forces by a factor of ten to one.

No instance of jaw popping has ever been observed in over forty years of extensive short circuit testing.

Figure 11: I-Line Connections—Blow-on Forces



Protection from Corrosion and Oxidation in Normal Service Conditions

Oxidation and corrosion can erode electrical contact areas if the connections are not properly protected. To resist corrosion and oxide development, the components of I-Line connections receive special platings during the manufacturing process. The I-Line bus receives a tin plating while the I-Line jaws are silver plated. A specially formulated compound is applied to the connections to maintain low-resistance contact areas.

Testing

All Square D® brand panelboard designs are verified by short circuit testing per UL 67 up to the maximum integrated equipment short circuit rating. Steady-state and cyclic temperature rise tests per UL 67 are also conducted. I-Line panelboards also undergo seismic testing per IEEE 344.

Square D Power-Style® QED switchboards are designed, manufactured and tested to meet the latest revisions of UL 891 for deadfront switchboards.

Square D brand I-Line Busway is designed, manufactured, and tested to meet the latest revisions of UL857.

Finally, I-Line connections are tested for micro-movement, an important failure mode that is omitted from standard testing. Micro-movement is movement of one to three-thousands of an inch caused by thermal expansion, mechanical motion, and electromagnetic induced vibration.

Summary

Square D® brand I-Line plug-on connections have many advantages over conventional bolt-on connections. Performance advantages include excellent surface preparation and development of contact spots during installation, long-term resistance to the effects of thermal cycling, and superior fault current performance due to parallel current paths that develop "blow-on" forces during fault conditions.

Even when compared to optimized bolted connections, the time-saving design and installation convenience built into the I-Line plug-on design gives it a significant advantage over other connection solutions. There are no loose connector parts to stock or replace and because the built-in jaw connectors are factory preset with the proper contact force, the possibility of tightening errors and cross-threading errors is eliminated, and the installation time is significantly reduced.

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