# Electrode Boiler Electrical Connection –

# 3-Wire or 4-Wire?


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## 1. Summary

In North America, almost all electrode boilers are installed with a 4-wire solidly grounded connection. However, in Europe and Asia, where there are thousands of electrode boilers installed, a 3-wire connection is employed. In this whitepaper, we will explain the following:

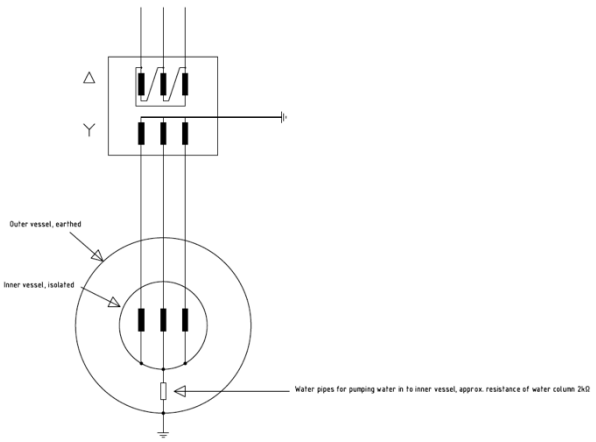
1. Understand the origin of why a 4-wire connection requirement exists in North America
2. Describe the jet-type boiler and why it requires the use of the 4-wire connection
3. Describe the high-resistance neutral electrode boiler and the features that make it safer than jet boilers
4. Why insulated immersion boilers can be connected with only 3-wire
5. Whether to use 3-wire or 4-wire connection in the United States and Canada

### Definition of an Electrode Boiler

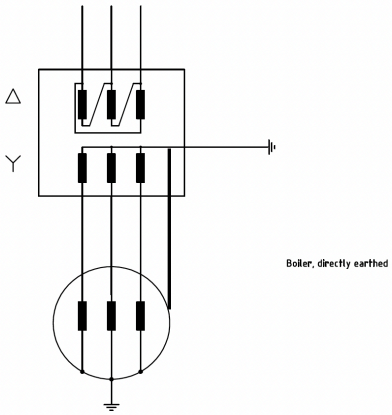
An electrode boiler is a steam or hot water boiler that produces hot water or steam via passing of electrical current directly through the water without the use of heating elements.

### 3-wire vs. 4-wire electrical connection

For a typical 3-phase electrical equipment, only 3 wires are connected with 3 phase power. These 3-wire conenctions can be supplied by either delta or wye transformer. The wye transformer can be impedance, resistor, or ungrounded. For a 4-wire system, the 4th wire is from the wye transformer's solidly grounded neutral wire.




**3-Wire Connection**




**4-Wire Connection**

**4-wire in North America, but 3-wire in rest of the world**

There is a notion in North America that all electrode boilers should have a 4-wire, solidly grounded connection. In Europe and Asia, almost all electrode boilers are installed with a 3-wire connection. There are two reasons for this, a difference in regulation and different types of electrode boilers used in North America and the rest of the world. In the rest of the world, electrical codes do not have special provision for electrode boilers. Therefore, jurisdictions evaluate the specific electrical connection and whether it is compatible with the electrode boiler's performance in terms of leakage current and fault current. In addition, the jet-type boiler is the only boiler available in North America and is a solidly grounded boiler design. The rest of the world uses mostly immersion boiler, which has a high resistance insulated neutral. We will describe the difference in the boiler design in more details in a later section, that allows the insulated immersion boiler to be connected to a 3-wire system.

In addition, ASME's CSD-1 also aligns to NEC. Therefore, this electrical requirement are either directly dictated if the site is required to follow NEC (USA) or indirectly via ASME CSD-1 (Canada). We must also note that in the USA, any power generating facility is not bound by the NEC code. In addition, NEC is not the law of the land in Canada. But rather, Canada has its version, aptly named Canadian Electrical Code (CEC).

This section of the NFPA code has had several revisions, but changes were limited to the numerical section identifier but the content has remained the same since the 1970s, when it was first introduced.

The US National Electrical Code, under section 495, that has a prescriptive connection method for how to connect the electrode boiler properly to the electrical grid. In summary, it states that electrode boilers shall be connected with a 3-phase, 4-wire solidly grounded wye system, or from isolating transformers arranged to provide such a system. In addition, we should note that it allows greater of 5 amps or 7 ½ percent of boiler full load current for 10 seconds or exceeds instantaneous value of 5 percent of boiler full load. The full text under NEC is listed below:

## Part V. Boilers

495.70 General. The provisions of Part V shall apply to boilers operating over 1000 volts, nominal, in which heat is generated by the passage of current between electrodes through the liquid being heated.

495.71 Electrical Supply System. Boilers shall be supplied only from a 3-phase, 4-wire solidly grounded wye system, or from isolating transformers arranged to provide such a system. Control circuit voltages shall not exceed 150 volts, shall be supplied from a grounded system, and shall have the controls in the ungrounded conductor.

495.72 Branch-Circuit Requirements.

(A) Rating. Each boiler shall be supplied from an individual branch circuit rated not less than 100 percent of the total load.

(B) Common-Trip Fault-Interrupting Device. The circuit shall be protected by a 3-phase, common-trip fault-interrupting device, which shall be permitted to automatically reclose the circuit upon removal of an overload condition but shall not reclose after a fault condition.

(C) Phase-Fault Protection. Phase-fault protection shall be provided in each phase, consisting of a separate phase-overcurrent relay connected to a separate current transformer in the phase.

(D) Ground Current Detection. Means shall be provided for detection of the sum of the neutral conductor and equipment grounding conductor currents and shall trip the circuit-interrupting device if the sum of those currents exceeds the greater of 5 amperes or 7 ½ percent of the boiler full-load current for 10 seconds or exceeds an instantaneous value of 5 percent of the boiler full-load current.

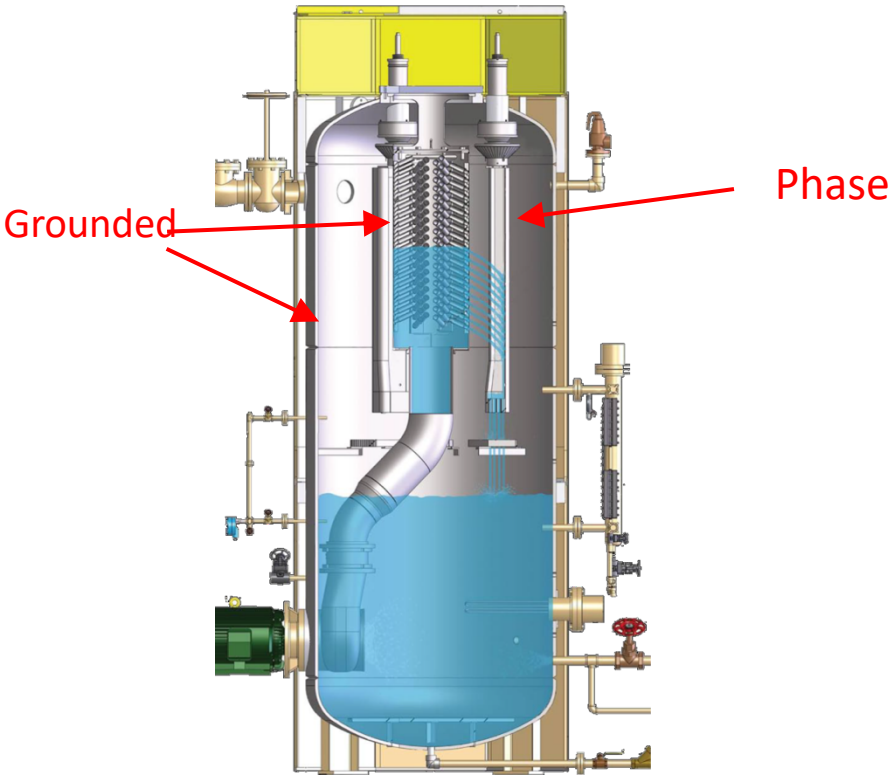
(E) Grounded Neutral Conductor. The grounded neutral conductor shall be as follows: (1) Connected to the pressure vessel containing the heating elements (2) Insulated for not less than 1000 volts (3) Have not less than the ampacity of the largest ungrounded branch-circuit conductor (4) Installed with the ungrounded conductors in the same raceway, cable, or cable tray, or, where installed as open conductors, in close proximity to the ungrounded conductors (5) Not used for any other circuit

495.73 Pressure and Temperature Limit Control. Each boiler shall be equipped with a means to limit the maximum temperature, pressure, or both, by directly interrupting all current flow through the heating elements. Such means shall be in addition to the temperature, pressure, or both, regulating systems and pressure relief or safety valves.

495.74 Bonding. All exposed non-current-carrying metal parts of the boiler and associated exposed metal structures or equipment shall be bonded to the pressure vessel or to the neutral to which the vessel is connected in accordance with 250.102, except the ampacity of the bonding jumper shall not be less than the ampacity of the neutral conductor.

**2. Jet-type boilers (Solidly grounded) – most common in North America:**

When this section of the NEC code regarding the electrode boiler was written in the USA, there was only one type of electrode boiler available at the time, the jet-type electrode boiler.

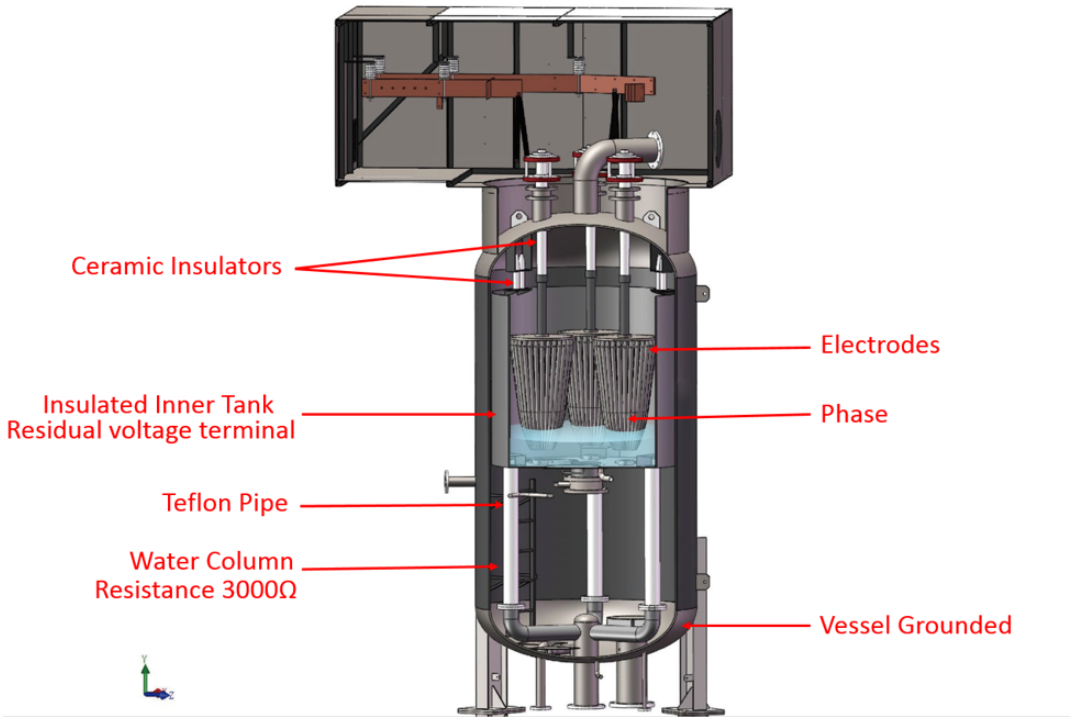



Exploded view of jet-boiler, from Precision Boiler

We will not delve into the details of the jet-type boiler except as related to the electrical connection. The jet-type boiler is a solidly-grounded boiler, meaning the current is traveling between phase to ground. Any phase imbalance within the 3 phase electricity will create a voltage that travels to the ground bond directly. In the NEC code, recall there is an allowance of greater of 5 amps or 7 ½ percent of boiler full load current for 10 seconds or exceeds instantaneous value of 5 percent of boiler full load. To put it into perspective, for a 13.8kV Boiler at 15MW, assuming a power factor of 1 (which is the case for electrode boilers), the full load current is 837A. At 7 ½ percent of full load, the allowable ground current is 62.8A for 10 seconds. Many industrial systems, including NFPA 70 (NEC) and IEEE standards, set ground fault protection trip levels much lower than 60A—often in the range of 5A to 30A. Therefore, a solidly grounded neutral wire is used to safely carry this current back to the transformer.

### 3. Immersion Boiler (High resistance insulated neutral):

In Europe, due to more stringent leakage current limits, the solidly grounded type of electrode boiler was going out of favor due to the safety risk of the high fault currents. As a result, the high resistance insulated neutral boiler was developed. The objective of this type of boiler is to reduce the leakage and fault current by introducing a resistance to ground in between inner and outer tank. This resistance is generally between 2-3000 ohm.

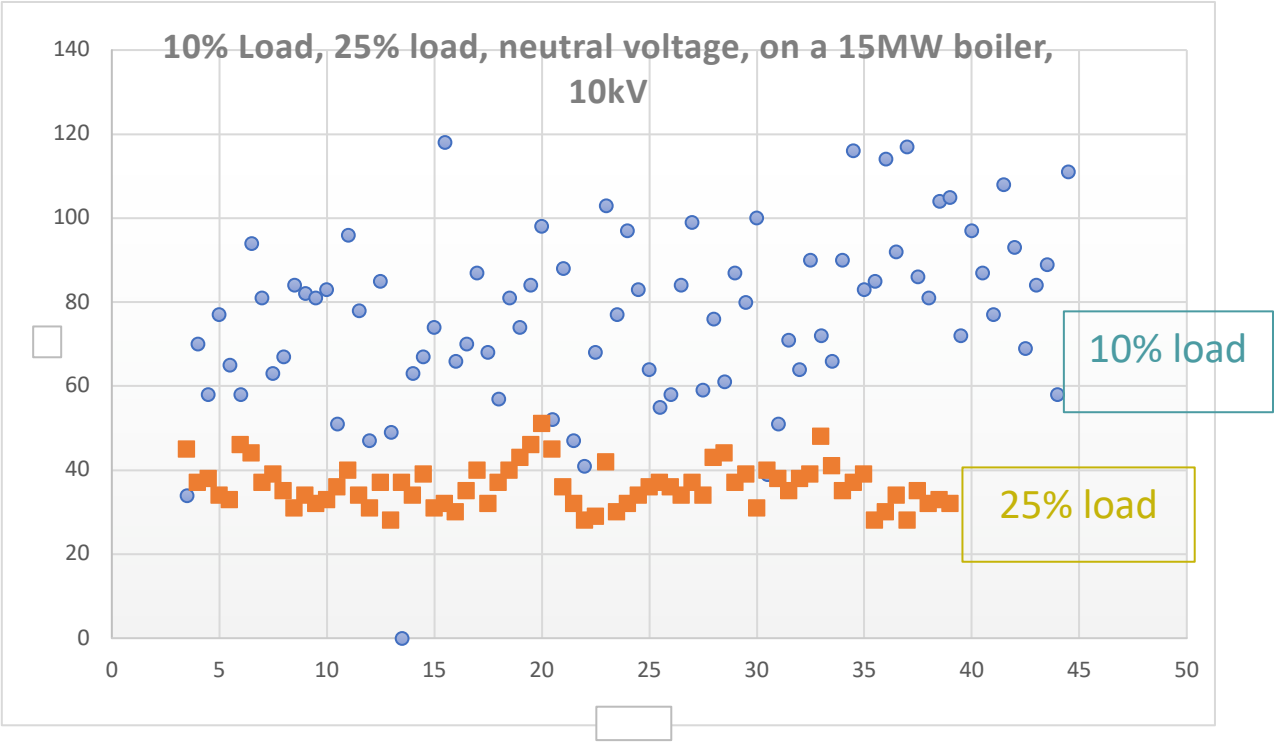



Exploded view of an insulated immersion boiler from ZETA

In an electrode boiler, phase imbalance caused by uneven current flow in the three phases and results in a residual voltage. This voltage travels to ground as a leakage current. Although the immersion boiler has the least phase imbalance due to its naturally level water service, phase imbalance still exists and results in a voltage in inner tank. By introducing a resistance of 2-3000 ohm, this leakage current is greatly reduced to less than 50mA. The leakage current performance of high resistance neutral immersion is orders of magnitude lower than the solidly grounded boiler.

**4. Electrical Performance of immersion boiler:**

From actual data with a 10kV, 15MW boiler, we can observe that for an immersion boiler, the phase imbalance increases at lower load. Even at 10% load, the worst case scenario, the phase imbalance is less than 2%. At 25% load, the phase imbalance reduces to 0.64%. This is due to reduction of surface irregularity as a the load increases. This results in lower phase imbalance as load increases. This phase imbalance is much lower than jet boilers due to much more variation in their spray process, stemming from uneven nozzle wear and electrode plate wear. They contribute to greater imbalance generated by the boiler.




**10% load:**
Median voltage: 77V
Current to Ground: 38.5mA
1.33% phase imbalance

**25% load:**
Median voltage: 37V
Current to Ground: 18mA
0.64% phase imbalance

Assuming a 2% phase imbalance, the neutral is at 160V with leakage to ground current of 53mA

With a solidly grounded system with estimated impedance of 0.5ohm, the ground current is approximately 320A.

With a 3000 ohm insulated neutral, acting like a 3000ohm resistor, the ground current is greatly reduced to 53.1mA.

Therefore, the current to ground at 2% phase imbalance:

| | Current to ground |
|---|---|
| Jet-type boiler | 320A |
| Insulated Immersion boiler | 53.1 mA |

Therefore, with such low leakage current and low fault current thresholds, these immersion boilers are able to be connected without a 4$^{th}$ neutral wire and they can also be connected to the same transformer that is shared with other equipment. This is because the low ground fault current does not interfere with other equipment connected to the same transformer. Therefore, the immersion electrode boiler can share the transformer with other equipment, provided that the transformer has sufficient capacity.

These immersion boilers are widely installed in Europe/Asia for the last 40+ years. They gained popularity first due to regulation requirements of reduced leakage current, but this technology has the potential to reduce capital investment by eliminating the need to purchase an isolation transformer.

**Key advantages for insulated immersion boiler vs. jet boiler:**

- Orders of magnitudes lower leakage current (measured in mA)
- Simpler install, no need for additional isolation transformer to create 4$^{th}$ wire
- No need for deviation request in Canada
- Can be installed with either 3-wire or 4-wire connection

**How about safety?**

Due to the lower leakage current design and lower touch potential, immersion boilers are much safer to both the electrical grid and to the operators around it than jet-type boilers. Whether it is connected to a 3-wire system or a 4-wire system, insulated immersion boilers offer a safer electrical option by reducing the leakage current and touch potential to anyone around the boiler.

## 5. 3 or 4-wire in Canada?

In Canada, there is no regulation requiring the use of 4-wire connection with electrode boilers. The immersion boiler with insulated neutral should be allowed for either a 3-wire or 4-wire connection. However, a 3 wire connection will avoid the need for a costly isolation transformation. For safety consideration, a solidly grounded jet-type boiler should always be connected with a solidly grounded 4-wire solution. However, a deviation request is necessary for a 4-wire solution because both neutral and the ground bond is connected to the same boiler body, this violates article 10-210(a) of the CEC.

**Rule 10-210(a)** of the **Canadian Electrical Code (CEC)** specifies that the grounded conductor (commonly known as the neutral) of a solidly grounded AC system supplied by the utility must be connected to a grounding conductor at **one point only** at the consumer's service. This single-point grounding ensures safety and prevents issues such as circulating currents or potential differences that could arise from multiple grounding points

Canada:

| | 3-wire connection | 4-wire connection |
|---|---|---|
| Jet-type boiler | NO | YES** |
| Insulated Immersion boiler | YES | YES* |

*The insulated immersion boiler can also be connected with a 4-wire solidly grounded connection but there are no meaningful electrical advantages with 4-wire connection.

**The jet type boiler will require a deviation since it will be connecting the ground in two locations: the neutral and the ground bond.

## 6. 3 or 4-wire in USA?

In the USA, in cases where NEC code should be followed, a 4-wire connection is required. However, exceptions can be made by local AHJ approval. The immersion boiler can be connected either via a 3-wire or 4-wire connection. Power generation locations, which are not required to abide by NEC, are allowed to use 3-wire connection. Code changes will be requested to update the NEC code for 2029 to allow for 3-wire connection on electrode boilers using the high resistance insulation design.

United States:

| | 3-wire connection | 4-wire connection |
|---|---|---|
| Jet-type boiler | NO | YES |
| Insulated Immersion boiler | YES*** | YES |

***In power generation plants only, or require local AHJ approval to circumvent NEC code.