Connecting the AVCON J1772 Control Box and Inlet to an EV using the Level II method(Onboard charger 30A max @ 240 VAC)

SAE J1772 is a standard (actually a "Recommended Practice") published by the Society of Automotive Engineers. It defines how EV's in North America with on-board chargers are to be connected to the mains power through an "Inlet" on the vehicle which, in addition to the main AC power pins (240 volt single phase up to 40 amps or more), has a "Pilot" pin that provides both a safety interlock and control information to and from the EV. The cable to this inlet is to come from a control box on the wall which contains a contactor, control and Ground Fault detection circuitry. The box , in conjunction with circuitry connected to the inlet, detects whether the vehicle is properly connected. before allowing the contactor to close. If you are going to do serious design work you should get a copy of J1772. Otherwise this text and the accompanying schematic should get you started.

Important points

- Your charger must not need nor use a connection to neutral since it is not provided for in J1772. The earth ground (frame) connection may not be used as a neutral return.
- If fans are used they must be 240 volt fans, or pairs of 120V fans wired in series.
- A neutral IS required to run the AVCON control box. It must be grounded per the NEC only at the service entrance to the premises or at the transformer. The earth ground must not be connected to the neutral in the box (nor anywhere else in the wiring system). It must however be connected to earth as is the neutral. The AVCON box checks for this. Thus four power wires go in but three come out.
- Later Revs of the AVCON box will close the contactor both for sealed batteries and flooded. This makes it possible to charge either from one plug (but see below for fan considerations). Earlier revs do not have this feature.
- The AVCON box does not check for a short between the pilot lead and earth ground.
- All that is needed for a simple connection is a single resistor and capacitor. An additional resistor and a switch provides the ability to turn the power to the charger off and on from the Vehicle.
- More elaborate schemes which check for available power, communicate digitally, and provide more sophisticated control are allowed (but be sure you have bought Inlets and Plugs with all the wires provided!)..

Details

First the power connections and safety issues; then how to connect the pilot lead for proper control:

Neutral wire:
There is no "neutral" provided for in J1772, only "earth ground" which is to be connected to the frame of the EV. It is used both to actually ground (connect to earth) the vehicle and to provide the return path for the pilot current and any leakage currents. The pilot current flow is used to check that the frame of the vehicle is actually connected to earth ("grounded"). Thus in Level II charging the charger must be connected line-to-line and use the 240 volts symmetrically, not deriving 120 volts from one line to the earth wire since unequal currents will then flow in the line connections. Many existing chargers in the field do not meet this requirement.

AC power
The AVCON control box switches 240 Volt AC power using a contactor with two poles in series with "Line 1" and "Line 2" coming from a circuit breaker (or fuse) which must be rated at 30 amps RMS (or more) because the duty cycle of the pilot waveform is fixed at 50%. The user should be aware that many chargers draw current in spikes 120 times per second rather than continuously. Because these spikes are discontinuous the RMS value of the current drawn (which is what heats up the fuses) can be far in excess of the average current (by a factor of as much as two, even three). Because of this, a 30 amp fuse can blow even with a 15 amp average current into a 144 volt battery pack. Its happened to me!

Earth.
The “Earth” connection (green in North America) must be connected to the frame of the vehicle. In a properly installed wiring system this conductor carries no current and must in fact be connected to the earth at the point of entry of the wires to the premises. Its purpose is to provide safety by

1. Insuring the frame of the EV (or washing machine or pool pump motor..) cannot have a potential much different from ground at any time, even if one of the “hot” wires (Line 1, 2 in our case) should become shorted to the frame because of insulation fault or drowning in water etc.
2. Causing the breaker to blow if such a short should exist. (Therefore the earth connection must be made with wire at least as large as the largest line conductor and the neutral (center tap of the transformer on the pole typically) must connect to ground somewhere too..)
3. Making sure that current has a place to go which may leak from the hot wires if the insulation is poor, thus allowing a GFCI to measure that current and trip a breaker.

The neutral conductor (usually white, but not always) allows the provision of 120 Volt power from a 240 volt circuit. It is the centertap of the power transformer out on the pole. If 120 Volt loads are connected between the lines and ground which are not carrying exactly the same currents, the difference current will flow in the neutral. In particular if there is a 120 Volt load only between one of the lines and neutral then all of the line current will flow back in the neutral. The neutral must be connected to earth also but only at the point of entry of the wiring to the premises (and/or at the transformer). Since this is the case electricians (and laymen) have often dispensed with the earth wire, feeling it was unnecessary. Indeed the code used to allow connections to be made without the earth ground. If a 240 volt load such as a water heater is connected line-to-line there is no neutral connection at all so the unbalance problem vanishes. EV chargers must be hooked up in this way as noted above.

GFCI
A ground fault current interrupter works by comparing the outbound current with the inbound current. If they are different then the difference must be going somewhere (hopefully not through you!) and the circuit should be opened. The combination of a grounded neutral and an earth ground assures that the current <u>does</u> have such a place to go. This differential measurement is typically done by running the two line wires thru a hole in a toroidal core where the fields produced by the two currents will cancel if they are equal. A secondary winding is wound on the toroid which picks up any difference current and trips the contactor if it exceeds a set threshold (about 6 ma AC in household devices and 20 ma in EV’s which tend normally to have more leakage from the battery pack to ground). In the 120 volt case the outbound current is in one of the lines and the inbound current is in the neutral. In the 240 volt case the outbound current is in Line 1, say, and the inbound current is in line 2. There is a problem if the charger uses the neutral to gain access to 120V for use, for example, in its own power supply circuitry. Then the currents in Line one and Line two will not be equal and the difference will be flowing in the neutral so the GFCI will trip. Solving this problem is easy: just run the neutral lead through the GFCI sensing core also. BUT this could not be done in the AVCON control because J1772 allows an earth connection but not a neutral. So chargers that need a neutral connection will work if they neutral is connected to the earth ground (wrongly) but then they will draw unbalanced currents which causes the GFCI circuitry to trip.

This means that there must be four wires to the box even though there are only three wires from there to the EV through the inlet... and the charger must not have a neutral connection or and must never put any current through the frame ground (earth). J1772 requires this because its based on the European way of doing things, not the usual US method requiring an extra earth ground.

Control

The minimum control circuit necessary on the EV to use in conjunction with the inlet uses one diode, one capacitor, and one resistor. By adding an extra resistor the power can be turned off and on with a switch in the vehicle (which can be part of the charger controller).

When the plug is installed in the inlet the first pin to make connection is frame ground. The last pin to connect is the pilot pin. The control box sends a 1 kHz 12 volt square wave through a 1000 ohm resistor to the pilot pin. The duty cycle of the square wave is set to indicate how much current can be supplied from the AC mains. In the AVCON box the duty cycle is fixed at 50% indicating that 30 Amps (RMS) is available. Therefore the circuit must supply at least 30 Amps since some chargers measure the square wave to determine how much current they can draw. An outlet which can only supply 20 amps will have a square wave with a smaller duty cycle and one which can supply more a larger one. The return current from the pilot pin is through a resistor and a diode in the EV to frame ground. If the frame ground connection is ever broken the box will immediately open the contactor. The nominal impedance the EV presents to the box is used to signal the condition of the EV as follows:

Case	Impedance	Pilot Voltage	Condition
	Open	+/- 12 Volts 1 kHz AC	Vehicle Disconnected
	2740 ohms plus diode and cap	9 volts DC	Connected, not ready to charge
	882 ohms plus diode and cap	6 volts DC	Connected, charging, sealed batts
	246 ohms plus diode and cap	3 volts DC	Connected, charging, flooded batts

The distinction between sealed and flooded batteries is made so that the control box can sense whether or not ventilation fans must be turned on during charging. According to the National Electrical Code this must be done if the vehicle is indoors and has flooded batteries which could release hydrogen during the latter part of the charge cycle. The AVCON box was designed for outdoor use and so has no fan control relay. However it <u>does</u> close the contactor for both the 6 volt and 3 volt (fan required) case so it must be used with the EV outside or, if inside, fans must be connected so they <u>always</u> come on when the contactor closes to provide power to the EV charger. Since the fans required are pretty small (148 cfm for 30 amps NEC 625-29(d)) this is not a huge nuisance for the case that sometimes sealed and sometimes flooded batteries are to be charged at the same site. Hooking up fans is straightforward IF you have 240 volt fans or if you use pairs of 120 volt fans which will work if connected in series. But here again if a single fan is hooked to one line of the contactor and to neutral the line currents will be unequal and the contactor will drop out. More expensive controllers are available which make the distinction and only turn on the fans when necessary.

The EV can have an optional switch to keep the charger power turned off. Indeed the control box can also have such a switch (although the AVCON box does not have one). Therefore the list of the resistors needed to achieve the above impedance is slightly different for the case with and without the EV switch. The simplest case, no switch, requires just a diode, capacitor and resistor called R1 on the schematic. In this case charging starts as soon a the plug is fully inserted. If a switch is required then the schematic changes slightly and the resistors R2 and R3 should be installed as shown.

	No Switch	Switch	Switch
Battery Pack	R1	R2	R3
Sealed	882 (910)	2740 (2700)	1300 (1300)
Flooded	246 (220)	2740 (2700)	267 (270)

The nearest standard 5% resistor values available at Radio Shack are shown in parenthesis. Interestingly, even though the J1772 standard calls out 1% resistors, they are not available at Radio Shack in values near to those listed. The 5% ones should work just fine however. The diode, D1 can be just about any Silicon diode that will pass at least 20 ma and stop at least 30 Volts such as the 1N4001 (Shack 276-1001). The 1 nF capacitor (same as .001 mfd or 1000 pf) should ceramic; unfortunately Radio Shack has not got such a part. Digikey (1-800-344-4539) has all the parts however, as follows: 1% Resistors:: 249XBK-ND, 267XBK-ND, 887XBK-ND, 1.30KXBK-ND, 2.74KXBK-ND all at $0.54 for 5. The cap could be P937-ND at 26 cents and the diode could be a 1N4933CT-ND at 18 cents. Unfortunately they have a minimum order, I think so your best bet might be a local radio parts store other than Radio Shack for the odd items.

In addition to the four wires mentioned (Line 1 and Line 2 with 240 VAC, Frame Ground, and Pilot) the inlet has a proximity switch to tell the EV that the cable is plugged in. This switch is a reed switch, magnetically operated and has very low current handling capability. It is to be used to disable the EV's controller so that the vehicle cannot be accidentally moved when the cord is plugged in. Some inlets have this switch normally open, some normally closed and some (Honda) have a double throw switch. This last one can conveniently be used to provide 12V from the vehicle battery to a relay that turns on the controller (usually the main Pack voltage) or to the charger control depending on whether the plug is in or not.

Some inlets have a 12 volt night light (again, Honda).

Control signals and Level III

There are 3 signal pins labeled Com1, Com2, and Signal ground. Inlets may or may not have these pins installed and the cable may or may not have the pins and wires installed, leading back to the control box. They are optional in the Level II connection. These three pins are meant to provide connection to the electronic signaling that runs around most modern cars. The physical connection is covered by J1850 and the codes and signals are covered by J2178. Codes and messages are being standardized for EV's . These can report the state of charge, battery voltage, current, etc. and as such provide a means to connect the charger control to instrumentation both onboard and off board The main use for these wires is to control an off board charger (telling it when to slow down or stop. As such this connection is mandatory for Level III charging which is aimed at high-speed charging (1/2 charge in 15 minutes in the extreme case!). The level III plug/inlet is the same except that two more high current pins (600V 400 Amps max) are wired into them and of course the three wires for Com and Signal Ground. Solar panels or batteries or a DC genset could presumably supply DC to the AC pins of a Level II cable if the charger could understand and control what was going on and if DC pins existed. Its a shame to have to use the heavy duty level III connection for this case.

Level I

Just for the record, level I charging consists of plugging the charger directly into a standard 120V wall outlet drawing a maximum of 20 amps 9but usually 15). No controlling nor interlocking is specified for this case. It would take a long time to charge most packs with 1800 watts or less (2400 max, see power factor discussion above) as compared to the 7200 watts that could come from a 30 amp 240 volt Level II charger that had power factor correction!

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