

THREE PHASE SCR CONTROL AND REGULATION BOARD

Datasheet and Applications Guide

Features Include:

- **Automatic frequency tracking of input mains from 30Hz to 90Hz (no phase delay errors!)**
- **Automatically corrects for phase rotation**
- **On-board diagnostic LED indicators**
- **Feedback for solid-state over temperature sensing of SCR heatsink**
- **Hard DC gate firing, suitable for firing large area devices**
- **The phase reference signals are filtered to reduce harmonic content above the fundamental**
- **On-board Feedback Control – eliminates the need for an external controller**
- **Improved logic implementation with state-of-the-art FPGA**
- **Optional on board Isolated voltage and current feedback inputs**
- **Industry standard size, form factor and connector interface**



The BAP1950 is a versatile three-phase bridge SCR firing board with many advanced features and functions. The BAP1950 is the ideal firing circuit for large industrial power supplies, motor controllers and generator controllers. It can be used to phase control AC mains; soft-start high power systems; produce variable, unregulated DC; and with the closed loop feedback option, produce regulated DC output with voltage control and current limiting. The BAP1950 is insensitive to phase sequence and mains voltage distortion. It features high gate isolation, soft and instant start/stop functions, phase loss inhibit and can be used at mains frequencies between 30 and 90Hz without adjustment. Its form factor and size are industry standard and requires no additional cards to implement all of its functions and options.

Functional Description

Signal Conditioning of Input Reference

Controlling SCRs requires varying the phase angle at which they turn on in order to control the portion of the input voltage that is conducted to the output. The BAP1950 phase locks to the input source in order to create the references required to control the conduction angle of SCRs in any topology. References can be derived from the cathodes of the three SCRs on J2, which are connected to the input source; or from an auxiliary connector, J5. In either case, the signals used to create the references are filtered in order to remove unwanted harmonics that will affect the precision with which the delay angle is controlled.

The phase rotation of the three-phase input is sensed and the SCR gating is automatically adjusted to account for either ABC or ACB rotation. Therefore, the three-phase input source cannot be connected with an incorrect phase rotation. However, if the auxiliary input J5 is used, the three inputs for J5 must be consistent with the rotation of the phases at J1 and J2. This is explained in more detail in the connection section on page 5.

SCR Gating Phase Locked to the Utility Input

In order for the delay angles to control the conduction angle of the SCRs, the delay angle must be phase locked and then phase shifted from the utility input by an amount determined by the delay angle control. The BAP1950 uses a phase locked loop circuit to keep the SCR gating signals in phase with the three-phase input. An additional control loop has been added that will force the delay angle to remain constant as the input frequency varies from 30Hz to 90Hz.

Delay Angle Control

The magnitude of the delay angle determines the point on the input waveform an SCR will be switched on. This controls the output voltage of a Converter (AC in, DC out) or an AC Controller (AC in, phase-controlled AC out). The BAP-1950 will accept a voltage or a current that will allow the user to control the delay angle. The default scaling for the Delay Angle Control input is:

0V corresponds to maximum delay angle (minimum conduction angle) or zero output

and

5V corresponds to minimum delay angle (maximum conduction angle) or maximum output.

The control input can be modified to accept a current input or a different scaling of the input voltage.

In order to provide a controlled and orderly start up sequence, the delay angle commanded by the user is not instantly applied to the SCRs at turn-on. At start up, the delay angle is forced to the maximum value. When the SCR control signals are phase locked to the input references, with no errors present, the delay angle will ramp down from the maximum value to the programmed value in approximately 500mS. While in operation, the SCR gate firing can be turned off using either the soft stop function (shorting J3-12 to J3-11) or the fast turn off feature (open the contact closure between J3-4 and J3-6). When the soft stop is used, the delay angle will ramp up to its maximum value in approximately 50mS. If the board is forced into a fast turn off condition, all SCR gate signals will be turned off within 20 μ S.

Logic Implementation

All of the logic required to perform the delay angle control is contained on a single FPGA (Field Programmable Gate Array). Since it is programmable, it can be modified to adapt to customer needs in certain applications.

DC Gate Drive

The BAP1950 comes equipped with DC gate drives, rather than picket fence drives, which offers improved performance in circuits with discontinuous load currents. If an SCR loses its holding current when being driven with a picket fence, the SCR will turn off and may not turn on again until it is turned on with the higher current leading edge pulse of the next turn on transition. The DC drive keeps current flowing into the gate so that the SCR will continue to be commanded on for the entire time that the SCR can be in conduction.

The current waveform sourced to each SCR gate is an initial 2 Amp peak pulse (rising at a rate of approximately 1A/ μ S) approximately 10 μ S wide, followed by 500mA of DC current for the remainder of the turn-on signal. The open circuit voltage applied to the gate is 24 volts, which enables the BAP1950 to drive large area devices under high dl/dt conditions.

Options for Powering the Board

There are several options for applying power to the BAP1950. Transformer T2 can be driven by 120 VAC or 240 VAC via connector J4. There are jumpers between T2 and J4 that configure the board to accept either of these inputs. The transformer can also be powered directly from the three-phase source that the SCRs are controlling. By removing J4 and installing jumpers JP5 and JP6, the voltage at the cathodes of the phase A and phase B load-to-line SCRs is connected to the primary of T2. In this condition the turns ratio of transformer T2 is determined by the magnitude of the input source.

Fault Detection and Shut Down Sequence

Under normal operation, the delay angle is controlled directly by the delay angle control voltage supplied by the user at J3-10, or by the error amplifier when configured as a DC power supply. It can also be turned off fast by removing the contact closure between J3-4 and J3-6 (this will illuminate the INHIBIT LED) or ramped down slowly by shorting J3-12 to J3-11 (this will illuminate the DISABLE LED).

If one or all of the input phases are lost or the input frequency changes too fast for the circuit to remain locked, an out of lock condition is detected. In such a case, the PHASE LOSS LED is illuminated and a fast turn off is initiated which inhibits all gate signals within 20 μ S. When lock is restored, the unit will ramp up to the programmed delay angle.

If the temperature sensing circuit is used, the OVERTEMP LED will be illuminated and the gate

signals are inhibited 20µS after the over temperature threshold is exceeded. The gate signals will ramp up to the programmed value after the heatsink

temperature drops 8°F (4.4°C). This value of thermal hysteresis can be modified to suit the customer's requirements.

Connectors

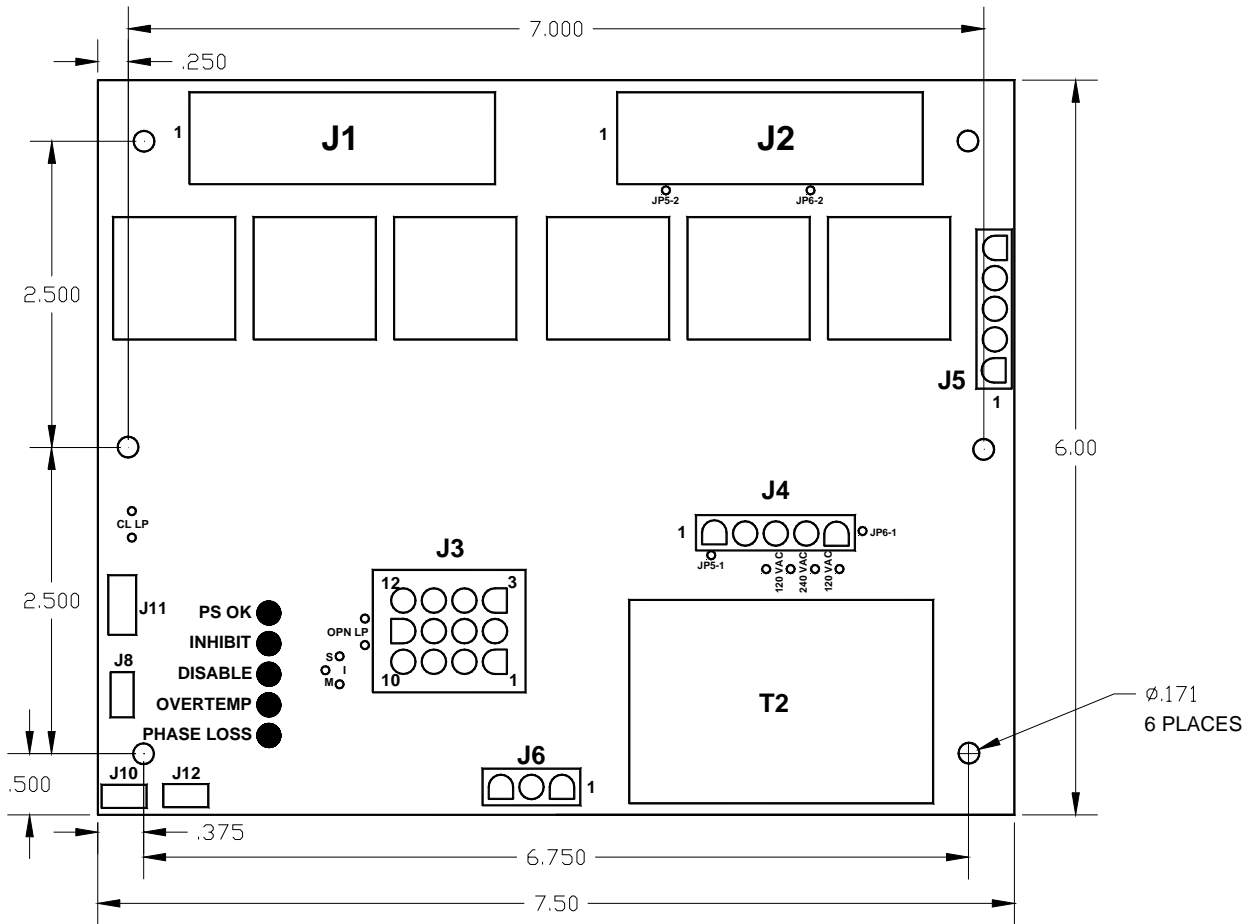


Figure 1: Mechanical Drawing of BAP1950

Gate Drive Connectors J1 and J2

Two Mate-N-Lok™ type connectors allow for a convenient interface with the SCR gates. The mates for these connectors are supplied with the board along with keying plugs to eliminate the possibility of inadvertently swapping J1 and J2. Only one mating connector is included if the board is to be used in a semi converter application.

Each connector has three pairs of wires to drive three SCRs. J1 is configured to drive the three upper

SCRs in a converter topology or the three SCRs with the anodes connected to the utility in an AC controller topology. J2 is configured to drive the three lower SCRs in a converter topology or the three SCRs with the cathodes connected to the utility in an AC controller topology. For this reason, the phase reference signals are obtained from the J2 connector. Therefore, if an AC controller or a semi converter is being controlled by the BAP1950 without using J2, J5 must be used to obtain the reference signals.

J1 Connector

Pin	Signal Name	Description
1	A+ Gate	Gate signal for phase A, upper SCR in converter
2	A+ Cathode	Reference for A+ Gate signal
3	Keying Plug	
4	B+ Gate	Gate signal for phase B, upper SCR in converter
5	B+ Cathode	Reference for B+ Gate signal
6	Blank	
7	C+ Gate	Gate signal for phase C, upper SCR in converter
8	C+ Cathode	Reference for C+ Gate signal

J2 Connector

Pin	Signal Name	Description
1	A- Gate	Gate signal for phase A, lower SCR in converter
2	A- Cathode	Reference for A- Gate signal; used to derive phase A reference
3	Blank	
4	B- Gate	Gate signal for phase B, lower SCR in converter
5	B- Cathode	Reference for B- Gate signal; used to derive phase B reference
6	Keying Plug	
7	C- Gate	Gate signal for phase C, lower SCR in converter
8	C- Cathode	Reference for C- Gate signal; used to derive phase C reference

Control Signal Connector J3

The control signal connector is the BAP1950 interface to the system controller. The table below describes the pin functions of J3 when the BAP1950 is being used with an external controller to vary the delay angle.

When the BAP1950 is configured as a DC power supply, J3-10 no longer controls the delay angle. One jumper on the board, OPN LP, is removed which isolates J3-10 from the circuit and another jumper M, S or I is installed connecting the regulation loop's

error amplifier to the delay angle control input. The jumper is installed if the board is operating independently. The M jumper is installed if the board is operating in the master mode, controlling another slave board. The S jumper is installed if the board is operating in the slave mode, being controlled by a master board. The rest of the pins on J3 perform the same function in DC power supply mode. An explanation of the feedback connectors and how they should be wired is included in the DC power supply option section on the following page.

J3 Connector

Pin	Signal Name	Description
1	24 VAC	From secondary winding of T2. 250mA available for customer use.
2	24 VAC	From secondary winding of T2. 250mA available for customer use.
3	24 VDC	250mA available for customer use.
4	Fast Turn off	Shorting this to pin 6 or 7 enables the board. Letting it float will disable gating signals within 20 μ S
5	Master/Slave	This pin is used when 2 or more boards are configured as Master/Slaves.
6	15 VDC	50mA available for customer use.
7	5 VDC	50mA available for customer use.
8	GND	Reference for BAP1950 control circuitry including delay angle control, therefore it must be tied to reference for delay angle control
9	Inhibit Enunciate	Normally low through a 1k resistor. Transitions high in a Fast turn off or in an out of phase lock condition.
10	Delay Angle Control	0 to 5 V analog input to control delay angle. 0V \rightarrow Max Delay Angle; 5V \rightarrow Min Delay Angle
11	GND	Reference for BAP1950 control circuitry including delay angle control, therefore it must be tied to reference for delay angle control
12	Soft Start/Stop	When it transitions from a contact closure to pin 11 to an open circuit the delay angle ramps down from maximum to programmed value. If the board is running, when it transitions from an open circuit to a contact closure to pin 11, the delay angle ramps up from the programmed value to the max value.

Power Supply Connection Options J4

The necessary power supplies to run the logic on the board and drive the SCR gates are generated through T2. There are several options for applying input power to T2:

1. Apply 120VAC across J4-1 and J4-5 install both 120 VAC jumpers between J4 and T2.
2. Apply 240VAC across J4-1 and J4-5 install center 240 VAC jumper between J4 and T2.
3. Remove J4, connect JP5-1 to JP5-2 and connect JP6-1 to JP6-2. The user must indicate the voltage applied to T2, i.e. the voltage being controlled by the SCRs, so that the correct transformer can be installed in the board.
4. 480 VAC input transformer available upon request.

J4 Connector

Pin	Signal Name	Description
1	VAC input	AC Input to transformer T2; 120 VAC or 240 VAC
2	Blank	
3	Blank	
4	Blank	
5	VAC input	AC Input to transformer T2; 120 VAC or 240 VAC

Phase Reference Options J5

The default method of deriving references is to sense the cathodes of the three SCRs on J2 that are connected to the input voltage. This is a convenient point to obtain the utility inputs, which are then attenuated and filtered so they can be phase locked to the delayed gate commands. The magnitude of the utility input must be known when the board is

ordered so that the correct components are inserted into the interface circuitry on the board.

Phase references may also be obtained by using auxiliary connector, J5. J5 is a Mate-N-Lok™ series connector that may be used if the circuit topology does not allow the input voltage to be sensed via the SCR cathodes normally available on J2. It is

important to connect J5-1 to the input phase that is controlled by J1 pins 1 & 2, J5-3 to the input phase that is controlled by J1 pins 4 & 5, and J5-5 to the input phase controlled by J1 pins 7 & 8 (see **Figure 3**).

J5 Connector

Pin	Signal Name	Description
1	Phase A Reference	Reference input for phase controlled by gate drives on J1/J2 pins 1 & 2
3	Phase B Reference	Reference input for phase controlled by gate drives on J1/J2 pins 4 & 5
5	Phase C Reference	Reference input for phase controlled by gate drives on J1/J2 pins 7 & 8

High Voltage Feedback J6

If the closed loop option is ordered, the DC output of the power supply is brought back to the board via J6. An isolation amplifier attenuates the high voltage and isolates it from the output so that the feedback can be referenced to the signal ground.

J6 Connector

Pin	Signal Name	Description
1	Output Voltage	DC output voltage up to 1000V; tied to the cathodes of upper SCRs, or after filter in a converter topology
2	Blank	
3	Output Reference	DC output reference; tied to the anodes of the lower SCRs in a converter topology

Current Limit Control J8

The value of current at which the power supply will foldback can be adjusted with the on-board pot or J8 can be used to connect an external pot (a 10K pot should be used in this application).

J8 Connector

Pin	Signal Name	Description
1	High Side	Connected to the high side of the pot
2	Pot Wiper	Connected to the wiper of an external 10K pot
3	GND	Connected to the low side of the pot

Remote Voltage Control J10

The output voltage of the power supply can be controlled remotely with an external pot (the minimum pot used in this application should be a 1K) or a 0 to 5V signal. This connector can be replaced with an on board 10K pot to control the power supply output voltage. The 5V reference at J10-1 has a limited source capability of 10 mA. Therefore, it should not be used for any circuitry other than the pot.

J10 Connector

Pin	Signal Name	Description
1	5V Reference	Precision 5V reference created on board used to control output voltage; limited to 10 mA. Connected to the high side of the pot.
2	Pot Wiper	Connected to the wiper of an external pot. This pin can also be driven by a remote voltage source referenced to pin 3, where 0V is 0V on the output and 5V is the full-scale output.
3	GND	GND; Connected to the low side of the pot

Current Feedback J11

The BAP1950 provides a connectorized interface to an open loop current transducer for current feedback to be used for an inner current loop and/or current limiting. The inner current loop enhances system performance by improving stability and allowing the user to set or vary a current limit. The 4 pin header on the board interfaces directly with the HAS and HAX open loop hall effect sensors from LEM, providing an inexpensive means for obtaining accurate current feedback.

The LEM current transducer can be placed on either side of the load. All diagrams show the current transducer on the positive load side, with the appropriate the current flow (arrow). If the current transducer is required on the negative side of the load, to eliminate floating the current transducer in high voltage supplies, for example, the current flow is reversed (arrow points away from the load).

J11 Connector

Pin	Signal Name	Description
1	15 VDC	15 VDC
2	-15 VDC	-15 VDC
3	Current Feedback	Voltage proportional to the current sensed
4	GND	GND

Temperature Sense J12

A temperature sensor can be used to interface with the board via J12. The temperature sensor can be mounted on a heatsink to prevent the SCRs from operating at a temperature beyond their ratings. A threshold can be set on the board, so that when the temperature is exceeded, the BAP1950 will inhibit

SCR gating and illuminate the OVERTEMP LED. The temperature sensor used is an LM-35A mounted near the hottest point of the heatsink. Selecting this option includes an LM-35 assembly that is to be mounted on the heatsink.

J12 Connector

Pin	Signal Name	Description
1	15 VDC	15 VDC
2	Temp	Analog voltage proportional to temperature
3	GND	GND

APPLICATIONS

The following will provide the user with an explanation of how the BAP1950 controls SCRs in several common applications, basic DC converter, regulated DC converter and AC Controller. These are the most common circuit topologies found in industry. Included is a functional description of the circuitry and instructions for connecting the BAP1950 in a system.

DC Power Supply – Full Control Converter

The basic design of an SCR three-phase bridge power supply is shown in Figure 2, below. This is called a full converter, converting 3-phase AC into DC. Connections to the BAP1950 board are shown. The SCRs are connected to the BAP1950 with connectors J1 and J1. The phase angle delay is controlled via J3. The customer control signals used to control the phase angle delay for firing the SCRs is accessed via J3. See the J3 connector connections on pages 4 and 5.

When the BAP1950 is configured as a basic AC to DC converter, see **Figure 2**, the phase angle delay is determined by the voltage (0V to 5V) on J3-10. The jumper on the board, OPN LP is shorted, and the M (Master), S (Slave) jumpers are opened. The I (Independent) jumper is shorted, since the board is operating independently. The other connections on J3 are used as needed. See J3 connector description on pages 4 and 5.

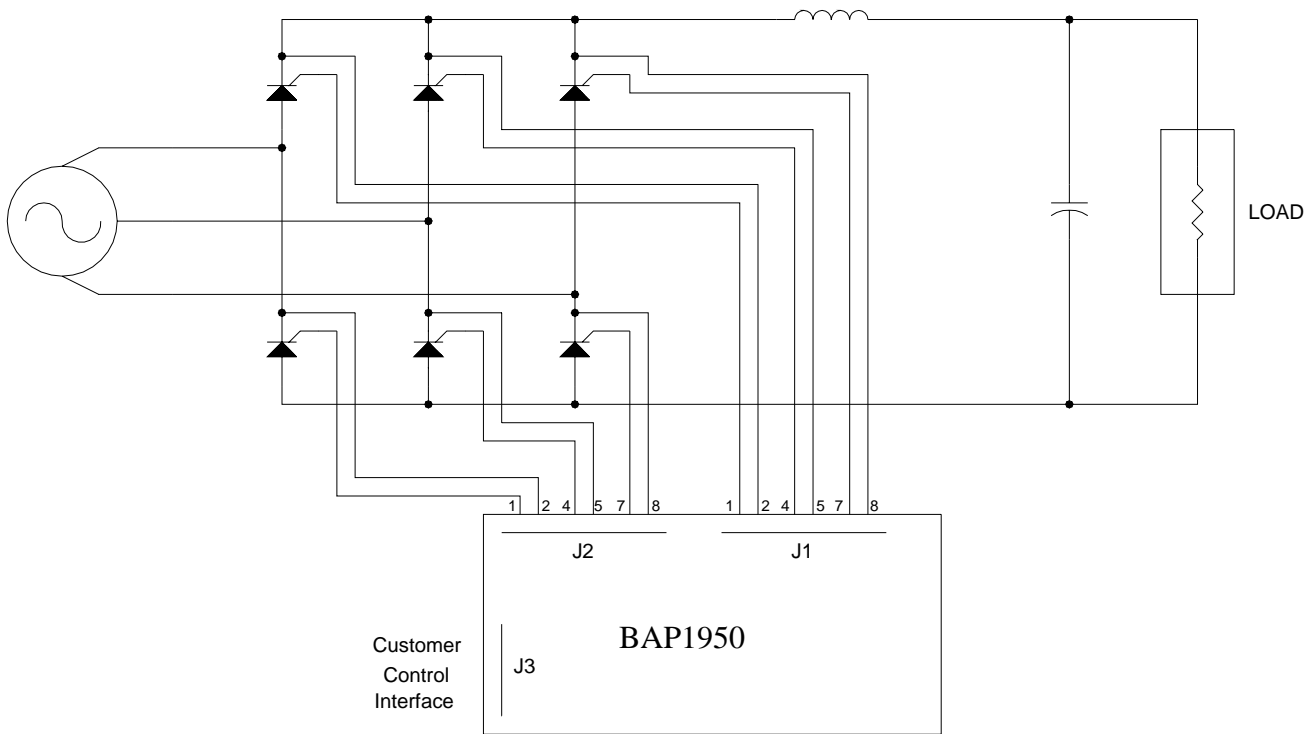


Figure 2: Full Converter connection

DC Power Supply - Half Control Converter

The default means of deriving references is to sense the cathodes of the three SCRs on J2 that are connected to the input voltage. However, in a half-control configuration as shown in **Figure 3**, rectifiers replace the SCRs and no reference is available.

Phase references may be obtained by using auxiliary connector, J5. J5 is a Mate-N-Lok™ series connector that may be used if the circuit topology does not allow the input voltage to be sensed via the SCR cathodes normally available on J2. It is important to connect J5-1 to the input phase that is controlled by J1 pins 1 & 2, J5-3 to the input phase that is controlled by J1 pins 4 & 5, and J5-5 to the input phase controlled by J1 pins 7 & 8 (see **Figure 3** below).

Regulated DC Power Supply

Designing a regulated DC power supply requires changing 2 jumpers and installing the isolation amplifier circuitry on the board. This allows the design of a DC voltage regulation loop with an adjustable current limit as well as an inner current loop for stability. Information must be provided to APS when ordering, regarding the system's output filter and required step response so that error amplifier compensation components can be selected. Computer simulations of the system's dynamic performance can be performed at APS to determine the compensation components that will optimize system response and ensure stability. With this information, one can use the BAP1950 board in the circuit configurations shown in **Figures 4 and 5**.

Figure 4 is the most common circuit used for regulated power supplies. The BAP1950 board has the optional isolation amplifier and compensating components installed. In addition, a Hall effect current transducer is employed for current feedback to the BAP1950. In order to optimize the performance of the system, the user must inform APS of the filter (capacitor and inductor) values. This will allow us to install the proper values of compensating components to insure proper operation, stability and response.

Figure 5 is another common circuit employed for regulated DC power supplies. This topology is used

when the output voltage is higher than 600V to 1kV rms. The advantage of this topology is that the mains voltage is usually below 600V rms and SCRs with blocking voltages below 2kV can be used. It is usually easier to put rectifiers in series strings than it is to put SCRs in series. In addition, the current

rating of the input mains SCRs is usually lower than they would be in the transformer secondary circuit. Depending on the specifics, the SCR and rectifier total costs may be lower with the circuit topology in **Figure 5** than the circuit topology in **Figure 4**.

Higher than Six Pulse Operation

In order to set up the BAP1950 as a DC power supply, OPN LP must be removed and an M, S, or I jumper must be installed. This will render the delay angle control at J3-10 inactive. The delay angle will now be controlled by the output of the error amplifier in the voltage regulation loop. The on board pot, external pot (connected to J10), or a remote voltage will command an output voltage which will drive the error amplifier to the required delay angle. The Soft Start/Stop and Fast turn off functions controlled by J3 remain active when the board is configured as a DC power supply.

regulate the DC voltage and limit the current. If 12 pulse, 18 pulse, or up to 36 pulse regulation is to be used, one board will be the master, requiring the installation of the M and I jumpers. Any slave boards will require the S jumper. The output of the voltage error amplifier of the master board will be exported out to J3-12 and will control the conduction angle on the master board and the conduction angle on any slave boards (the slave boards will import the error amplifier signal on J3-12). A DC power supply with a 12-pulse rectifier using two BAP1950s in a master/slave configuration is illustrated in **Figure 6**.

When the I jumper is installed, the BAP1950 will independently control a three phase SCR bridge,

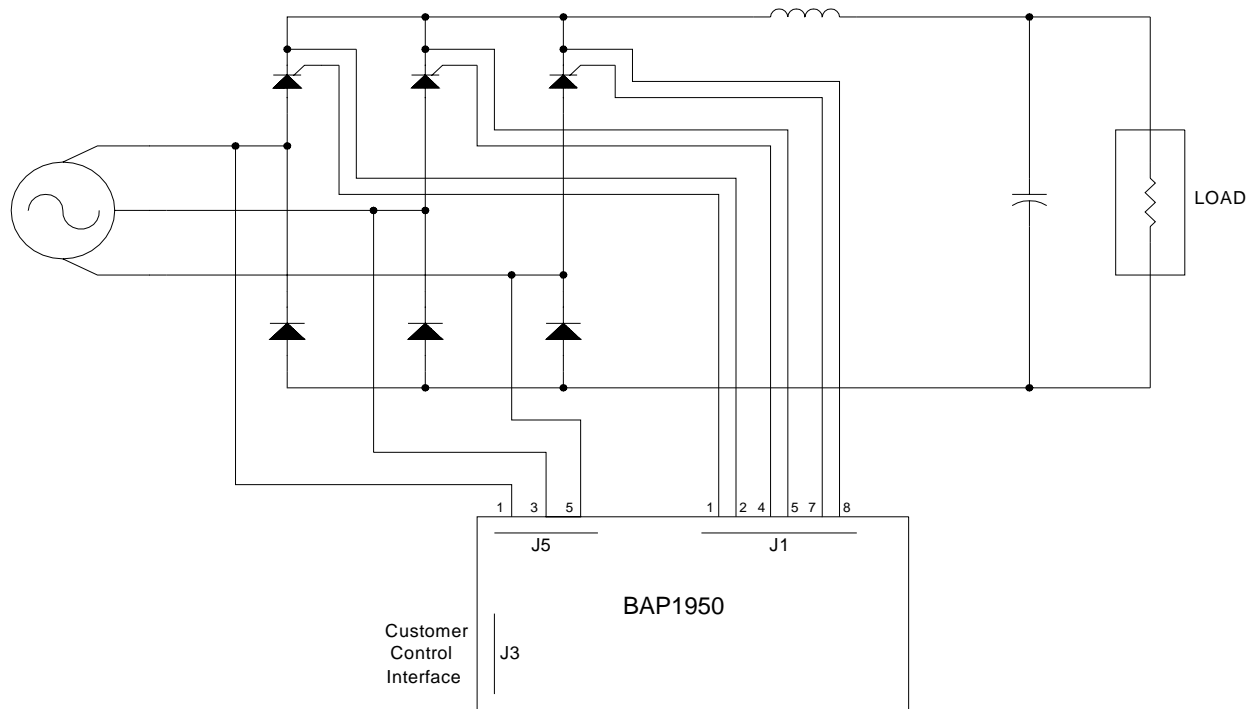


Figure 3: Sensing input voltage with auxiliary connector J5 to obtain phase reference, with half-control topology.

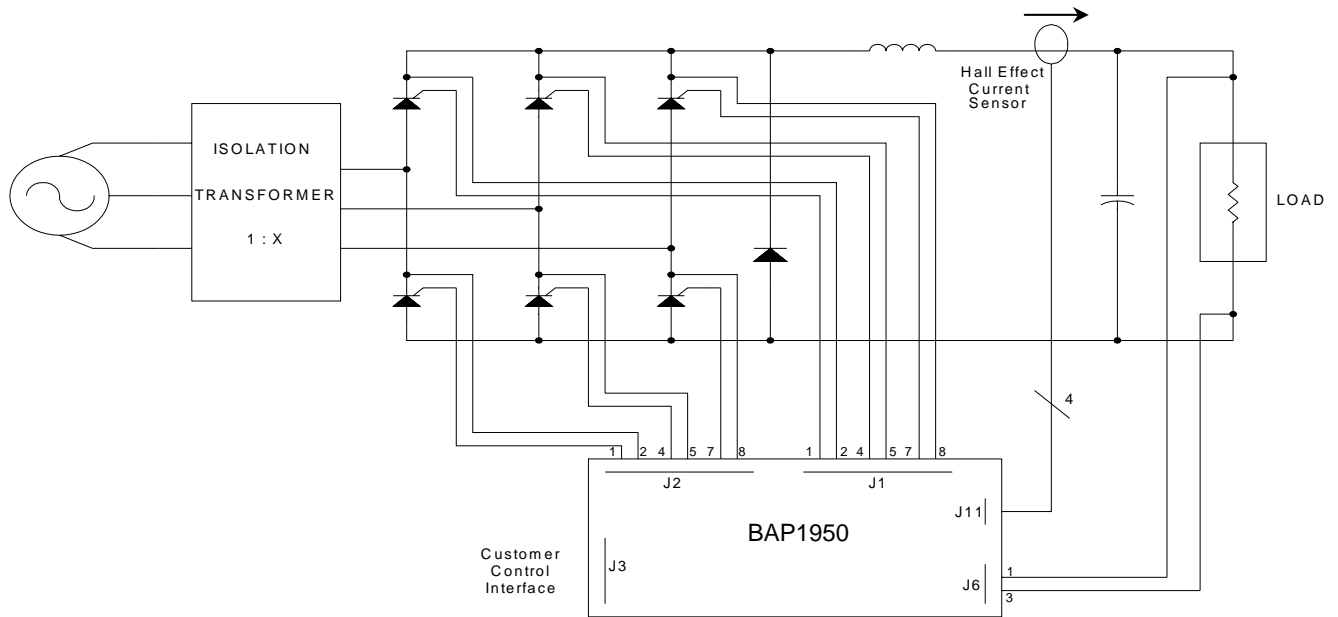


Figure 4: Basic regulated DC power supply using the closed loop option of the BAP1950 board.

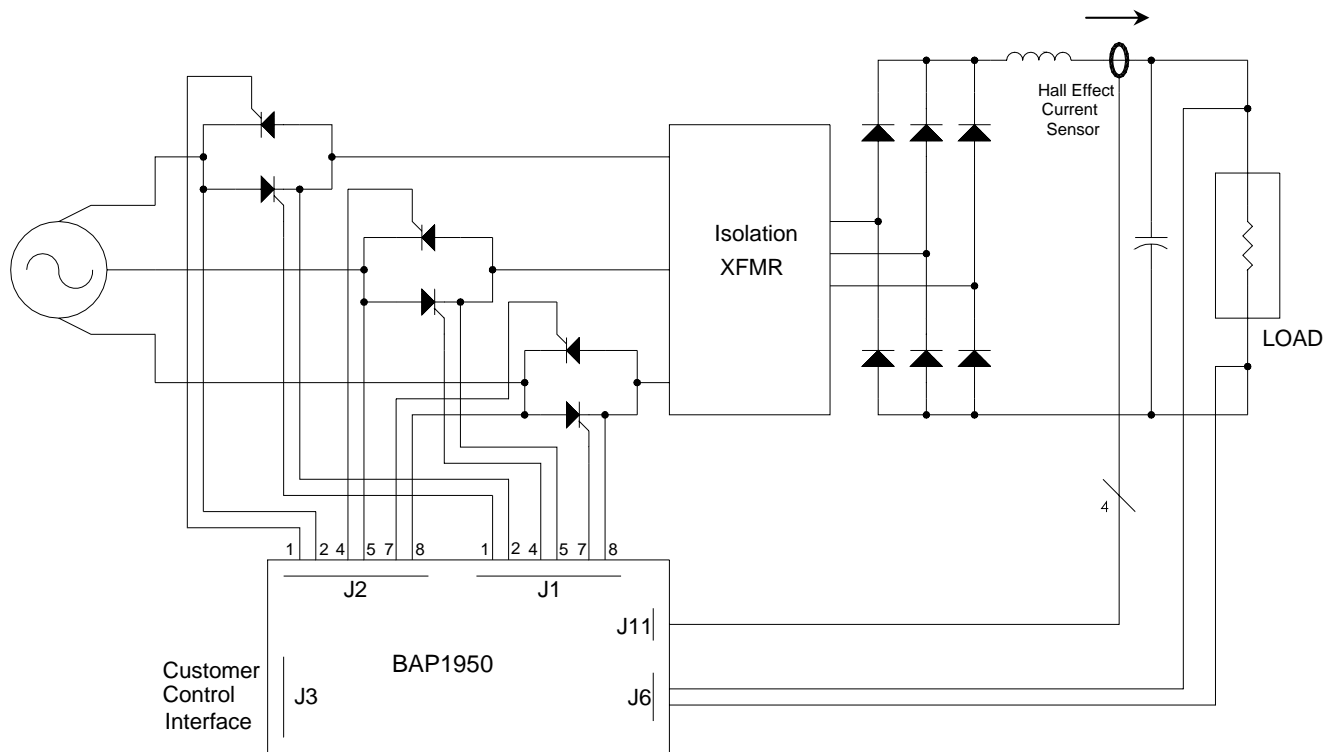
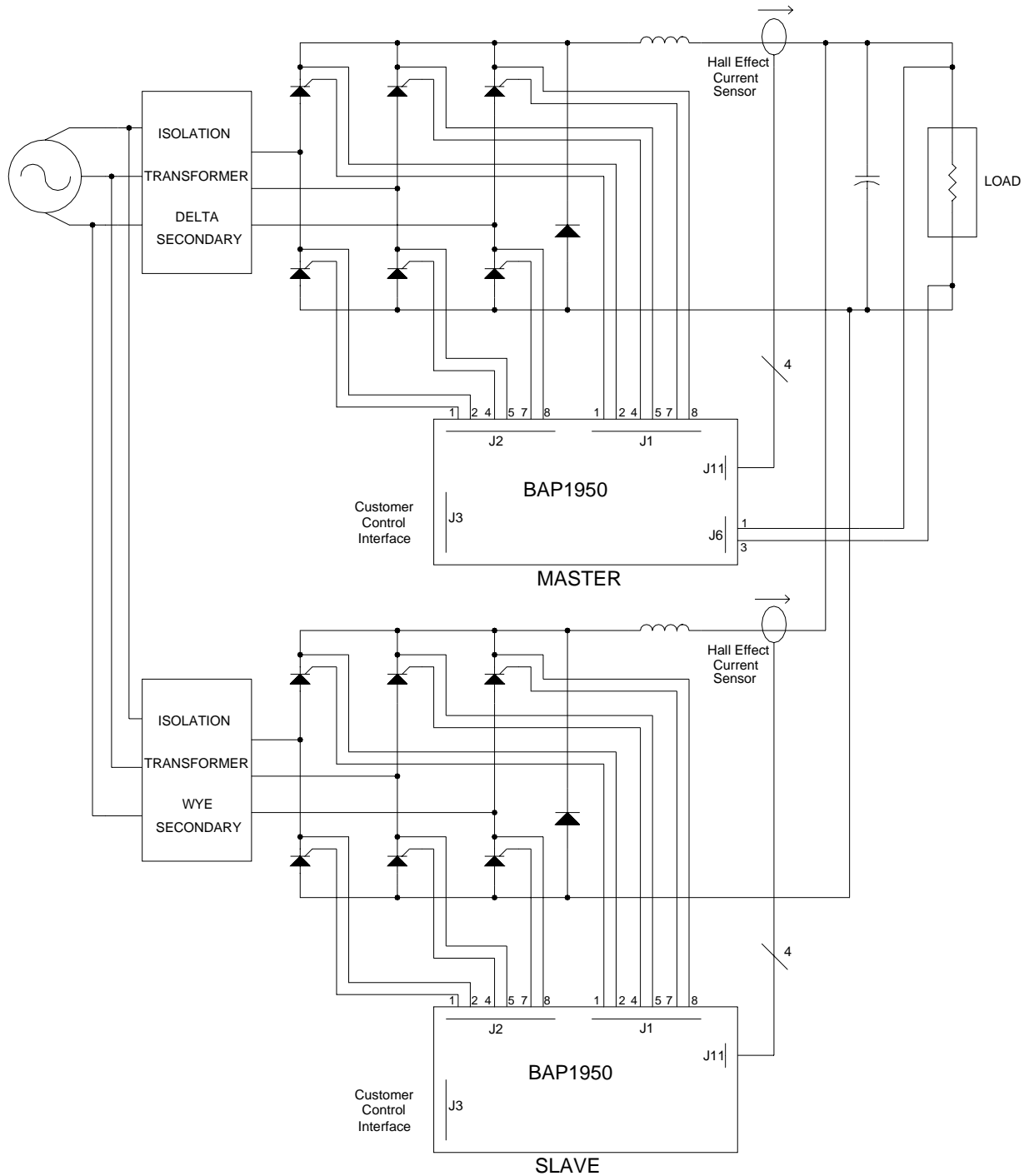


Figure 5: DC regulated power supply using AC Controller topology

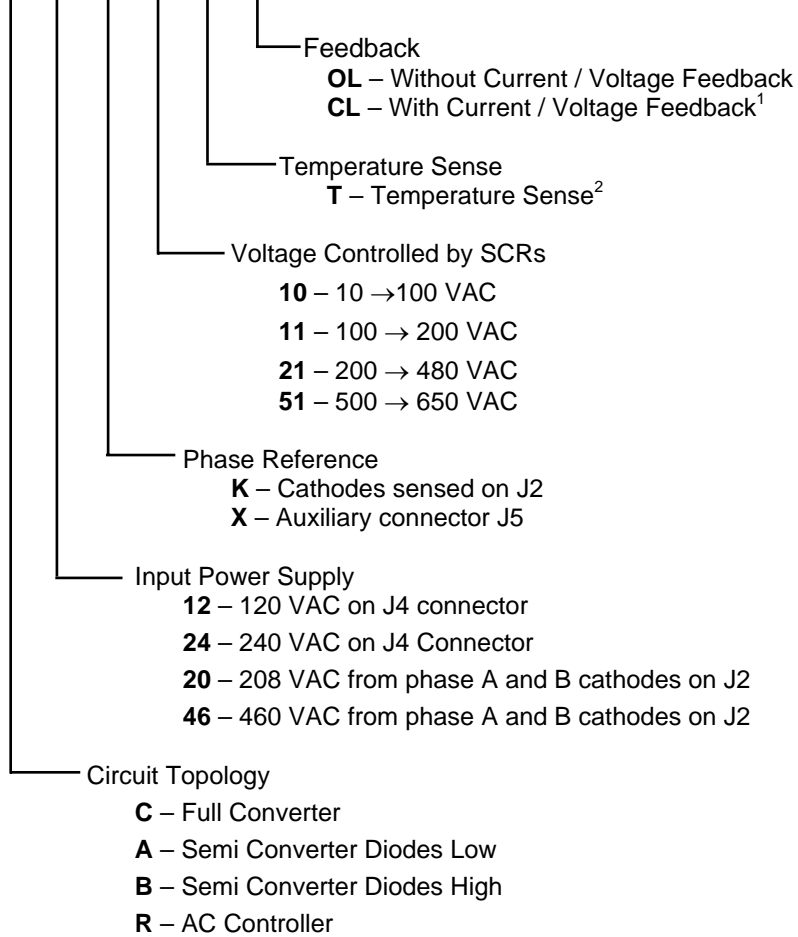
BAP1950 Three-Phase SCR Control Board





Ordering Information:

BAP1950-X-XX-X-XX-X-XX



¹ Closed loop option requires the following information:

1. Full scale output voltage (1kVdc max.)
2. Maximum output current
3. Current sensor being used (mfg. and part number)
4. How will output voltage and current limits be controlled?
 - a. If using potentiometers, are they to be on-board or off-board?
 - b. If providing voltages, what is full-scale voltage?

² Consult factory for OverTemperature threshold settings – heatsink OverTemperature set-point can be set between 40°C and 100°C.