PACIFIC POWER SOURCE
17692 Fitch Irvine, CA, 92614 USA

APPLICATION NOTE

USING A MODEL 3060-MS SERIES AS A REGENERATIVE AC SOURCE FOR PV INVERTER TEST APPLICATIONS

Abstract

This application note describes the necessary procedure to use a standard Pacific Power Source Model 3060-MS AC Power Source into a fully regenerative AC source for the purpose of testing grid-tied inverters. Either functional test or regulatory compliance testing can be accomplished without the need for additional loads recapturing most of the energy produced by the inverter. Examples are provided for common inverter compliance tests. This information is relevant to both existing 3060-MS (Figure 1) owners and new customers alike that are involved in testing grid-tied inverters for typically found in solar or wind applications.

Figure 1: 3060-MS AC Power Source

Introduction

The Pacific Power Source Model 3060-MS is a 62.5KVA AC Power Source that is widely used for production test, frequency conversion, and utility grid simulation applications by both end-users and independent test labs. While most Units Under Test (UUT) draw power from the Model 3060-MS AC Power Source, grid tied inverters are designed to generate AC power and feed it back into the utility grid. The utility grid is capable of absorbing power without too much difficulty as it has a huge power capacity compared to the unit that is back driving it.

That is generally not the case however for a programmable AC power source like the Model 3060-MS which is primarily designed to **deliver** AC power to a UUT. When testing grid-tied generators such as solar or wind inverters for compliance with national and international standards, the generator to be tested must be connected to an AC Power Source that is capable of simulating the required voltage and frequency anomalies that naturally occur on the AC mains.

During these tests, power from the inverter is being pushed back into the AC source. There are two appoaches available to address this back-driving , both of which are discussed in the next section.

Dissipative Load Bank

Customers most cost effective approach to create a suitable test setup for these applications is to use a resistive load bank that is sized to dissipate the maximum power that can be generated by the UUT. With this a setup, any power being generated by the unit under test will flow into the load and dissipate in the form of heat.

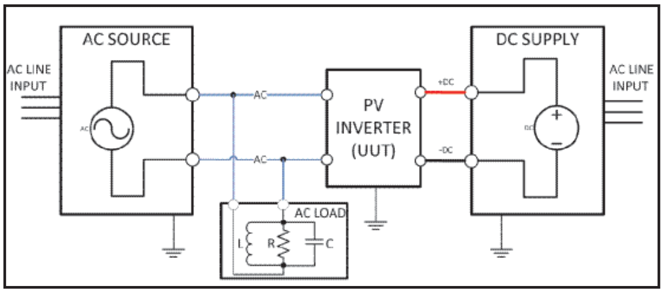
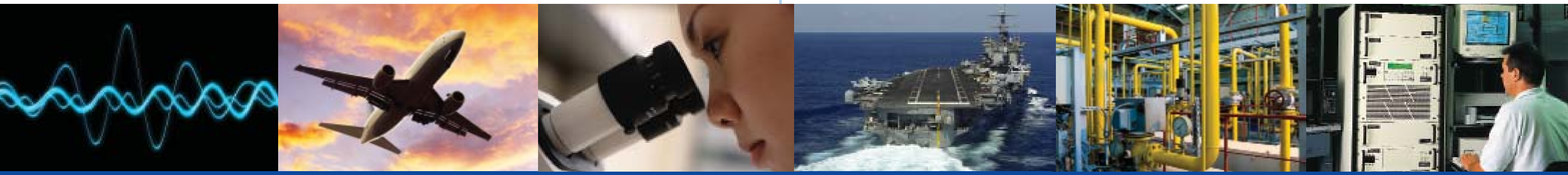


Figure 2: PV Inverter Test Setup with AC Load

Resistive load banks are generally inexpensive and available at a wide range of power levels. Most are air cooled so may require sufficient HVAC support or can be placed outside. For lower power level inverter testing, the amount of heat generated from dissipation is small enough to not require any additional provisions.



FREQUENCY CONVERSION AEROSPACE R & D MILITARY MANUFACTURING CUSTOM

Note: some grid-tied inverter compliance tests require the use of an RLC load so the dissipative load bank (R component) is often required regardless of the type of AC Power Source used in the test setup.

Regenerative AC Source

As power levels of the inverter to be tested increase, dissipating this energy may not be attractive to some users as it is not inherently eco-friendly or 'green'. From a practical point of view the cooling requirements for the 62.5kVA load shown in Figure 2 become more significant than for smaller AC Power Source PV inverter test.

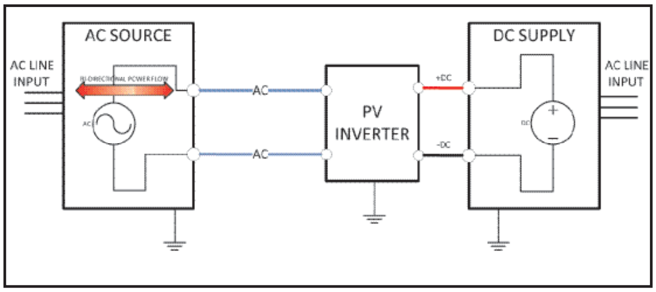


Figure 3: PV Inverter Test Setup - Regenerative

While the standard 3060-MS is not regenerative, it can be converted by the addition of a suitable regenerative DC load. This may sound counter-intuitive as the objective is to shunt away AC power but it will be clear from the next section how this can be accomplished by using a bidirectional rectifier.

Effect of Reverse Current Flow on a Typical Switching AC Power Source

While linear AC Power Sources like the Pacific Power Source's AMX Series are capable of absorbing and dissipating some amount of power from the load, most switching AC Power Sources do not have this capability. When AC power is driven back into a switching AC Power Source by a UUT, the fly-back protection diodes across each FET or IGBT in the AC amplifier output stage will rectify this AC current into its internal DC bus. Refer to Figure 4, diodes D1 through D4 for reference. This has the effect of "pumping" up the DC bus voltage. If this process is allowed to continue, the DC voltage on the bus will continue to rise until it exceeds its design specification and gets severely damaged or – the better product design approach – an over-voltage protection mechanism kicks in to shut down the AC Power Source to preventing damage.

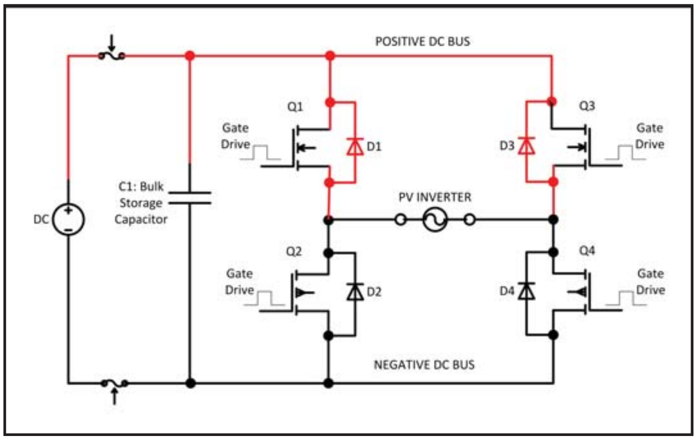


Figure 4: Basic H bridge Inverter Diagram

Either way, the grid simluating AC Power Source will cease to provide the required AC voltage and frequency to the inverter under test, thus interrupting the UUT qualification test.

To prevent this condition from affecting the AC Power Source, the energy flowing into the DC bus must either be shunted somewhere or dissipated. A dissipative approach would be no different than adding an external AC load to the test setup as described earlier. Shunting the power to the AC grid that provides power to the AC Power Source is the premise behind a regenerative AC source.

This can be accomplished by a using a bidirectional rectifier input stage with the appropriate control logic that is capable of reversing the phase angle between AC input voltage and current. By reversing the AC current flow on the AC input of the AC source, the excess energy being pushed into the DC bus can be shunted to AC grid, similar to the operation of a PV or wind inverter.

Regenerative DC Load Alternative

In the absence of such a complex active input rectifier stage, a simpler alternative is to use a DC to AC inverter that is grid tied. A good example of such a grid-tied regenerative DC load is the Regatron model TC.GSS 32KW. This 32KW DC load is capable of supporting input voltages to 500Vdc and sinking up to 50Adc to the AC grid.

Figure 5: Regratron AG TC.GSS Regenerative DC Source/Loads

When connected to the internal DC bus of a 3060-MS, the TC.GSS will redirect power fed into the MS's 400Vdc bus to the mains connection, effectively converting the 3060-MS to a regenerative AC source. For testing inverters greater than 32KW, two TC.GSS units working in parallel are needed to support the full 50KW capability of the 3060-MS AC Power Source.

The following paragraphs describe the required setup of 3060-MS and TC.GSS and some typical test results using this configuration. Examples shown are based on model TC.GSS.32.500.400.S for 400VLL AC Grid simulation as it applies to Europe and Asia. For US high power inverter applications tested on 480VLL utility grid voltage, a 480Vac version of the TC.GSS will be required.

Interconnecting the AC Source and DC Regenerative Load

To allow the DC load to control the DC bus voltage level under reverse current conditions, the DC load input terminals need to be connected to the internal of the 3060-MS. The 3060-MS uses a single ±200V dc bus rail to drive the output amplifier bridge so only one set of DC cables is needed between the TC.GSS and the 3060-MS. This DC cable set can be routed from inside the 3060-MS through one of the two available cable conduits that exists at the top of the MS cabinet. The TC. GSS should be placed next to the MS to keep cable runs as short as possible.

Suitable wire gauge should be used to support maximum DC current at either 32KW or 50KW. For a single TC. GSS 32KW setup as used in this example, the maximum DC current would be no more than 80Adc so #4 AWG American or 5.19 mm diameter /21.5 circular mils International stranded copper wire was used. Consult with a local electrician for correct wire type and gauge to ensure compliance with local electrical codes.

Access to the 3060-MS internal DC bus is available only after removing the front panels and should be undertaken only after all AC input power is disconnected from the MS cabinet. Once de-energized, the front panels are removed to reveal the internal DC bus bars.

DC power cables may be routed through one of the available cable guides on either left or right hand side of the MS cabinet, or if on a raised floor, out the bottom of the unit. It is generally advisable to route the DC cables in from the cabinet before connecting them to the DC bus bars.

There are two attachment nuts that hold the DC Bus fuses in place, one for the positive and one for the negative DC bus. The positive DC terminal is on the left hand side when facing the front of the MS. The negative DC terminal is on the right hand side. Terminate the DC cables with ring lugs and remove each not to attach each DC cable. Refer to Figure 6.

Figure 6: 3060-MS Bus Bar Connections

If inverters with power levels higher than 32KW need to be tested, a second TC.GSS will be required connected in parallel with the first one. The DC load must be configured for parallel operation to support 50KW operation of the 3060-MX in regenerative mode.

The completed setup is shown in Figure 7. This application was not a permanent installation so units were not installed in an instrument cabinet as would typically be the case.

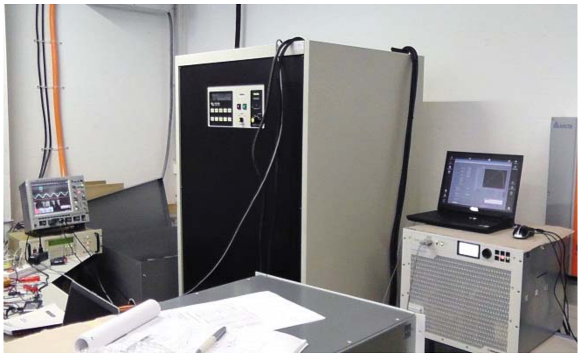


Figure 7: 3060-MS and DC Loads Combined

Figure 8: DC Cable Routing from MS Cabinet

DC Load Settings

Under normal operating conditions, the 3060-MS DC bus is around ± 208Vdc for a total DC bus voltage of 416Vdc. As previously explained, when reversed current is flowing, the DC bus voltage will start to rise. To allow this energy to be delivered back to the utility grid, the TC.GSS is programmed to engage when it detects a DC input voltage of 420Vdc. This setting helps ensure a smooth transition between source and sink mode on the 3060-MS.

The 3060-MS has a diagnostic display panel (D3 Menu) that monitors the internal DC bus voltage. From this screen, the actual transitions between source and sink mode can easily be viewed. Some DC voltage imbalance between positive and negative DC bus may be observed which is normal. (Figure 9)

Figure 9: Internal DC Bus Monitor Display in Source Mode Operation

The TC.GSS also displays actual regenerative mode on its display as negative DC current and DC power readings. Refer to Figure 10.

Figure 10: Regenerative Mode Engaged at set DC Voltage

Complete Inverter Test Setup

Once the regenerative DC Load has been properly installed and configured, the rest of the setup is no different than any other grid tied inverter test setup.

The output of the 3060-MS is applied to the UUT while Pacific's SCU/UPC-32 Programmable Controller is used to command voltage and frequency transients on the output of the AC Power Source.

Steady State Operation

Several tests were run to verify regenerative operation using PV inverters designed for 400Vac L-L utility connection. Under steady state conditions, the 3060-MS Controller will also display negative AC power and Power Factors using its AC measurement functions. As the power factor of most PV inverters is close to 1.00, the VA power and true power are generally close to the same. The 3060-MS diagnostic display (Figure 9) shows that the DC bus is operating at +208/-216 or 424Vdc during regenerative mode which is only slightly higher than the 416Vdc observed during normal source mode of operation. Most of the power flowing into the 3060-MS output is being delivered back onto the grid.

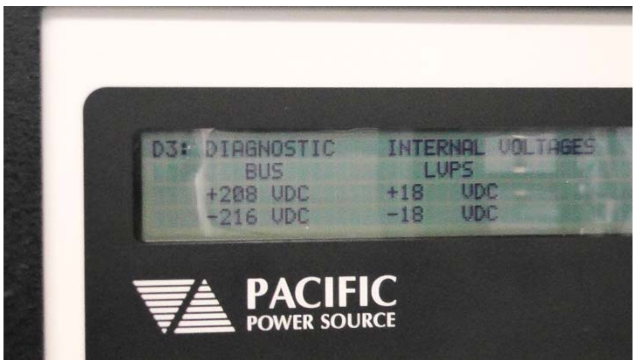


Figure 11: Internal DC Bus Monitor Display in Sink Mode Operation

With steady state operation verified to be normal, a series of dynamic grid anomaly tests (voltage dips) were ran to validate transient response of the MS + TC.GSS combination.

Dynamic Inverter Tests

Grid tied inverters are subject to several International and National safety standards. National standards can vary from country to country and the reader is advised to familiarize himself with local standards. The tests performed for this application note were based on IEC standard IEC 61000-3-15 which was published in September 2011. ("Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network") It attempts to consolidate several national standards for low voltage ride through and other common LV network disturbances.

Short Duration Voltage Dips

IEC 61000-3-15 applies short duration voltage dips to the inverter under tests as shown in the table below. These dips can easily be programmed on the 3060-MS when equipped with the SCU-UPC32 controller. The provided UPC Studio Windows software contains a test sequence capability that can be used to program these voltage dips.

Test Step	Dip to % Unom	Time in cycles (Tc)	Start Phase	Repeat	Delay Between Dips	Delay to Next Step(s)
1	70	1.0	0.0°	3	10	5
2	70	2.0	0.0°	3	10	5
3	70	5.0	0.0°	3	10	5
4	40	1.0	0.0°	3	10	5
5	40	2.0	0.0°	3	10	5
6	40	5.0	0.0°	3	10	5
7	0	1.0	0.0°	3	10	5
8	0	2.0	0.0°	3	10	5
9	0	5.0	0.0°	3	10	5

Table 1: IEC 61000-3-15 Short Duration Voltage Dips

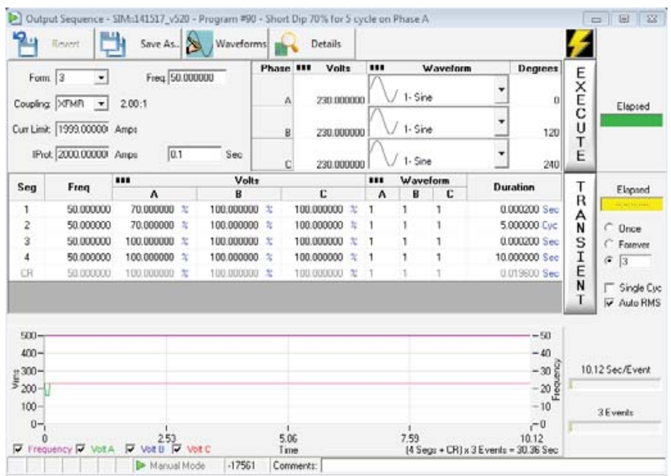


Figure 12: UPC Studio Sequencer Screen for 70% Voltage Dips

Figure 12 shows one of the programmed DIP test sequences applied to the inverter. The operation of the TC.GSS DC load during these AC voltage dip tests can be observed on its internal scope function which monitors DC voltage and current over time. Figure 12 shows the steady DC voltage level of the DC load input. Notice the sudden change in DC current during AC voltage dips as the amount of power flowing into the AC source changes with the AC voltage.

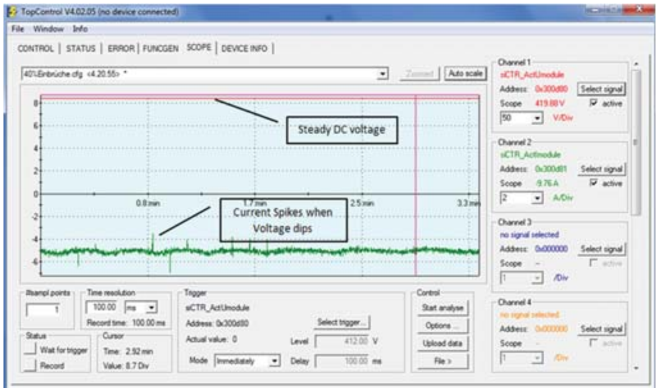


Figure 13: TC.GSS DC Load Scope View of DC Voltage and Current

When applying a 0% voltage dip for a 2 cycle duration (40 msec), the inverter shut down and attempted to re-synchronize to the AC line once it returns to nominal values. During this time, the 3060-MS bus returned to its normal source mode level and the TC.GSS disengaged. After application of the sequence of three dips, the inverter under test re-connected with the AC source and regenerative mode was restored. This represents a passing condition as the generator dis-engaged as expected as a result of the grid anomaly. The same can be observed on the DC Load scope function display as the 3060-MS exits and enters regenerative mode.

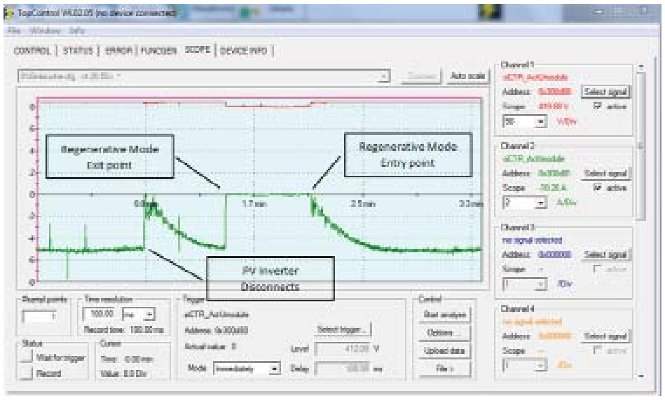


Figure 14: Exit and Entry to and from Regenerative Mode during 0% Vdips

Long Duration Voltage Dips

Long duration voltage dips are used to simulate brown out conditions as they can occur on public utility networks. They are generally longer in duration (200 msec) but less severe. During this test, the nominal voltage is decreased 2% at a time till it reaches 80% of nominal.

Test Step	Dip to % Unom	Time in cycles (Tc)	Start Phase	Repeat	Delay Between Dip(s)	Delay to Next Step(s)
1	100	10.0	0.0°	2	5	5
2	98	10.0	0.0°	2	5	5
3	96	10.0	0.0°	2	5	5
4	94	10.0	0.0°	2	5	5
5	92	10.0	0.0°	2	5	5
6	90	10.0	0.0°	2	5	5
7	88	10.0	0.0°	2	5	5
8	86	10.0	0.0°	2	5	5
9	84	10.0	0.0°	2	5	5
10	82	10.0	0.0°	2	5	5
11	80	10.0	0.0°	2	5	5

Table 2: IEC 61000-3-15 Long Duration Voltage Dips

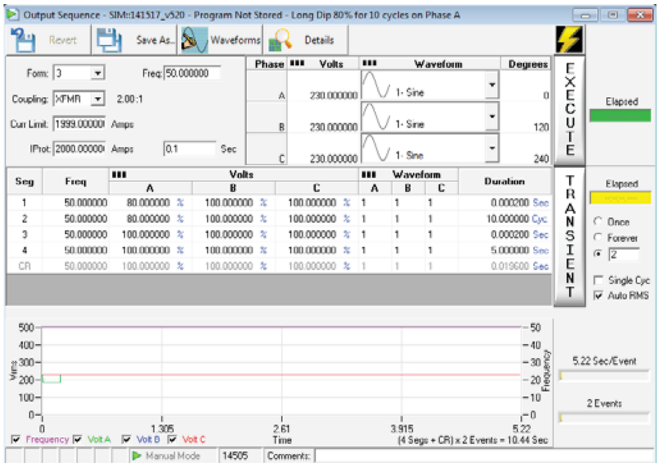


Figure 15: Long Duration Voltage Dips Sequence Setup

During the application of these longer duration but lower dip level voltages, the inverter under test continue to operate. Internal DC bus voltage of the 3060-MS remained stable at the regenerative mode level of 424Vdc.

Frequency Variations

Frequency transients are aimed at verifying that the inverter only operates over its allowable AC frequency range. This range is generally narrow and not symmetrical around the nominal frequency. When frequency excursions outside this range occur, grid tied inverters must disconnect form the utility grid within 0.2 to 0.5 seconds, depending on national standards.

The test applied to the inverter for this application note consisted of a series of 0.10 Hz frequency increment steps to test for upper frequency limit compliance of a 50 Hz nominal inverter. Test sequence is shown in Table 3.

Test Step	Frequency (Hz)	Time (sec)	Delay to Next Step (sec)
1	50.30	0.200	0.0
2	50.40	0.200	0.0
3	50.50	0.200	0.0
4	50.60	0.200	0.0
5	50.70	0.200	0.0
6	50.80	0.200	0.0
7	50.90	0.200	0.0
8	51.00	0.200	0.0
9	51.10	0.200	0.0
10	51.20	0.200	0.0

Table 3: Frequency Variations Applied

In this case, the inverter failed the frequency disconnect test as it continued to operate beyond the national limit standard for the relevant country (51Hz). Internal DC bus voltage of the 3060-MS remained stable at the regenerative mode level of 424Vdc.

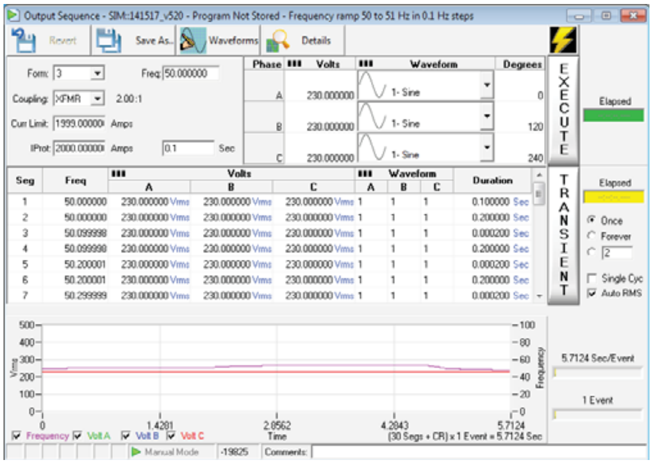


Figure 16: Frequency Variations Sequence Setup

Conclusion

The addition of a regenerative DC load to maintain a normal internal DC bus voltage on the 3060-MS AC Power Source effectively creates a fully regenerative programmable AC source. This approach is particularly cost effective for existing 3060-MS Series users that are faced with new test requirements involving solar or wind inverters at power levels up to 50KW or higher. (For higher power level test requirements, 3060-MS Series cabinets can be paralleled to more than 500KW).

Adding regenerative capability as described in this application note protects their investment and allows them to use an already familiar and proven piece of test equipment. For new users or those with expanding power needs, system upgrades are available.

Simple inverter test sequences can be developed quickly using the free UPC Studio software as illustrated in the examples for this application note. More elaborate sequences including other test and measurement equipment to monitor DC input and AC power quality can be created using the optional UPC Test Manager software which provides a powerful Test Executive with built in report generator.

For further information on configuring regenerative 3060-MS Based AC test systems, contact Pacific Power Source, Inc.

Acknowledgements

Author would like to recognize the engineering and application support team at Regatron AG corporate headquarters for their support and cooperation in providing the required TC.GSS regenerative DC Source/ Loads and performing these tests. Also would like to acknowledge the support provided by our distributor for Germany, Austria and Switzerland, Schulz Electronic GmbH.

Regatron Contact Information:

Regatron AG
Kirchstrasse 11
9400 Rorschach
Switzerland
Tel. +41 71 846 67 44
Fax +41 71 846 67 77
tc.support@regatron.ch

PACIFIC® POWER SOURCE
17692 Fitch, Irvine, CA 92614 USA
Phone: +1 949.251.1800
Fax: +1 949.756.0756
Toll Free: 800.854.2433
E-mail: sales@pacificpower.com
www.pacificpower.com