PACIFIC POWER SOURCE
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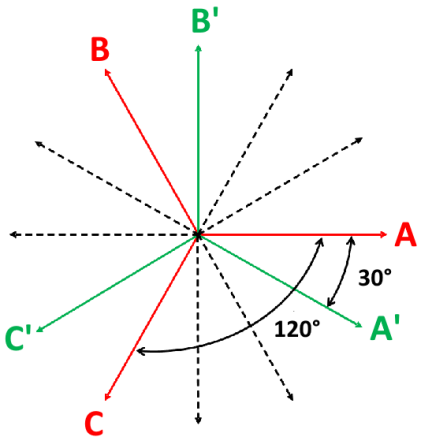
Six Phase AC Power Applications

AFX
AGX
AZX
GSZ
RGS



1 Six Phase Power Applications

While three phase power distribution is used for utility power transmission and most high power loads require three phase AC power inputs, there are many applications that benefit from using six phase AC power.

Six-phase AC power is used in specialized applications because of its benefits over traditional three-phase systems. Here are some key applications where six-phase AC power is utilized:

1.1 High-Power Rectifiers and Converters:

Six-phase power systems are often used in high-power rectifiers and converters to improve performance and efficiency. Six-phase systems **reduce the voltage ripple** on a DC rectifier system compared to three-phase systems. This is important for applications requiring stable DC power such as avionics DC power systems. The IEEE and other electrical engineering publications often discuss the advantages of six-phase rectification in power electronics. This is probably the most used application of six phase AC power.

1.2 Electrolysis Processes:

Industrial electrolysis processes, such as aluminum and other metal refining, benefit from the smoother DC output provided by six-phase rectifiers. The reduced ripple helps in maintaining consistent electrolysis conditions, improving the quality and efficiency of the process. Papers on electrochemical engineering and industrial process optimization highlight the use of multi-phase systems for enhanced performance.

1.3 Railway Electrification:

Six-phase systems can be used in railway electrification to supply power to trains. The use of six-phase power can help reduce the size and weight of transformers and improve the efficiency of power transmission to the trains. This is especially relevant for low frequency (16.7 Hz) AC power used in railway traction.

1.4 Power Transmission and Distribution:

In some advanced power transmission and distribution systems, six-phase power is used to reduce the phase angle difference, thereby minimizing transmission losses and improving the stability of the power grid.

Source: Research on smart grid technology and advanced power distribution systems often mentions the potential benefits of six-phase power in reducing losses and enhancing grid stability.

1.5 High-Efficiency Motor Drives:

Six-phase motor drives are used in applications requiring precise control and high efficiency, such as in aerospace and high-performance industrial machinery. Six-phase motors can offer better torque characteristics and smoother operation than three-phase motors.

Source: Industrial automation and motor control literature, including IEEE Transactions on Industry Applications, discuss the benefits of multi-phase motor drives.

1.6 High-Power Poly-phase Inverters:

In high-power inverter applications, such as in renewable energy systems, large-scale energy storage and high power airborne or maritime applications, six-phase inverters can provide better performance by reducing harmonic distortion and improving power quality.

For airborne applications, the need to reduce weight is driving the DC output voltages of these power inverters up to ever higher DC voltage levels – in excess of 400Vdc - in an effort to reduce the DC current on aircraft busses to lower weight, keep physical hardware at a minimum (less copper / smaller conductors and smaller interconnects).

These applications leverage the benefits of six-phase systems, such as reduced harmonic distortion, improved efficiency, and better performance in high-power applications.

When polyphase AC is rectified, the phase-shifted pulses overlap with each other to produce a DC output that is much “smoother” (has less AC content) than that produced by the rectification of single-phase AC.

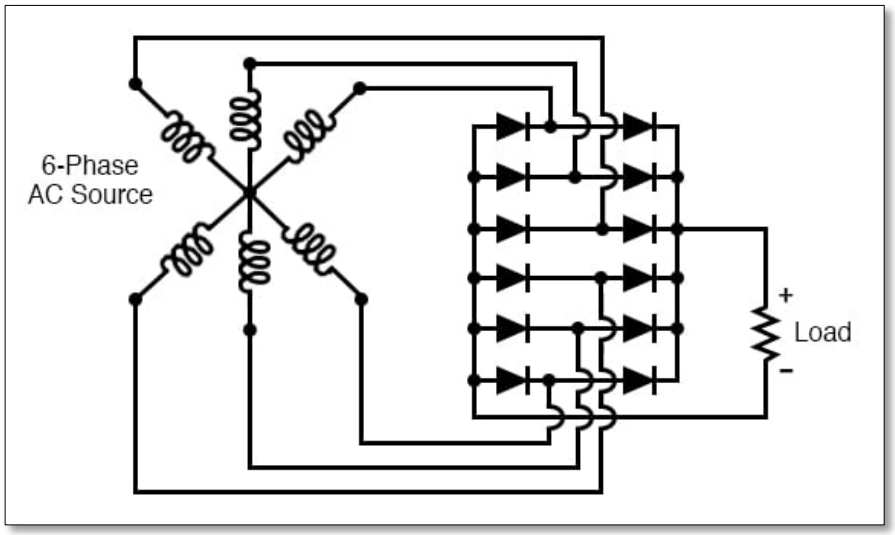


Figure 1: Six Phase AC/DC Rectifier

The diagram in the figure below shows the full-wave rectification of a three-phase AC. A six phase version will yield half as much AC ripple. This is a distinct advantage for high-power rectifier circuits, where the sheer physical size of filtering components aimed at reducing output ripple would be prohibitive when low-noise and ripple DC power must be obtained.

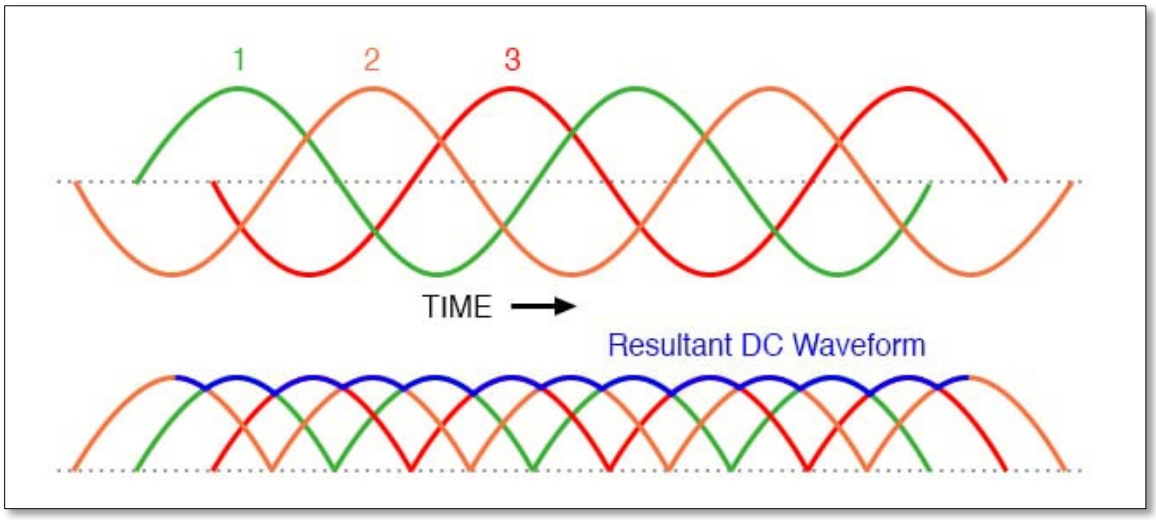


Figure 2: Rectifier Output AC Ripple

2 Creating Six Phase AC Power using Two Three Phase AC Sources

Commercially available programmable AC power sources at power levels above 4kVA are usually available with three phase AC output. This matches the worldwide utility power grids that they are designed to replicate for development and test applications. Instances of commercially available six phase programmable AC power sources are extremely rare, so a different approach is needed.

However, using the right type of product, it is relatively easy to create a six phase AC power output using two commercially available three phase AC power sources. This invariably requires that the phase angles of one of these AC power sources are freely programmable. Static inverters or AC generator sets typically have fixed phase angles between phases – i.e., they don't support phase angle programming – and can thus not be used for this purpose.

A fully programmable AC power source or grid simulator like the Pacific Power AFX, AGX, AZX, GSZ or RGS series can be used for this as all phase angles are fully programmable.

3 Six Phase Input, 12 Pulse Bridge DC Rectifier Example

A six phase AC input DC rectifier that uses six AC inputs to create a low ripple DC output using multiple full bridge rectifiers is illustrated in the image below. To distribute the 12 DC voltage peaks evenly, all six phases have to be 30 degrees apart (360 / 12) = 30°.

To create a six phase AC power source output, we will use two three phase 3150AFX programmable power sources. One will function as the master unit, the other will be synchronized to the master unit using its external sync input I/O line. On the master AFX unit, phase A will be at zero phase angle and function as the reference for all other phases. The auxiliary unit's phase A will be programmed to 30° and phase B and C

shifted by 120° and 240° with respect to Aux unit's Phase A and thus 30° from the master unit's phase B and C phases respectively.

This setup is shown in the figure below.

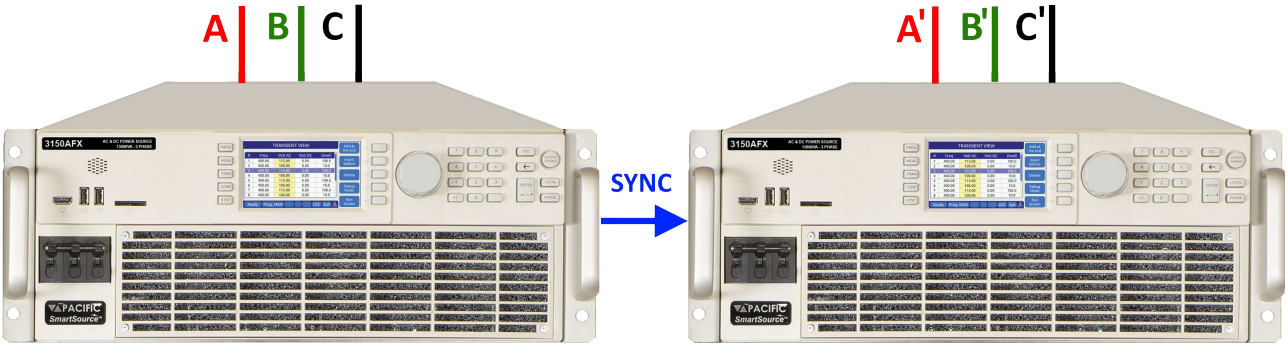
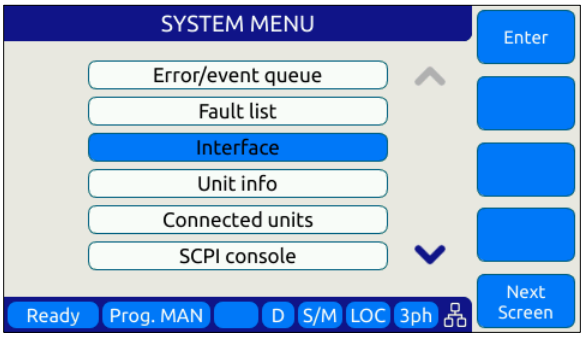


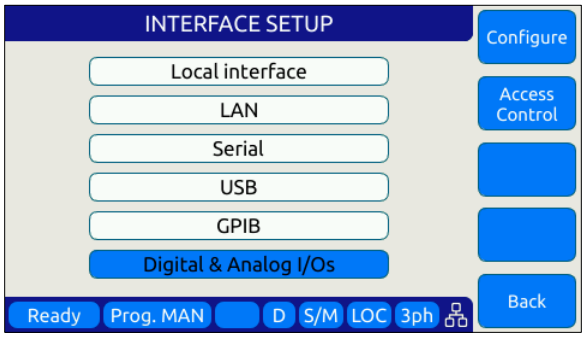
Figure 3: Two 15kVA AC Sources Synced for 6 Phase Output

4 SYNC OUTPUT & SYNC INPUT Settings

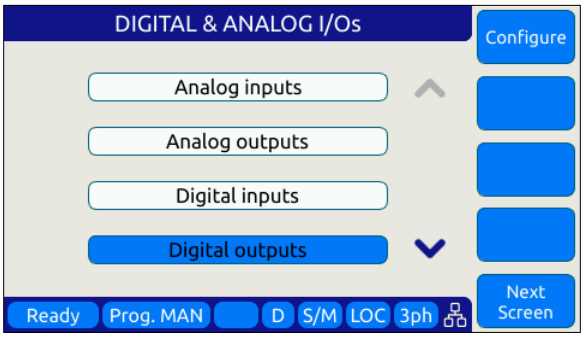
To set up both power sources for this application, either the front panel or the SmartSource Suite web interface can be used. For ATE systems, relevant remote control SCPI commands can be used in the test program.

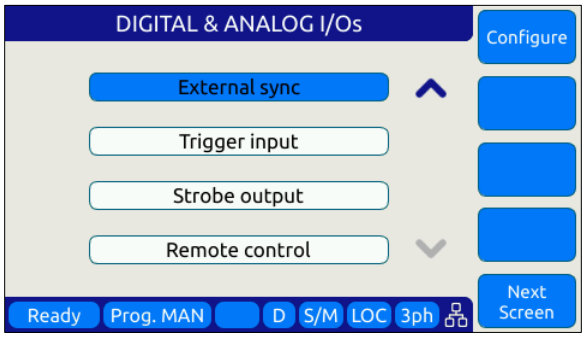
SYNC mode settings are located in the SYSTEM MENU under Digital & Analog I/O's.





On the Master unit, we need to set the SYNC output so scroll down and select "External Sync" on the second screen.



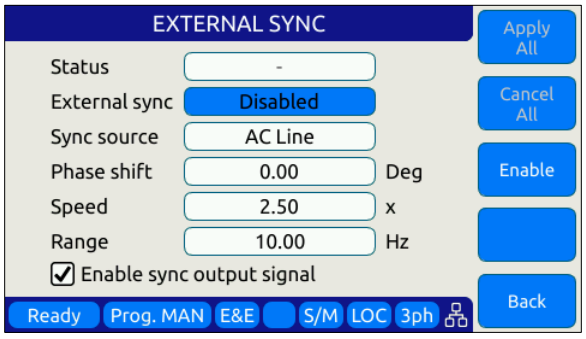


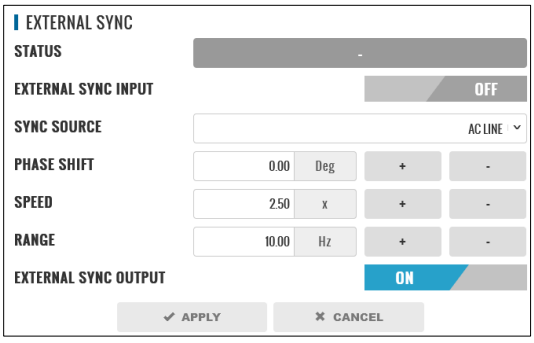
Make the following setting changes on both units to have them operating in synchronized, six phase mode:

1. On the master unit, both SYNC IN and SYNC OUT settings must be enabled.
2. To minimize and phase jitter between the two units, the Speed setting on the auxiliary unit should be set to a value of "1". This provides the lowest phase jitter but also the slowest sync relock speed. With this setting, any frequency changes on the master must be made slowly, i.e. not fast frequency transients should be used on the master unit. Also, any frequency set changes required must be made on both units at the same time. This implies being under program control.
3. To enable high resolution for the sync mode, use the following command:

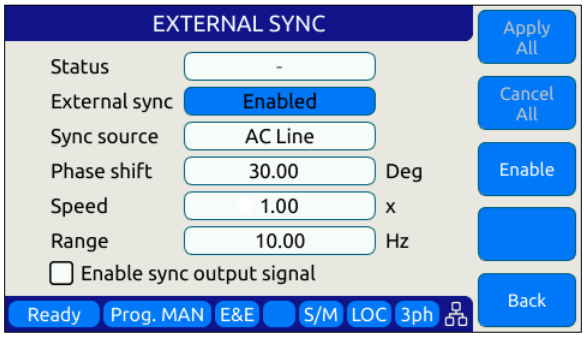
   SOURce:SYNChronize:OUTput:HIGHRESolution 1

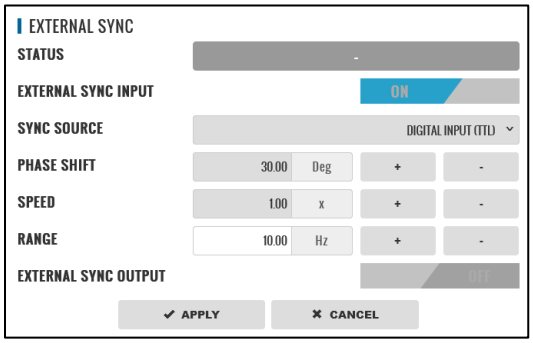
4. On the master unit or cabinet system, the EXTERNAL SYNC **OUTPUT** setting must be enabled at the bottom of the EXTERNAL SYNC menu screen "**Enable sync output signal**" or the SmartSource Suite web interface as shown on the right (make sure the click on the APPLY button to confirm settings). The other settings in this menu apply to SYNC input and are not relevant when External sync input mode is Disabled.



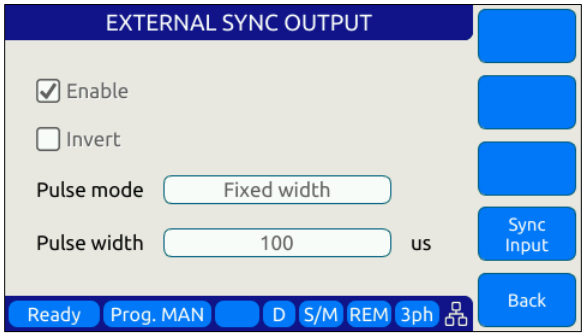


5. On the auxiliary unit or cabinet system, the EXTERNAL SYNC **INPUT** setting must be enabled, either from the front panel in the EXTERNAL SYNC screen or the SmartSource Suite web interface as shown on the right (make sure the click on the APPLY button to confirm settings). Make sure both power sources are set to the exact same output frequencies.

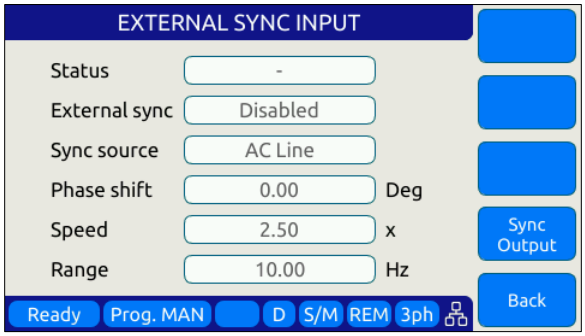




6. Note that EXTERNAL SYNC setting screens on AZX and GSZ Series models are slightly different as they have a separate EXTERNAL SYNC OUTPUT screen as shown below.



AZX or GSZ Master Unit/System – Sync Output

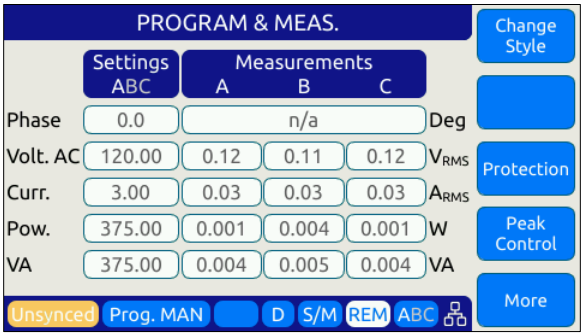


AZX or GSZ Auxiliary Unit/System – Sync Input

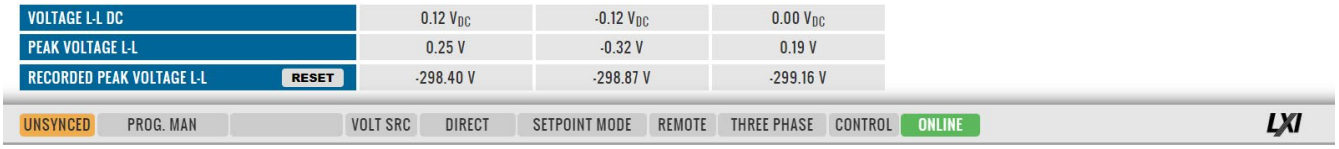
All these settings can be done using remote control using a suitable ATE program that controls both units via LAN, USB or GPIB.

5 Sync Status

During operation, the Auxiliary unit will synchronize it's output frequency and phase + programmed phase offset to the master unit. If synchronization is lost, an "**Unsynced**" error message will appear at the bottom left of the LCD screen in yellow. In the SmartSource Suite web browser interface, a similar message will appear in the Status bar.



Front Panel Warning



SmartSource Suite Browser warning

6 Frequency and Sync Cable Considerations

Note that a phase locked system setup like the one described here may have a slight phase error between the two units. This phase error is small but can become more impactful at higher fundamental frequency settings. At 50 or 60 Hz, this phase error impact will be negligible.

6.1.1 360 Hz to 800 Hz Frequency Applications

At 400Hz or even higher frequency settings, it may be necessary to adjust the auxiliary unit's phase A setpoint to compensate for a small phase error. This is done by adjusting the phase A setpoint using the available 0.01° programming resolution. For optimal results, this should be done under typical load conditions.

For these AC power frequency sync range applications, a shielded DB25 cable set with a shielded DB25 connector at each end and twisted pair wires is recommended. It is important to keep this sync cable as short as possible.

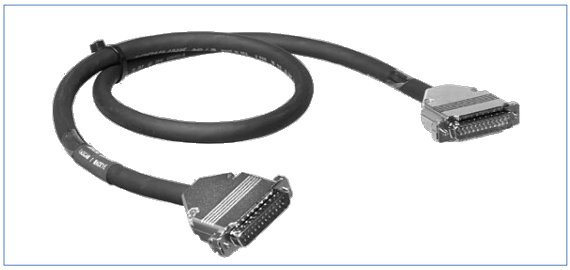


Figure 4: DB25 Sync Cable Assy

6.1.2 1000 Hz to 3000 Hz Frequency Applications

For very high frequency AC power applications requiring more than 1200 Hz, the AFX Series can be used up to 3000Hz although at reduced voltage and power output using the extended frequency range.

For these high AC frequency sync applications, a special BNC type coax shielded cabling and connectors is highly recommended. It is also important to keep this sync cable as short as possible.

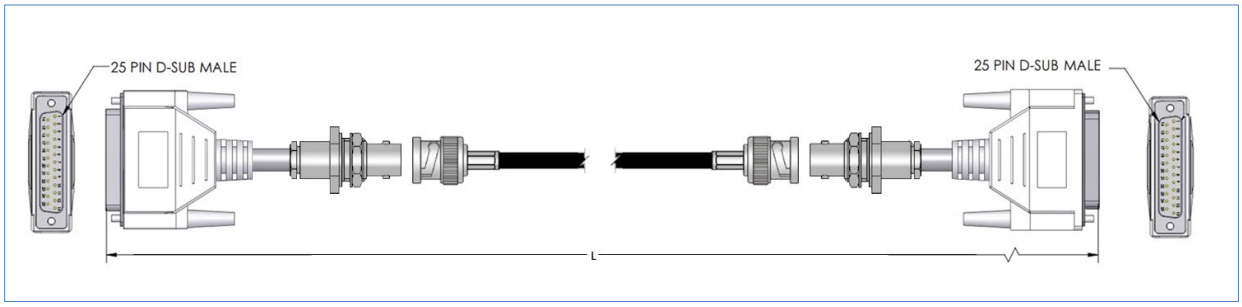


Figure 5: Custom Coaxial Sync Cable Assembly.

7 Example 180kVA Customer System

An actual example of a six phase test system in use by an Aviation Company in the US is shown below. This system consists of two 90kVA AFX Based power sources in two standard 19” racks. Each 28” tall cabinet contains one 15kVA AFX master and five 15kVA AFX Auxiliary units in parallel.

One cabinet serves as the Master three phase source and the second cabinet is synchronized to the first one to create a 180kVA, six phase AC system for testing 12 pulse high power rectifiers.

8 Summary

Six phase AC test system can easily be created using commercially available power sources as long as they are capable of being synced together. All PPS AC power sources support this capability so 6 phase six systems can be created starting as low as 1000VA and as high as 880kVA.

9 Customer Support

For application support, contact Pacific Power Source’s Customer Service - Toll Free US: +1 (800) 854-2433 or your local authorized Pacific Power Source distributor or send an email to support@pacificpower.com.

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