PACIFIC POWER SOURCE

APPLICATION NOTE

Grid Impedance Simulation Testing

Simulating Grid Impedance with Programmable Impedance Function.

1 Preface

Due to rapid growth of Distributed Energy Resources (DER) connected to the public power grid, characteristics of the power grid like impedance and dynamic response to sudden load changes are becoming increasingly important. With the growing number of active grid contributors such as PV inverters, wind turbines, natural gas-powered backup generators and Battery Energy Storage Systems (BESS), testing the dynamic properties like the grid impedance and the time response of the AC grid are changing rapidly.

The ability to dynamically change the impedance of a regenerative grid simulator to evaluate the impact of changing grid impedance on the operation of a wide variety of grid connected AC powered devices is of great importance. Traditionally, this has been accomplished using Resistive and Inductive elements connected between the grid simulator and the unit under test. However, the wide range of current requirements and impedance values needed to effectively evaluate a range of operating conditions makes this conventional approach cumbersome and costly. This is especially true for higher power applications as the power dissipation and heat generation in these resistive and inductive elements becomes significant at high currents.

To avoid this, Pacific Power Source AC Sources and Grid Simulators come standard with programmable impedance – typically referred to as **Prog-Z** functionality - for both real-time and RMS type grid impedance simulation. This programmable implementation eliminates the drawbacks of using lumped impedances and provides far greater flexibility for evaluating different impedance conditions.

2 Prog-Z Principle of Operation in AC Sources

Before we discuss applications where the programmable impedance feature is used, it helps to understand how it is implemented on a programmable power source or grid simulator like the RGS series.

Programmable impedance uses a form of current compensation by which the output current signal sensed by the Power Source is summed with the output voltage reference signal. This summation is done in real time to decrease or - in the case of negative impedance - increase the output voltage as the current demanded by the load changes.

When Prog-Z is off, the power source controller generates both the output amplitude and waveshape (as programmed by the operator) by sending the appropriate waveform and amplitude data to each output phase inverter. The output stage then replicates the oscillator waveform and provides the voltage and current necessary to drive the equipment under test.

When Prog-Z function is enabled, the operator specified impedance values are used to determine the resulting output waveform RMS produced by the power amplifier for each phase. The resistance portion voltage drop is determined solely by the load current. The inductive portion voltage drop is a function of the load current and the frequency. As such, the overall impedance and accordingly the voltage drop will be higher at higher frequencies.

The position of the programmable impedance elements in the overall AC source schematic is illustrated in the figure below. Note that for balanced three phase load conditions, the neutral current will be zero so a programmable impedance in the neutral will have no effect. For single phase applications, the prog-Z setting represents the sum of Z_L and N_L and can be accomplished by programming the total L_A impedance value.

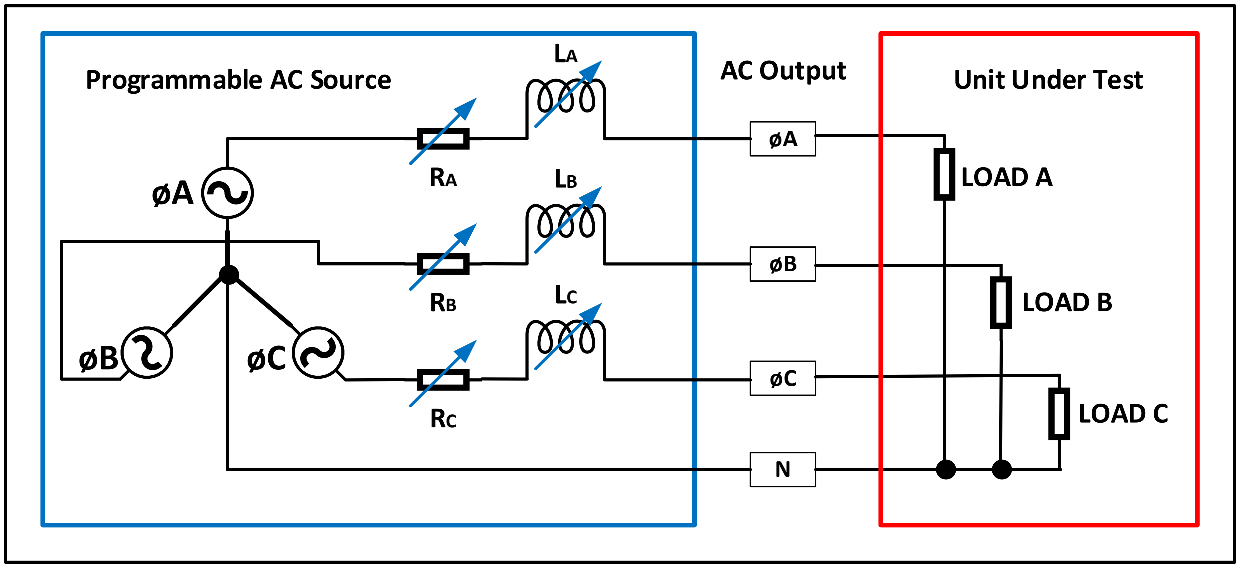
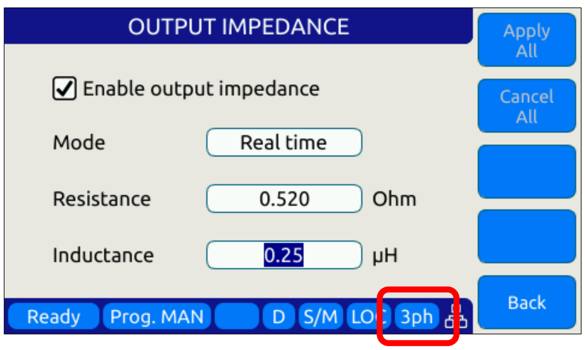


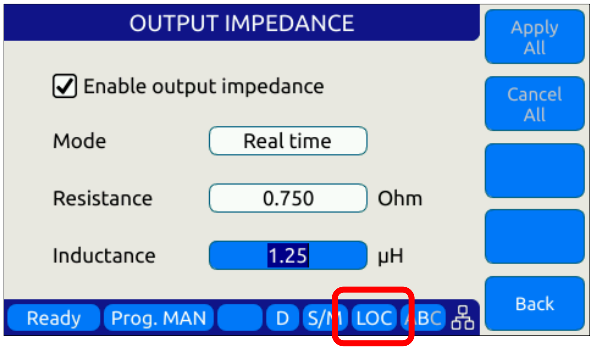
Figure 2-1: Three Phase AC Source with Programmable Impedance

For three phase configurations, the R and L values for each phase can be programmed individually per phase as needed for unbalanced impedance simulation or can be set to the same values for each phase for balanced impedance simulation which is more common.

3 RMS and Real-Time impedance implementations.

Front panel impedance programming is available from the CONF menu, either for all three-phase coupled (3ph, left screen) or different impedance values for individual phases (Unbalanced A**B**C, right screen).

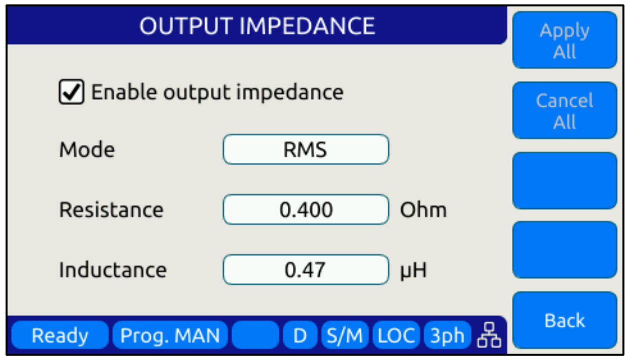




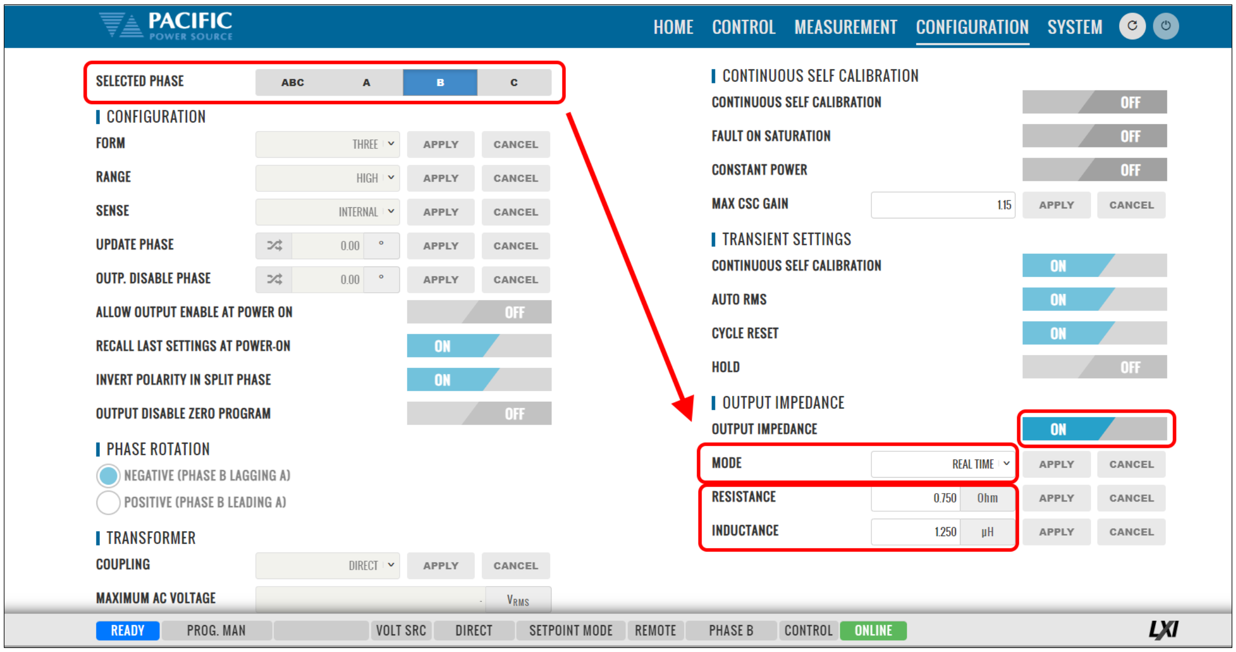
Impedance can also be toggled between Real time mode as above or RMS mode as shown in the LCD screen below.

Available setting ranges for Resistive and Inductive components for each phase impedance are wider in RMS mode than in Realtime impedance mode.

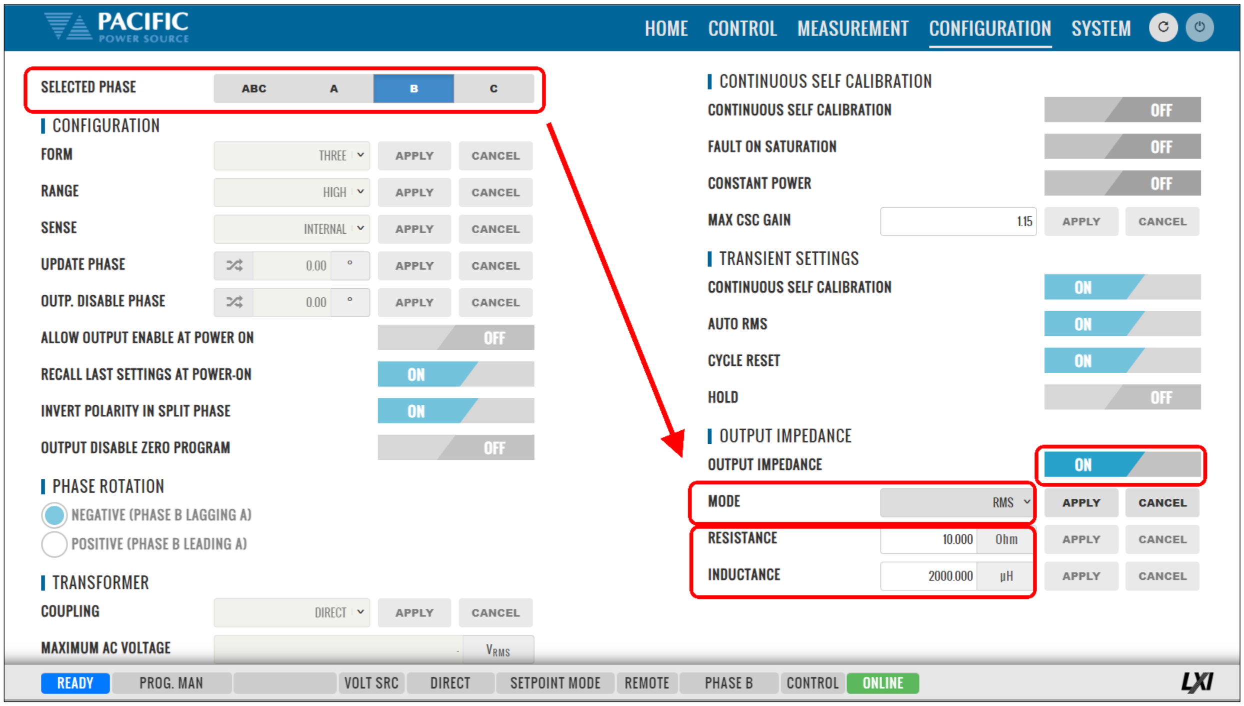
The RMS impedance mode is more suited for applications requiring high Resistive and / or Inductive value impedance settings.



The standard SmartSource Suite web browser interface also provides access to the programmable impedance settings. An example of the Real-Time Impedance mode setting screen is shown here.



Toggle the Mode to **RMS** Mode Impedance Setting to selected RMS mode instead.



New impedance settings take effect after the APPLY button is clicked.

4 Application Examples for Programmable impedance.

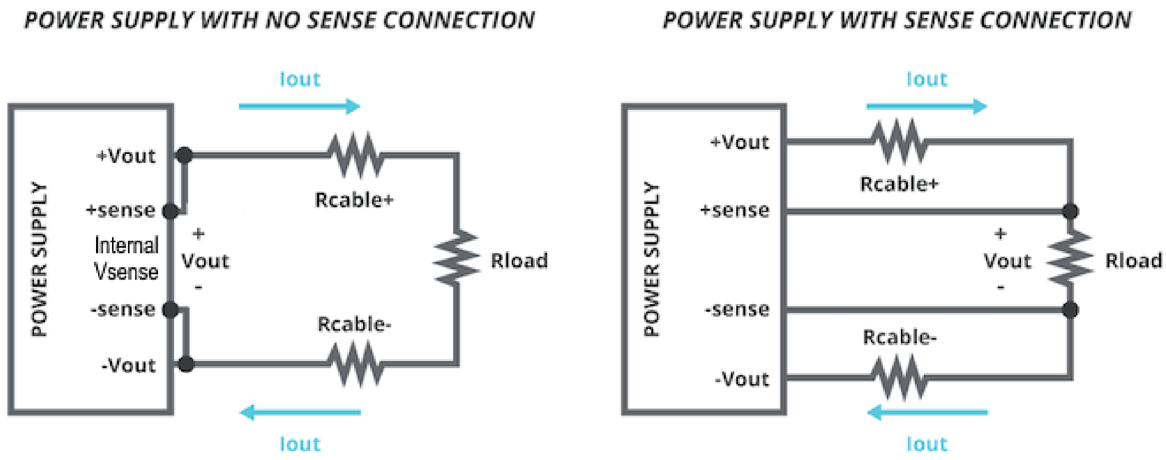
Following are some typical uses of the programmable impedance function:

- Simulate the effect of line losses due to cable length by varying the output impedance of the grid simulator.
- Adjust for voltage drop due to line losses if external voltage sense lines cannot be used to compensate due to in-line disconnects such as AC circuit breakers.
- Test for voltage flicker per IEC 61000-3-3 without the need for a lumped flicker impedance unit by programming the Prog-Z to the IEC/TR 60725 Flicker Impedance standard values instead.
- Test for current resonance points during IEC 61000-4-13 Harmonics and Interharmonic immunity compliance testing of grid connected products that require CE marking.
- Boost output voltage as a function of load by setting negative R and L impedance values in situations where external voltage sense connections are not possible. See next section.
- Test up to three individual EUTs simultaneously using FORM5 output configuration with different frequency and output impedance settings for each individual EUT.

5 Compensate for Line Losses

The Prog-Z function can also be used to compensate for line losses between the Grid Simulator output and the load if external voltage sense connections are not possible. In that case, the calculated voltage drops in the load cables can be compensated for by entering a negative impedance value.

Example



The Voltage across Rload in the left example schematic will be:

$$V_{(Rload)} = Vout - (2 * (Rcable * Iout))$$

If Iout = 10Arms, Vout = 230Vac and Rcable = 0.1 Ohm, $V_{(Rload)}$ will be 228Vac. That also means Rload = 228 / 10 = 22.8 Ohms.

The voltage across Rload in the example on the right will be 230Vac as the external sense lines boost the Vout value from the 230Vac programmed set point to232Vac to overcome the line losses in the power cables. Since we know Rload = 22.8 Ohms, the load current in this situation is 230 / 22.8 = 10.087 Arms.

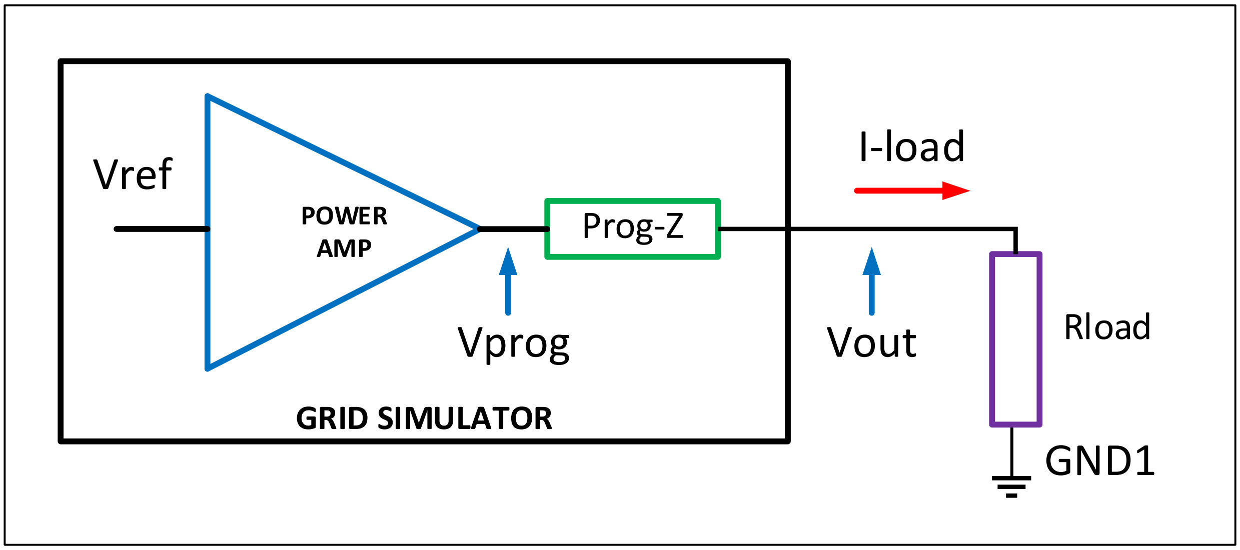
In the absence of external voltage sense, the same situation can be accomplished by using the Programmable impedance function in RMS mode and setting R to -0.200 Ohm.

Note: Care must be taking to avoid unstable condition when using this type of positive feedback.

6 Impact of Programmable Impedance on Current and Voltage

Using the programmable impedance function of a grid simulator or AC power source affects the voltage applied to the EUT and consequently the load current which is a function of the applied voltage and load impedance. This will be explained using a couple of examples with different impedance settings.

We will use a simple example of a purely restive load connected to phase A of the grid simulator. This situation is illustrated in the figure below.



Case 1: Vprog = 230Vac, 50Hz; Prog-Z = Off; Rload = 50 Ohm: Vout will be 230Vac and Iload will be 230 / 50 = 4.6 Arms.

Case2: Vprog = 230Vac, 50Hz; Prog-Z = 1.0 Ohm, 0.0 uH; Rload = 50 Ohm: Vout will be Vprog – (Z * I-load) = (230 – 4.51) or 225.49 Vrms and I-load will be 225.49 / 50 = 4.51 Arms.

Same situations for cases 3 & 4 if Prog-Z is set to 2.0 Ohms or 3.0 Ohms respectively. The higher the Prog-Z setting, the 'softer' the grid and thus, the lower the grid voltage and load current.

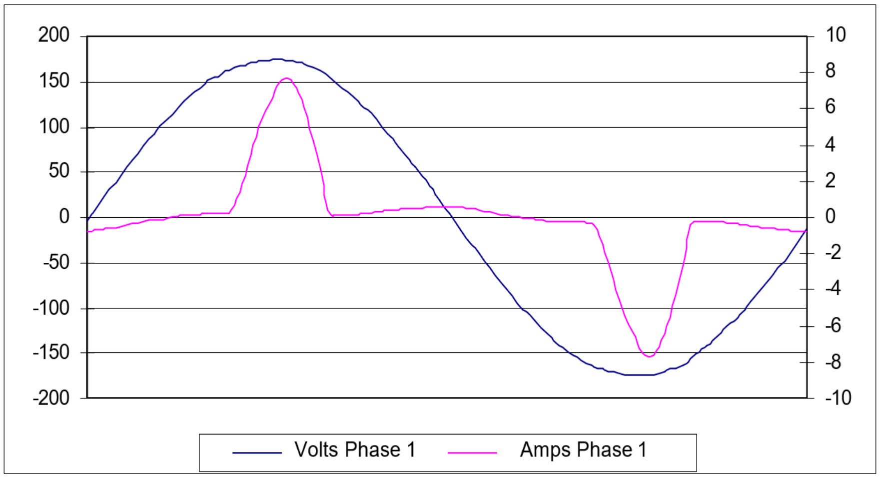
Case	Vprog	Vout	Prog-Z	R load	I load	Peak Curr	Check
1	230	230.00	0.00	50	4.60	6.51	230.00
2	230	225.49	1.00	50	4.51	6.38	225.50
3	230	221.16	2.00	50	4.42	6.25	221.00
4	230	216.98	3.00	50	4.34	6.14	216.95

7 Non-Linear Load Currents and Prog-Z

While these cases are straightforward as the current is linear due to the resistive loads, the impact of Prog-Z on the peak current becomes more pronounced for the cases where the load is non-linear.

The following graphs and tables demonstrate the results of Programmable Impedance on a non-linear load using an AGX-Series Power Source.

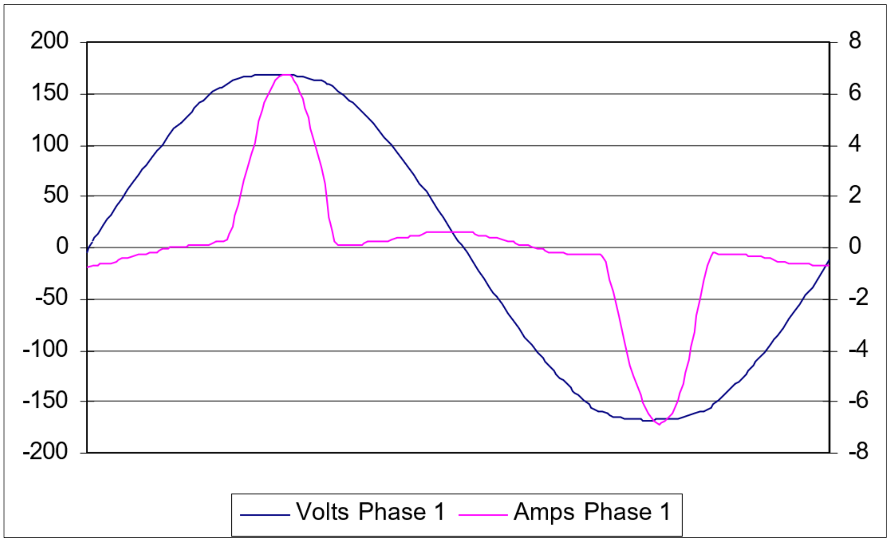
The first graph depicts the output voltage and current waveforms of a typical non-linear load with Prog-Z set to zero ohms. Of note is the peak current demand of 7.71Apk creating a 2.78:1 crest factor.



Prog-Z = 0 ohms	
Vrms	124.20
Irms	2.77
Ipeak	**7.71**
Icrest	2.78
KW	0.23
KVA	0.34
PF	0.66

Figure 6-1: Prog-Z = 0 Ohms

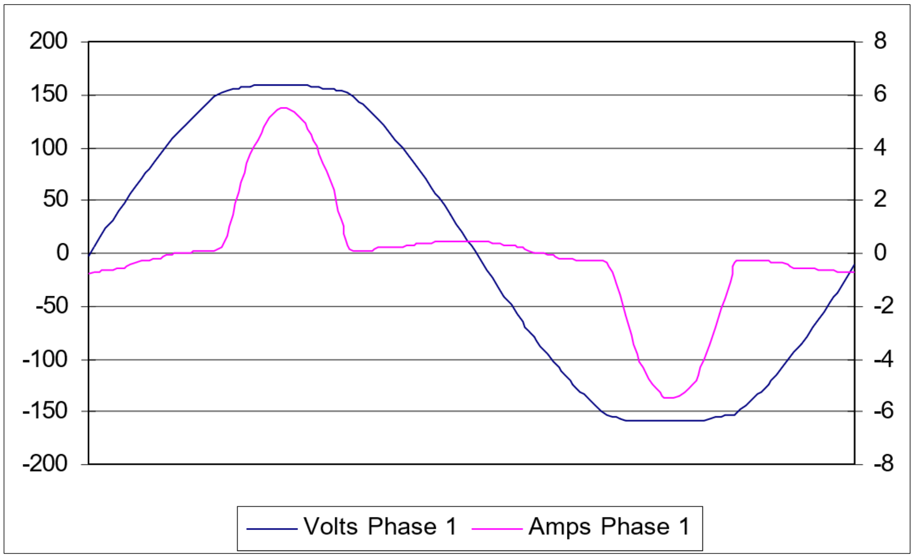
Using the same load, Figure 4 depicts the result of 1 ohm of output impedance. Here we see the results on the peak of the voltage waveform as the current is demanded by the load. This increased impedance served to reduce both the Peak current and the Current Crest Factor. Note the flat topping of the voltage waveform as the current term modifies Vout.



Prog-Z = 1 ohm	
Vrms	122.46
Irms	2.58
Ipeak	**6.70**
Icrest	2.59
KW	0.21
KVA	0.31
PF	0.68

Figure 6-2: Prog-Z = 1.0 Ohms

As an extreme example, 3 ohms of output impedance is programmed. Again, as the output voltage is reduced, the peak current and crest factor change accordingly.



Prog-Z = 3 ohms	
Vrms	119.2
Irms	2.29
Ipeak	**5.50**
Icrest	2.39
KW	.19
KVA	027
PF	0.71

Figure 6-3: Prog-Z = 3.0 Ohms

A final example demonstrates the effect of negative impedance. In this case the output current boosts the output voltage as the current increases. Negative impedance may be used to compensate for line losses that occur with external magnetics or other high impedance distribution lines.

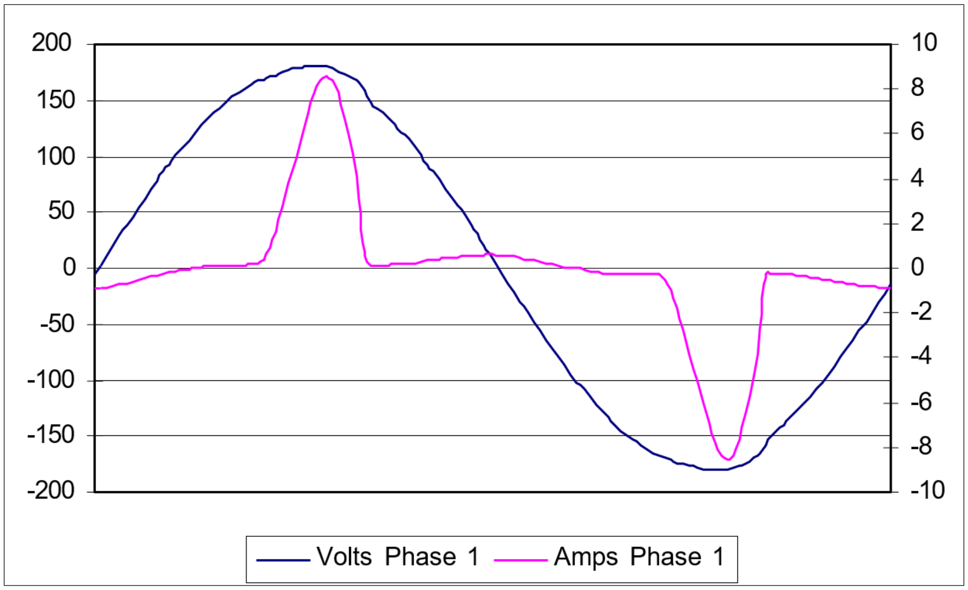


Figure 6-4: Prog-Z = Negative 1.0 Ohms

Prog-Z = -1 ohm						
Vrms	Irms	Ipeak	Icrest	KW	KVA	PF
126.20	2.95	**8.99**	3.04	0.24	0.37	0.65

8 Summary

As previously stated, Prog-Z, Pacific's waveform editing, and transient capabilities may be combined to form an extremely powerful Power Line Disturbance Test System. For common steady state or frequency conversion applications, Prog-Z along with Continuous Self Calibration (CSC) may be used to improve power source regulation into dynamic loads. The CSC function maintains a constant output voltage at the metering point by comparing the metered value with the programmed output voltage and automatically changing the power source output voltage. With CSC maintaining the "programmed to actual (external metered at the load)" output voltage accuracy (operating over several cycles), Prog-Z may be used to compensate for fast or intermittent load changes that may occur as loads are switched onto the power grid.

Due to the "real time" nature of the feature, Programmable Output Impedance offers the following benefits:

1. Speed; sub-cycle response times to load induced current demands are accommodated.
2. Impedance values can be adjusted by the user **without** the need to turn the output off and back on to do so.
3. Requires no additional hardware.

As the purpose of Prog-Z is to modify the output voltage waveform, the following precautions should be noted:

1. Large values of Programmable Impedance may cause output voltage distortion to increase into linear loads as the voltage waveform begins to flatten out or clip.
2. Leading power factors may cause positive regulation and extreme cases may cause the power source output to become unstable.
3. In the three phase mode, only one Prog-Z value is provided. It is assumed that a balanced load is applied to the source and each phase is to be equally modified.

9 Customer Support

For application support, contact Pacific Power Source's Customers Service - Toll Free US: +1 (800) 854-2433 / support@pacificpower.com or your local authorized Pacific Power Source distributor.

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