6100A/6101A - Alternative verification methods

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Alternative verification of 6100A/6101A

The following describes how to verify the performance of your 6100A if the sampling measurement techniques described in Chapter seven of the user manual are not available. The same techniques can be used to measure 6101A Auxiliary units but a 6100A is required to control the 6101A.

Rigorous type testing of the 6100A has shown that when the phase and gain of each voltage or current channel are correctly adjusted, all other specifications will be met. The gain and phase measurements required can be made using the equipment listed in the following paragraphs. All measurements are of sine waves and phase angle measurements are made between the voltage and the current outputs.

Recommendation

Users should be aware that the 6100A is optimized for use with sampling measurement instruments. Some RMS sensing meters have AC input bandwidths of many MHz and cannot reject non-harmonic components. As a result, this type of instrument may give misleading results. It is recommended that only sampling techniques or those described below are used to verify or adjust the performance of the 6100A.

Equipment recommended for amplitude measurements

Fluke 5790A AC measurement standard

Fluke A40 and A40A Current shunt set characterized with a Fluke 792A-700A adapter.

The Fluke 5790A-7001 adapter cable for use with the A40A shunts.

Precision DC current source such as 5520A (for use in AC/DC transfer current measurements)

The four wire sensing voltage connector lead provided with the 6100A.

The current connector lead provided with the 6100A.

For 6100A/80A only, Measure-Tech (Precision Measurements) EL-980 AC current shunt set.

Equipment recommended for phase measurements

Clarke-Hess Model 6000 Phase-meter

Fluke A40 and A40A Current shunt set characterized with a Fluke 792A-700A adapter.

The Fluke 5790A-7001 adapter cable for use with the A40A shunts.

Dual 4mm ‘banana’ to BNC adapter.

N type (Male) to BNC adapter.

The four wire sensing voltage connector lead provided with the 6100A.

The current connector lead provided with the 6100A.

Measurement tolerances

In the processes that follow, measurement system accuracy may be significant against the 6100A specification. As an example, when measuring current, the combined specification of the 5790A and the A40/A40A shunts is about the same as the 6100A. So how do you know if the 6100A meets its specification? In some cases you cannot tell. A simple way to categorize results is to calculate two tolerances for each measurement. A Pass tolerance is derived by subtracting the measurement system accuracy figure from the 6100A specification. The second, a Fail tolerance figure comes from the addition of the two numbers. Then there are three possible outcomes from the measurement.

If the measured error is more than the Fail tolerance the 6100A definitely does not meet its specification.

If the measured error is less than the Pass tolerance the 6100A definitely meets its specification.

If the result is between the Fail and Pass tolerance you cannot tell. The result is said to be indeterminate.

The larger the measurement system tolerance, the wider the indeterminate band. If the measurement system tolerance is greater than the 6100A specification, the 'definitely passes' result cannot exist, that is, you cannot say the result shows that the 6100A definitely passes. In the extreme, the measurement may only be capable of showing whether or not a gross error exists unless something is done to improve the measurement. This would be the case with phase angle measurement if the measures describe in the "Phase-meter resolution limitations" were not implemented.

Amplitude measurements

5790A initial set-up

There are no special set-up conditions for the 5790A and it should be left in its power up configuration including auto ranging. See table 4-1 in chapter 4 of the 5790A user manual for details of power up settings.

6100A initial set-up

Read Chapter 3 of the user manual for an overview of 6100A front panel operation.

On the 6100A set the harmonic edit mode for voltage and current to 'Absolute RMS' (user manual section 4-8)

Set the 6100A voltage terminal configuration to 4-wire (user manual section 4-11).

If the 'Direct Mode' key on the front panel is not illuminated, press the key to select Direct Mode (user manual section 4-13).

Select voltage or current as required and 'Enable' the channel as described in user manual section 4-17. For safety and to avoid overload error reports 'Disable' voltage while measuring current and vice versa. Note that a channel must be enabled and the OPER key pressed before voltage or current appears at the output terminals.

Voltage amplitude verification

Voltage measurements should be made with the 6100A connected via the special 4-wire sense lead provided connected to the 5790A Input 2 binding posts.

Recommended voltage measurement points are set out in Table 1 below. Where a harmonic number is specified, ensure all other harmonics including the fundamental frequency are removed from the output (user manual section 4-23)

Voltage Range	Frequency (Hz)	Setting (volts)	Sine mode or harmonic number	6100A specification (mV)	Measured value
16	60	6	sine	1.7	
	60	16	sine	2.8	
	6000	3	H100	2.5	
33	60	13	sine	3.6	
	60	33	sine	5.2	
	6000	6	H100	5.1	
78	60	31	sine	5.8	
	60	78	sine	10.7	
	6000	15	H100	9.7	
168	60	67	sine	12.6	
	60	168	sine	23.2	
	6000	33	H100	21.3	
336	60	134	sine	25.1	
	60	336	sine	46.4	
	6000	66	H100	46.8	
100 8	60	330	sine	80.8	
	60	1000	sine	184.0	
	6000	200	H100	85.4	

Table 1. Recommended voltage verification points

Current amplitude verification

The A40 and A40 shunts are specified by their AC/DC amplitude errors at various frequencies. They are not design to be used for absolute measurements of AC currents. To achieve the required accuracy, use the AC/DC transfer current measurement technique described in chapter 4, section 4-25 of the 5790A user manual. Note that the combined specification is valid from 50% and 100% of the shunt value.

Recommended 6100A current measurement points are set out in Table 2 below. Use the shunt most appropriate to the value being measured. Where a harmonic number is specified, ensure all other harmonics including the fundamental frequency are removed from the output (user manual section 4-23)

Current Range	Frequency (Hz)	Setting (amps)	Sine mode or harmonic number	6100A specification (µA)	Measured value
0.25	60	0.1	sine	19.9	
	60	0.25	sine	38.5	
	6000	0.05	H100	31.3	
0.5	60	0.2	sine	33.8	
	60	0.5	sine	71.0	
	6000	0.1	H100	56.5	
1	60	0.4	sine	61.6	
	60	1.0	sine	136	
	6000	0.2	H100	107	
2	60	.8	sine	117	
	60	2.0	sine	266	
	6000	0.4	H100	208	
5	60	2	sine	284	
	60	5	sine	656	
	6000	1	H100	511	
10	60	4	sine	770	
	60	10	sine	1646	
	6000	8	H100	1044	
21	60	8	sine	1.7mA	
	60	20	sine	3.8mA	
	6000	4	H100	2.7mA	
80	60	32	sine	8.5mA	
	60	80	sine	20mA	
	3000	16	H50	11mA	

Table 2. Recommended current verification points

Voltage from current terminals amplitude verification

Recommended voltage from current terminal measurement points are set out in Table 3 below. Where a harmonic number is specified, ensure all other harmonics including the fundamental frequency are removed from the output (user manual section 4-23)

Voltage Range	Frequency (Hz)	Setting (volts)	Sine mode or harmonic number	6100A specification (µV)	Measured value
0.25	60	0.1	sine	50	
	60	0.25	sine	80	
	6000	0.05	H100	80	
1.5	60	13	sine	170	
	60	33	sine	340	
	6000	6	H100	350	
10	60	31	sine	1100	
	60	78	sine	2240	
	6000	15	H100	3000	

Table 3. Recommended voltage from current terminal verification points

Phase angle measurement fundamentals

The phase angle between voltage and current components at the same frequency is important for power calculations. The following procedure allows the phase angle between voltage and current outputs at the same frequency to be measured. Where the wave shape of voltage or current signals is important the phase angle of harmonics relative to their fundamental frequency must be known. The instruments recommended in this procedure cannot provide that information. See the chapter 7 of the user manual for details of the sampling method used at Fluke Service Centers.

To compare current and voltage phase angles the current signals must be converted to voltages using current shunts. The Fluke A40 and A40A shunts typically have bandwidth in excess of 1MHz. This makes their errors of the same order but generally less than the 6100A phase angle specifications. If other shunts are used it is important their bandwidth is known. The effect of shunt bandwidth is discussed below.

Effects of bandwidth on phase angle measurements

The accuracy of phase angle measurements may be significantly affected by errors due to the bandwidth of the measuring system. If the measurement system bandwidth exhibits a single pole roll off, equation (1) can be used to estimate the phase error due to bandwidth.

$$E_{phase} = \arctan\left(\frac{f}{fbw}\right) \qquad (1)$$

where *f* is the frequency of the measurement and *fbw* is the bandwidth of the measurement system.

Table 4. provides estimated phase angle errors for various frequencies at different bandwidths.

	Bandwidth (Hz)			
	10kHz	100kHz	1MHz	10MHz
Signal frequency				
60Hz	344m°	34m°	3.4m°	0.3m°
600Hz	3.4°	344m°	34m°	3.4m°
6kHz	31°	3.4°	344m°	34m°

Table 4. Effect of system bandwidth

Phase angle measurement limitations - voltage

The Clark-Hess model 6000 phase-meter is recommended because its maximum voltage input is 350V and external attenuators are not required. Nevertheless, care should be taken not to exceed this limit when the 6100A 1008V range is selected. The phase angle measurements using the 1008V range can be adequately performed with output settings less than 350V.

Phase angle measurement limitations – current

The Clark-Hess model 6000 phase-meter minimum input is 10mV. The output of the A40 and A40A shunts is typically 500mV at full rated input current. Best phase measurement results will be achieved when shunts are used at 20% of the rated current value or above.

Phase-meter resolution limitations

At first glance the specification of the Clark-Hess model 6000 phase-meter is not appropriate for measurement of the 6100A. Two techniques can be employed to improve this situation significantly.

At lower frequencies the 6100A 1 year specification is 3m°. The best resolution of the Clark-Hess model 6000 phase-meter is 10 m°. When you add in the bandwidth error of the current shunts the performance of the measurement system is more than 4 times worse than the 6100A specification. The effect of measurement system errors can be reduced however. Say the phase-meter displays 60.01°. Because the reported phase angle is rounded it could be any value between 60.005 and 60.014° and that represents an uncertainty of ±0.005° due to display resolution. Higher effective resolution can be artificially achieved by using the 6100A setting resolution of 1m° to seek out the 'flicker point' between two values on the Clarke-Hess phase angle display. For example, if the phase-meter display can be made to flick between say 60.01 and 60.02 by changing the 6100A setting by ±0.001°, the measured value could be considered to be 060.014 for the lower 6100A setting and 060.015 for the higher. Now the resolution of the phase-meter is effectively ±0.001°.

In the second technique the errors between the two phase-meter input channels are reduced by making measurements before and after swapping the voltage and current signals at the phase-meter inputs. This second technique should be employed at each frequency at which measurements are made. Note that neither of the methods described remove the effect of shunt bandwidth.

Consider the following example; the 6100a voltage output is connected to the phase-meter 'reference' channel, the output of the current shunts to the 'input' channel.

Measurement number	6100A output setting	Phase-meter reading	Value deduced from Flicker technique
	60.000	60.00	
1	60.007	60.01	60.005
2	60.006	60.00	60.004

Now, we swap the inputs so that current is the reference, voltage is connected to the 'input' channel.

Measurement number	6100A output setting	Phase-meter reading	Value deduced from Flicker technique
	60.000	60.01	
3	59.998	60.00	60.004
4	59.999	60.01	60.005

To analyze the results:

Let E_{6100A} be the 6100A error (which is to be determined). Let E_{PM} be the phase meter error at this frequency due to input channel differences.

Let us define the measurement error as:

$E_{1,2} = E_{6100A} - E_{PM}$ for measurements 1) and 2)

and because the inputs to the power meter have been reversed, as:

$E_{3,4} = E_{6100A} + E_{PM}$ for measurements 3) and 4).

Now 1) and 4) gave the same deduced result of 60.005 but the power-meter errors were reversed by swapping the inputs. Using our pre-determined error relationships:

$60.007 + E_{6100A} - E_{PM} = 599.999 + E_{6100A} + E_{PM}$

$60.007 - 599.99 = 2.E_{PM}$

$E_{PM} = 0.004$.

Now substituting for E_{PM} in 2) and using the value deduced from the flicker technique:

$60.004 = 60.006 + E_{6100A} - 0.004$

$E_{6100A} = 60.004 - 60.006 + 0.004 = 0.002$.

That is, the 6100A error at its 60.000 degrees setting has been measured to be 0.002°.

The example above assumes a unique power-meter value displayed for every 6100A setting but instrument short term stability and noise will almost certainly make the results appear more random. The most reliable way to employ the 'flicker point' technique is with automated measurements where every reading can be captured and used in a statistical evaluation. Nevertheless, it is not unreasonable to assign an uncertainty due to meter resolution of ±0.002° when the flicker point technique is manually applied by an experienced operator. The effect of shunt bandwidth must be combined with the resolution error in order to properly estimate systematic phase angle error.

Phase angle verification

In the 6100A current phase angle is specified with voltage as the reference. The 6100A voltage output should be applied to the power-meter reference input except when performing the input reversal method to reduce uncertainty.

Implications of the 6100A design

Phase angle verification measurements are simplified by the 6100A design approach. Voltage and current channel phase angles are adjusted to have zero error with respect to a common internal phase reference signal. It is therefore not necessary to measure the phase angle between every voltage and current range combination. Further more, as the design ensures there is no variation in phase accuracy with setting, measurements can be made at whatever phase angle is deemed most appropriate.

6100A initial set-up

Phase measurement requires both the voltage and current channels to be ‘Enabled’ together. User manual section 4-17 describes how channels are enabled and how to switch between editing voltage and current output parameters. Set both voltage and current channels to Sine mode (user manual section 4-22).

The recommended verification scheme involves measuring each current range against a single voltage range, then each voltage range against a single current range. These measurements should be repeated at each frequency of interest. This reduces the number of measurements required at each frequency from 66 to 17.

Select an appropriate voltage range on the 6100A and set the output as required, e.g., Table 5 assumes that 120V; 60Hz is used as the reference voltage. Measure phase angle with the current settings shown in Table 5.

Voltage Range: 168V			Voltage setting: 120V				Frequency: 60Hz
			V to reference		Reversed		
A40 / A40A / EL-980 Shunt	Current Range	Setting	Low Flicker value	High Flicker value	High Flicker value	Low Flicker value	Calculated error (m°)	6100A specification (Frequency <70Hz)
-	0.25V	0.2V						0.003°
-	1.5V	1.2V						0.003°
-	10V	8V						0.003°
200mA	0.25A	0.2A						0.003°
500mA	0.5A	0.4A						0.003°
1A	1A	0.8A						0.003°
2A	2A	1.6A						0.003°
5A	5A	4A						0.004°
10A	10A	8A						0.004°
20A	21A	16A						0.004°
EL9830	80A	50A						0.004°

Table. 5 Phase measurements to single voltage range

In Table 6. it is assumed the 2A range is chosen for comparison with each voltage range.

Current Range: 2A			Current setting: 1.6A			Frequency: 60Hz		
			V to reference		Reversed			
A40 / A40A Shunt	Voltage Range	Setting	Low Flicker value	High Flicker value	High Flicker value	Low Flicker value	Calculated error (m°)	6100A specification (Frequency <70Hz)
2A	16V	0.2V						0.003°
2A	33V	1.2V						0.003°
2A	78V	8V						0.003°
2A	168V	0.2A						0.003°
2A	336V	0.4A						0.003°
2A	1008V	0.8A						0.003°

Table. 6 Phase measurements to single current range

Phase angle can be verified at other frequencies by choosing the same appropriate harmonic for voltage and current. The voltage and current channels should be set to Harmonic mode (user manual section 4-22). Set up the required harmonic bearing in mind the amplitude limitation for harmonics (see user manual section 1-8). For harmonic frequencies < 2850Hz amplitudes up to 30% of range may be set. The maximum amplitude allowed decreases with frequency to 20% at 6kHz. Set voltage and current 1st harmonic amplitude to zero to remove the fundamental frequencies from the outputs.

See user manual section 1-28 for phase angle accuracy specification of signals > 69Hz or where either the voltage or current output is less than 40% of range.