Precision electrical power sources calibration using electrical energy and frequency standards

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Abstract. This paper presents an alternative method for precision electrical power sources calibration. As traditional method, the proposed method uses a power and energy standard, but also employs a frequency standard. Calibration results for both methods are discussed and their advantages are pointed out.

Keywords: power and energy; calibration; frequency.

1. Introduction
Precise electrical power sources, as relay test systems, are widely used in power utilities for calibration services of instruments used in supervisory, control and protection systems, installed in high voltage substations and power plants, such as transducers, digital relays and intelligent electronic devices (IEDs). Usually, in order to establish traceability, these precision power sources are calibrated by the power utility in its reference metrology laboratory, using a precise power and energy meter (power and energy standard). Finally, this power and energy standard standards is calibrated by the National Metrology Institute (NMI) or by a high performance calibration laboratory. Figure 1 shows this traceability chain.

![Traceability chain for precise electrical power sources calibration](image)

Figure 1: Traceability chain for precise electrical power sources calibration.

Metrology laboratory power and energy standard instrument is usually calibrated by the NMI in order to establish electrical energy traceability for electrical energy meters [1]. As this instrument also presents...
power measurement function (active and reactive), this function should also be calibrated by the NMI in order to make possible calibration of precision power sources. Calibration of this additional function makes the cost of the calibration higher. Besides that, some efforts also should be done to compile active and reactive power calibration data to establish adequate traceability.

This paper presents a calibration method to assure traceability to precise electrical power sources calibrations using power and energy standard electrical energy calibration data, a frequency standard instrument for traceability of time measurements, and a counter. This frequency standard can be a low cost one, such as frequency or signal generators, due to the fact that time and frequency measurement uncertainties are much lower than electrical energy measurements. Additionally, this kind of instrument can be easily found in electrical metrology laboratories so probably no investments in buying one should be done, only in calibrated it. Expected results are uncertainties lower than traditional method, due to expected good stability of electrical energy measurement function of the power and energy standard. Other expected results are less power and energy standard calibration data to manage, and also a less costly calibration for this standard, because active or reactive power calibration will not be necessary.

2. Calibration Methods

Traditional precision power source calibration method is a direct comparison of the power, active or reactive, generated by the source to the power and energy standard indication. The estimate of the generated power is the indication of the power and energy standard, corrected by its last calibration certificate. All the uncertainties are calculated in W or var.

In the proposed method, the power and energy standard measures the energy delivered by the precision power source during an interval of time, so the estimate of the generated power is given by Eq. 1, where \( W_S \) is the electrical energy measured by the power and energy standard and \( \Delta t_S \) is the time interval. Power and energy standard and frequency standard both send pulses to the counter. Pulses from the power and energy standard are proportional to its \( K_h \), the “energy constant”, in Wh/pulse or varh/pulse. Pulses sent by the frequency standard are proportional to the its frequency setting.

\[
P_X = \frac{W_S}{\Delta t_S} \tag{1}
\]

In each measurement, an exact number of pulses to be received from the frequency standard is set in the counter. It starts counting the pulses sent by the power and energy standard after the first pulse from the frequency standard is received. After the last pulse sent by the frequency standard is received, the number of pulses sent by the power and energy standard is displayed and should be recorded. So using \( K_h \), the measured electrical energy can be calculated. \( \Delta t_S \) is calculated using Eq. 2, where \( NP \) is the number of pulses received by the counter from the frequency standard and \( f \) is the frequency setting. Figure 2 shows this measurement method.

\[
\Delta t_S = \frac{NP}{f} \tag{2}
\]

![Figure 2: Measurement scheme for the new calibration method](image-url)
In this paper, the power and frequency standard used was from Radian Research Inc., model RD-31. According to its manufacturer, its accuracy is 0.02% [2]. Voltage range measurement ranges from 10 V to 630 V @ 60 Hz, while current measurement ranges from 10 mA to 120 A @ 60 Hz. It presents a counter function, so no additional counter instrument is necessary. Is also measures the electrical energy delivered by the power source, so the energy constant is not required. Calibration history has shown that is drifts less than 0.005% for electrical energy measurements.

The frequency standard is a function generator from Agilent (now Keysight), model 32250A. Its accuracy is 0.0002%, and frequency range is from 1 µHz to 80 MHz [3]. Figure 3 shows Radian RD-31 and Agilent 33250A standards.

![Figure 3: Agilent 33250A and Radian RD-31 standards.](image)

3. Calibration results

For comparison purpose of traditional the new methods, the following examples show results for a precision power source calibration at three phase active power, 66.4 volts, 5 amps and unity power factor, so 996 W.

Measurement uncertainties were estimated using methodologies defined in [4]. Eq. 3 shows the traditional method mathematical model for estimation of error of measurement $E_X$, where $P_{IX}$ is the power adjusted in the power source, $P_S$ is the power measured by the power and energy standard, $\delta P_S$ is the correction due to the finite resolution of the power and energy standard, $\delta P_C$ is the correction due to the accuracy of the standard, $\delta P_C$ is the correction obtained from the last calibration certificate of the power and energy standard and $\delta P_T$ is the correction due to the temperature dependence of the power and energy standard. Uncertainty budget for traditional calibration method is shown in Table 1.

$$E_X = P_{IX} - P_S - \delta P_S - \delta P_S - \delta P_C - \delta P_T$$  \hspace{1cm} (3)

| quantity | Estimate $x_i$ | standard uncertainty $u(x_i)$ | probability distribution | sensitivity coefficient $c_i$ | uncertainty contribution $u_i(y)$ |
|----------|----------------|-------------------------------|--------------------------|-------------------------------|--------------------------|
| $P_{IX}$ | 996.00 W       | -                             | -                        | -                             | -                        |
| $P_S$    | 995.99 W       | 0.003 W                       | normal                   | -1                            | -0.003 W                 |
| $\delta P_S$ | 0 W            | 0.115 W                       | rectangular              | -1                            | -0.115 W                 |
| $\delta P_S$ | 0 W            | 0.000 289 W                   | rectangular              | -1                            | -0.000 5 W               |
| $\delta P_C$ | -0.108 W      | 0.034 9 W                     | normal                   | -1                            | -0.034 9 W               |
| $\delta P_T$ | 0 W            | 0.008 0 W                     | rectangular              | -1                            | -0.008 0 W               |
| $E_X$    | 0.118 W        |                               |                          |                               | 0.120 W                  |

Table 1: Uncertainty budget for the traditional calibration method.
Eq. 4 shows the proposed method mathematical model for estimation of error of measurement $E_X$, where $P_{IX}$ is the power adjusted in the power source, $W_S$ is the measured active energy during the time interval, $\delta W_S$ is the correction due to the historical drift of the power and energy standard, $\delta W_{iS}$ is the correction due to the finite resolution of the power and energy standard, $\delta W_C$ is the correction obtained from the last calibration certificate of the power and energy standard, $\delta W_T$ is the correction due to the temperature dependence of the standard, $f_S$ is the frequency adjusted in the frequency standard, $\delta f_S$ is the correction due to the accuracy of the frequency standard, $\delta f_C$ is the correction obtained from the last calibration certificate of the frequency standard and NP is the number of pulses to be received by the power and energy standard counter function. In this example, time interval is 10 seconds, so frequency is adjusted at 100 Hz and thus the number of pulsed is set at 1000 in the power and energy standard. Uncertainty budget for new calibration method is shown in Table 2. As the indication of the power generated by the precision power source is fixed, variations on it will appear on the uncertainty of the measured energy by the power and energy standard ($W_S$).

$$E_X = P_{IX} - \left(\frac{W_S + W_{iS} + W_C + W_T}{NP}\right) (f_S + f_C)$$

Table 2: Uncertainty budget for the proposed calibration method.

| quantity | Estimate | standard uncertainty | probability distribution | sensitivity coefficient | uncertainty contribution |
|----------|----------|----------------------|--------------------------|-------------------------|-------------------------|
| $P_{IX}$ | 996.00 W | -                    | -                        | -                       | -                       |
| $W_S$   | 2.766763 Wh | 0.008 9 mWh | normal | -360 | -0.0032 W |
| $\delta W_S$ | 0 Wh | 0.080 mWh | rectangular | -360 | -0.029 W |
| $\delta W_{iS}$ | 0 Wh | 0.00289 mWh | rectangular | -360 | -0.0010 W |
| $\delta W_C$ | -0.0011 mWh | 0.097 mWh | normal | -360 | -0.0349 W |
| $\delta W_T$ | 0 Wh | 0.011 mWh | rectangular | -360 | -0.0080 W |
| $f_S$   | 100 Hz  | -                    | -                        | -                       | -                       |
| $\delta f_S$ | 0 Hz | 0.20 mHz | rectangular | -9.96 | 0.0012 W |
| $\delta f_C$ | 0.0020 Hz | 0.17 mHz | normal | -9.96 | 0.0009 W |
| $E_X$   | -0.033 W | -                    | -                        | -                       | 0.046 W                |

As it can be seen when comparing Table 1 and Table 2, measurement uncertainty in the proposed method is about 62% lower than in the traditional method, mainly due to the low drift of the power and energy standard in the electrical energy measurement function.

4. Conclusion
This paper presented an alternative method for three-phase precision electrical power sources calibration. This method can be used if a frequency standard and a power and energy standard with counter function are available in the metrology laboratory. The proposed method has an advantage of using power and energy standard calibration points already used for electrical energy meters traceability establishment, so it is possible to reduce calibration costs of that standard. In the case presented in the paper, another advantage was the reduction of measurement uncertainty, at about 62%, due to the good drift of the power and energy standard used by the laboratory in the electrical energy measurement function.

References
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