Computer-aided transducer calibration system for a practical power system

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Abstract: The paper describes a new computer-aided automatic calibration system developed for the instrument calibration department of the Taiwan Power Company. One- or three-phase power transducers, including voltage, current, watt, VAR and power factor transducers, can be calibrated in this system. The generated calibration power condition is programmable. Its voltage/current amplitude and phase angle are adjustable between 0V and 300V, -10A and 10A, and 0° and 360°, respectively. A 386 personal computer controls all the operations inside the calibration system and interfaces with users. A menu-driven, user-friendly software interface has been developed to support the system. It offers the user flexibility of operation and ease of usage. The IEEE-488 interface bus is connected in closed-loop mode to control all stimulated equipment and the transducers under test. Special emphasis is placed on the user friendliness of this computer-aided calibration system and its capability of calibrating ten transducers using only one set-up. The experimental results for various transducers are given, and the uncertainty of the system is discussed.

1 Introduction

Power transducers are increasingly used owing to the automated applications in power systems. The increasing proliferation of power transducers has added a substantial burden to calibration departments. Routine performance verification has become a major cost factor as well as a load on available manpower. In recent years, small computers have acquired an important role in the automatic calibration of test and measurement instrumentation. They have been effective in reducing the cost and increasing the quality and repeatability of these calibrations. These calibrations are repetitive and tedious, yet complex enough to take an engineer or trained technician to do the job. With appropriate computerisation, calibration can be performed quickly and efficiently. Computerisation can assure quality and repeatability by following a fixed procedure and pro-

ducing a full written report upon completion of the calibration. The user interface can be made friendly so that someone with minimal knowledge can easily perform complex calibrations. There have been a variety of computer-aided calibration systems introduced by test equipment suppliers [1-4]. Several of these systems emulate manual calibration systems by simply automating manual test procedures [5,6]. These systems are functionally oriented towards the unit under test in a specific manner. Some require experienced operator expertise in a high-level software language to prepare test procedures [7,8].

In this paper, the design and implementation of a computer-aided automatic calibration system are described. This system has been developed for the instrument calibration department of the Taiwan Power Company. One- or three-phase power transducers, including voltage, current, watt, VAR and power factor transducers, can be calibrated using this system.

2 Calibration philosophy

The most widely utilised approach to calibration is to compare the testing unit with a standard unit under the same test conditions [9-15]. The accuracy of this method of comparison mainly depends on the accuracy of the standard unit. Hence, these standard units also require regular calibration. Another calibration approach generates a controlled testing environment in which testing units are placed. The outputs of the testing unit are compared with what is known of the generated environment.

Calibration of power transducers has traditionally been carried out by comparing the testing unit with a standard one. In such an approach, the accuracy of the standard unit is crucial, and precise knowledge of the testing condition parameters is not required. With the advent of multifunction instruments capable of measuring voltage, current, power factor and active and reactive power, knowledge of each of the source parameters has become advantageous. The measurement of real power and reactive power, in particular, is greatly simplified if the voltage, current and phase angle are known. This concept has led to the development of a dual-channel sine wave generator for generating the controlled voltage and current of a single-phase AC power source.

The system developed adopts the standard power source approach. Three single-phase controllable AC power sources have been built with programmable voltage/current amplitudes and phase angles. The power sources can produce testing power conditions and feed

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the transducer being calibrated. Mismatches between the transducer outputs and the specifications of the testing condition are then used to tune transducer parameters.

3 Hardware system architecture

The hardware architecture of the computer-aided automatic calibration system (CAACS) is shown in Fig. 1.

Fig. 1 Hardware system architecture

It is composed of a personal computer (PC), three programmable power condition generators (PCGs), a programmable switching box (PSB), a digital multimeter (DMM), the IEEE-488 interface and the transducers under test (TUT). The function of each element is as follows:

3.1 Power condition generator

Each power condition generator consists of a signal generator (SG), a voltage amplifier (VA) and a transconductance amplifier (IA). The VA and IA boost the signals from the SG and provide the testing voltage and current environments.

Fig. 2 Signal generator

3.1.1 Signal generator: The SG is a digitally synthesised standard signal source [16–20]. There are three SGs, for phases A, B and C, respectively. Each SG syn-

thesises two separate low-level sinusoidal voltages with adjustable amplitudes and phase angles. As shown conceptually in Fig. 2, it consists of a phase reference counter, two comparators, two address counter, two ROMs with stored sine wave patterns, and two 16-bit digital-to-analogue converters (DACs). The phase angle reference counter repeatedly counts from 0 to 2π . When the reference angle reaches the current/voltage phase angle, the current/voltage-channel address counter is triggered, and the ROM starts to output a digital sine wave pattern. The DACs convert the digital pattern into analogue signal.

At 60Hz the phase angle resolution is approximately $1\mu\text{rad}$, and the amplitudes of i and v can be independently set between 0V and 15V by controlling the DC reference voltage supplied to another 16-bit DAC; this technique provides an amplitude resolution of approximately 0.228mV.

3.1.2 Voltage/transconductance amplifier: Precision power amplifiers are designed to boost the amplitudes and maintain the phase angle inherent in the SG's output signals [21–23]. Owing to the precise requirements for voltage and current phase angles, a linear amplification technique is utilised. Switch-mode conversion is not feasible, because it is difficult to compensate for the phase lag of its output filtering. A developed VA boosts the low-level voltage reference to the nominal test range of 0V – 300V RMS. A designed IA converts the current-reference voltage signal into the test current. The test current ranges from –10A to 10A. The designed bandwidth of these power amplifiers is 20kHz.

3.2 Programmable switching box

The PSB is mainly composed of several electromechanical relays. These relays can connect the PCGS, TUTs and the DMM following commands from the computer. Hence, it directs the power path from the PCG to the TUT and transmits the transducer output to the DMM. Ten selectable channels are built into this PSB.

3.3 Digital multimeter

The DMM reads the DC output of the testing transducer and relays it to the PC. A high-precision $7\frac{1}{2}$ -digit multimeter is used. The accuracy is $\pm (20 \text{ parts per million } R + 2 \text{ parts per million } FS)$ at $23^\circ\text{C} \pm 1^\circ\text{C}$ with a temperature coefficient of 12 parts per million/ $^\circ\text{C}$.

3.4 IEEE-488 interface

Data transmission between the PC, DMM, PSB, VAs, IAs and SGs is through an IEEE-488 connection.

3.5 Personal computer

The PC is the 'brain' of the CAACS. All the system operations are controlled by PC. It sends specified V/I phase angle and amplitude to power condition generators. The generated testing power condition is fed to the TUT through the PSB. Channel selection inside the PSB is controlled by the PC through the user interface. Transducer output is also routed through the PSB to the DMM. The DMM delays its receiving action for several seconds until the TUT output has stabilised. The length of this delay depends on transducer performance and is supplied by the PC. The PC receives the DMM output and compares it with the transducer specification that is stored in a PC database file in advance.

4 Software system design

This software was developed with three goals: to automate the calibration procedure; to be user friendly; and to produce and manage calibration results. The software configuration and the kernel programs controlling all the system operations are described as follows:

The software configuration, as illustrated in Fig. 3, consists of two levels: the system level and the application level. At the application level, a control kernel composed of a user menu and a procedure control program has been developed. These programs are specifically designed to facilitate the calibration of power transducers.

Fig. 3 Software configuration

The user menu program is written in Turbo Vision Pascal with object-oriented programming construction. It is designed for users who are either familiar with or totally fresh to computer operations. A mouse or keyboard can be used as the input device. Pop-up windows with various dialogue boxes are used to customise the calibration process.

The procedure control program controls the system operation sequence. It is written in Microsoft C. A simplified flowchart describing the control procedure is shown in Fig. 4. If self-calibration is required, the operator connects a null channel of the PSB and performs self-calibration using the normal calibration procedure. After that, the operator inputs other necessary routine data about this test work and chooses the method of calibration: single point, equally spaced multiple points, or fixed increments from zero to full scale.

Self-calibration is used to minimise inaccuracies originating in the calibration system itself owing to ageing, temperature etc. It is optional before each calibration process. After that, the whole procedure is controlled by the PC via the screen interfacing with users. The specification data for testing transducers are required in advance. Channel selection inside the PSB for each transducer to be tested has to be specified. Then the PC sends the testing command to the power condition generator. The SG and VA/IA produce and amplify testing sinusoidal V/I signals, respectively. The generated testing power condition is fed to the TUT through the channel in the PSB. Transducer output is also routed through the PSB to the DMM. The multimeter delays its receiving action for several seconds until the transducer output has stabilised. The duration of the wait is determined by the PC. It depends on the transducer type and performance. The PC receives the DMM reading and compares it with the transducer specification. If the mismatch lies beyond the tolerance range,

the transducer parameters are adjusted. The process is repeated until the mismatch becomes small enough. If necessary, this process is repeated for other calibration points. For other transducers connected to the PSB, the whole procedure is applied to them, one by one.

Fig. 4 Simplified flowchart of system operations

Fig. 5 Transducer calibration results

—○— voltage transducer
 - - -○- current transducer
 —×— PF transducer
 - - -×- watt transducer
 —•— VA transducer

5 Experiments and results

The objective of this Section is to illustrate how to set up a testing condition and to demonstrate the effectiveness of this calibration system. Inside the CAACS, each of three PCGs can work independently. One- or three phase power transducers can be calibrated by co-ordinating the PCGs. In all testing conditions, the single-phase voltage is 120V RMS and the current range is from -5A to +5A.

Table 1: Transducer specifications

Transducer name	Type	Specification	Tolerance limits
VAr	FPK-211	input : 120V 5A 60Hz output : 0~±1mA DC/ 0~±1500W	±0.2%RO/PF+0.05%RO
Watt	FPW-211	input : 120V 5A 60Hz output : 0~±1mA DC/ 0~±1500W	±0.2%RO/PF+0.05%RO
Voltage	FPVX	input : AC 0~150A output : 4~20mA DC	±0.2%RO
Current	FPAX	input : AC 0~5A output : 4~20mA DC	±0.2%RO
Power factor	FPPF	input : 120V 5A 60Hz output : 4~12~20mA DC/ -1.0-0~+1.0	±0.25%FS±0.3

Five transducers of different types, including voltage, current, watt, VAr and power factor transducers, are tested in the CAACS. Table 1 shows their specification data. The calibration results in graphical form are presented in Fig. 5. Each transducer output curve is inside the specific tolerance error band specified in Table 1.

The uncertainty of the CAACS mainly comes from the PCGs. ADCs inside the SG may have nonlinear error, offset displacement error, gain displacement error etc. The power amplifiers may suffer profile distortion and phase inaccuracy. With special design and implementation considerations for those points, the uncertainty of this system is kept within 200 parts per million.

6 Conclusions

A computer-aided automatic calibration system has been developed for the instrument calibration department of the Taiwan Power Company. It is specially designed for the use of power utilities. With the computer-aided automation, a large portion of the original calibration work load is transferred to this system. One- or three-phase power transducers can be calibrated using this system. The experimental tests give satisfactory results and illustrate the effectiveness of the developed system.

The main features of this system are its user-friendly interface and its capability to calibrate ten transducers using only one set-up. This system demonstrates how a computer-aided system can be used to promote quality and efficiency and reduce the work load of a calibration department. The menu-driven software structure makes it easy to use. This reduces learning time and speeds the preparation of test procedures. The data-management capabilities of this software make this a complete system for preparing procedures, calibrating and managing the results.

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8 References

- INOUE, T., YAMAMURA, K., and ENDO, M.: 'Automatic calibration system for a laser power meter', *IEEE Trans.*, 1985, **IM-34**, pp. 431-436
- LENTNER, K.J., and FLACH, D.R.: 'An automatic system for AC/DC calibration', *IEEE Trans.*, 1983, **IM-32**, pp. 51-56
- BETHEA, M.D., and ROSENTHAL, B.N.: 'An automated thermocouple calibration system', *IEEE Trans.*, 1992, **IM-5**, pp. 702-706
- OLDHAM, N.M., PARKER, M.E., and SMITH, A.G.: 'A high-accuracy 10Hz - 1MHz automatic AC voltage calibration system', *IEEE Trans.*, 1987, **IM-36**, pp. 883-887
- SO, E.: 'A microprocessor-controlled current-comparator-based DC voltage calibrator', *IEEE Trans.*, 1987, **IM-36**, pp. 291-295
- TSAO, S.H.: 'Microcomputer-based calibration systems for variable voltage dividers', *IEEE Trans.*, 1983, **IM-32**, pp. 169-173
- SMITH, J.A., and KATZMANN, F.L.: 'Computer-aided DMM calibration software with enhanced AC precision', *IEEE Trans.*, 1987, **IM-36**, pp. 888-893
- RINGEARD, D., and MALOEUVRE, M.: 'CALIBRATE: a software for control and calibration of electronic measurement devices', *IEEE Trans.*, 1988, **IM-37**, pp. 497-500
- WOODS, D.: 'Simplified calibration technique for general six-port reflectometer requiring only two coaxial airline standard', *IEEE Proc. A*, 1983, **130**, (5), pp. 250-253
- CLOTHIER, W.K., and MEDINA, L.: 'The absolute calibration of voltage transformers', *Proc. IEE*, 1957, **104A**, (15), pp. 204-214
- BETTS, P.J., CLOTHIER, W.K., and SMITH, H.A.: 'Method for the absolute calibration of current transformers', *IEE Proc. A*, 1982, **129**, (5), pp. 322-327
- FIANDER, J.R., and SMITH, A.S.: 'Voltage-transformer testing-set calibrator', *Proc. IEE*, 1975, **122**, (6), pp. 675-680
- BESAG, E.: 'Calibration of a reference capacitor using general-purpose precision instruments', *Proc. IEE*, 1977, **124**, (9), pp. 833-836
- BETTS, P.J.: 'Two-stage current transformers in differential calibration circuits', *IEE Proc. A*, 1983, **130**, (6), pp. 324-328
- SMITH, F.C., CHAMBERS, B., and BENNETT, J.C.: 'Calibration techniques for free space reflection coefficient measurements', *IEE Proc. A*, 1992, **139**, (5), pp. 247-253
- OLDHAM, N.M., LAUG, O.B., and WALTRIP, B.C.: 'Digitally synthesized power calibration source', *IEEE Trans.*, 1987, **IM-36**, pp. 341-346
- OLDHAM, N.M.: 'Power calibration standard based on digitally synthesized sinewaves', *IEEE Trans.*, 1985, **PAS-104**, pp. 3117-3121
- OLDHAM, N.M. and TURGEL, R.S.: 'A power factor standard using digital waveform generation', *IEEE Trans.*, 1981, **PAS-100**, pp. 4435-4438
- VASTRADE, C., VRE, R.D., COUVREUR, M., and HUYBRECHTS, R.: 'Calibration of high accuracy wattmeters with a standard generator', *IEEE Trans.*, 1985, **IM-34**, pp. 220-223
- KINARD, J.R., and HARRIS, L.A.: 'Wattmeter calibration at zero power factor using digitally generated sinewaves', *IEEE Trans.*, 1976, **IM-25**, pp. 547-549
- TURGEL, R.S., and OLDHAM, N.M.: 'High-precision audio-frequency phase calibration standard', *IEEE Trans.*, 1978, **IM-27**, pp. 460-464
- LAUG, O.B.: 'A precision power amplifier for power/energy calibration application', *IEEE Trans.*, 1987, **IM-36**, pp. 994-1000
- LAUG, O.B.: 'A wide-band transconductance amplifier for current calibrations', *IEEE Trans.*, 1985, **IM-34**, pp. 639-643