



## Study on a Novel Fully Automatic Transformer Calibrator Overall Test Device

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May 8, 2019

# Study on a Novel Fully Automatic Transformer Calibrator Overall Test Device

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**Abstract**—The existing transformer calibrator has many problems such as, low accurate, poor stability, error interference of frequency conversion, small range of working circuit, etc., this paper focus on those problems, adopting adjustment technology of rectangular coordinate system and polar coordinate system, automatic measurement feedback technology with high accurate, designs an adoptable digital program-control standard signal source with two channels of phase and amplitude, realizing automatic feedback of phase and amplitude after the frequency and load changing, realizing the automatic verification and calibration of transformer calibrator and PT secondary drop test instrument. The device designed in this paper has already passed the test of third-party detection mechanism, all of the technical indexes and function meet the demand.

**Index Terms**-- transformer calibrator, transformer calibrator overall test device, measurement feedback, Fourier transform

## I. INTRODUCTION

Plenty of transformer calibrators are used widely on the transformer verification nowadays presently, which are the most important device to guarantee the accurate of meters [1],[2]. As required by implementing regulations of metrological law, all of those transformer calibrators must be periodic certificated [3]. Transformer calibrator overall test device made by domestic manufacturers still have many problems as below: (1) output of traditional transformer calibrator overall test device depends on manual operation, which is low efficient. (2) The traditional transformer calibrator overall test device doesn't have high accurate measure feedback and output regulation, it just depends on debugging of delivery test, which has poor stability and hard to test. (3) The traditional device adopts RC phase shift circuit to generate quadrature component, which means frequency

would affect the accurate of device. (4) RC phase shift can only work on the range of 20%-50% of work circuit voltage and current. (5) After JJF1619-2017 promulgated, both of PT secondary drop test instrument and electronic transformer calibrator do not have difference voltage and difference current which is necessary when being calibrated, so transformer calibrator overall test device based on difference-measured principle would have huge error when the amplitudes of ratio error and phase error are large than normal, especially the amplitudes of phase error is abnormal [4]-[6].

This paper in view of the problems above, design and develop the feedback circuit, signal generating circuit and control system of standard power source, achieving the goal of fully automatic verification and calibration of transformer calibrator and PT secondary drop test instrument.

## II. PRINCIPLE OF TRANSFORMER CALIBRATOR OVERALL TEST DEVICE

So far, there are three methods to achieve the overall test of transformer calibrators: standard proportion source method, standard comparison method and standard apparatus method [7].

Standard proportion source method is established by the measurement parameters of transformer calibrator, according to measurement characteristics of transformer calibrator. In this case, if the output parameters of this transformer calibrator overall test device is in the reasonable range, the accurate class and other indexes of which are reasonable, it can be treat as a standard equipment. There are three realization forms for standard proportion source method: electrical type, electron type, electrical- electron combined type [8,9]. Standard proportion source method of electrical type normally has the problem, which is difficult to make

voltage and current same phase, limited by output power. The existing problem of electron type is that, the operating voltage and difference voltage are both output by the same power amplifier, the operating current and difference current are both output by the same power amplifier, therefore, the load of power amplifier is heavy, increase the difficult of technology. The electrical- electron combined type usually does not have negative feedback system, the accurate, phase property and reliability of linearity need to be improved.

Standard comparison method adopts high accurate transformer calibrator, the four main measuring circuits of which compared with transformer calibrator, if the error of standard transformer calibrator can be ignored, the error of transformer calibrator is the indication difference of two instrument. This method requires a high quality of power resource, because the interaction between amplitude adjustment and phase adjustment of power resource is serious.

Standard apparatus method making the standard metrology appliance as a standard, does the overall test on transformer calibrator. This method is difficult to do the complete inspection for a measurement range, which can only test for some typical indication.

### III. KEY DESIGN TECHNIQUES

This paper designs a standard source of transformer calibrator overall test device with high accurate and high stability, which performs high accurate sample and feedback on output signal through 24 bits A/D and precise transformer. FPGA adopts Fourier transform to calculate the ratio difference and phase difference of real out, then feedback to microprocessor, regulating output to guarantee output and set value be consistent.

The main technology indexes and function:

(1) Between 10% to 100% operating range, accurate of the operating circuit is 0.05 class, accurate of the difference circuit is 0.1 class.

(2) The test range of ratio difference is 0.01% to 10%, phase difference is  $0.05'$  to  $500'$ , resistance is  $0.001 \Omega$  to  $1 \Omega$ , admittance is  $0.001 \text{ mS}$  to  $1 \text{ mS}$ .

(3) Resolution range of ratio difference is 0.00001%, phase difference is  $0.0001'$ , resistance is  $0.0001 \Omega$ , admittance is  $0.0001 \text{ mS}$ .

(4) Frequency range is 49.5 Hz to 50.5 Hz, harmonics output is 10% of amplitude range of fundamental harmonic, time of harmonics is 3rd to 11th.

(5) It can test the error, accurate of dialgauge, resolution, harmonics suppression, frequency influence, standard deviation, etc.

(6) It can overall test transformer calibrator and PT secondary drop test instrument automatically.

#### A. Vertificate all Kinds of Transformer Calibrator

Principle of transformer calibrator overall test device is shown as fig 1, which includes FPGA, 24 bits A/D, spinodal frequency conversion circuit, accurate voltage transformer,

accurate current transformer and conditioning circuit. The device simulates output signal of standard transformer in reality by digital computation and regulation to produce two channels of signals, which are standard voltage signal  $U_1$  and standard current signal  $I_1$ , to simulate the output signal of transformer and terminal voltage of PT secondary drop test instrument. By this way, we can test the traditional transformer calibrator and PT secondary drop test instrument by flexibly changing the output connection.

The output  $U_1$  ( $I_1$ ) realizes 0.01% degree measurement, by A/D sampling and calculating through conditioning circuit. The output  $U_4$  ( $I_4$ ) surplus  $U_3$  ( $I_3$ ) to make micro error signal  $\Delta U$  ( $\Delta I$ ), and then first amplifies the signal by program-control amplifier, second samples by A/D and calculates to realize the accurate measurement on 0.01% degree, which can supply 0.05 degree of standard signal, and 0.1degree of difference standard signal.

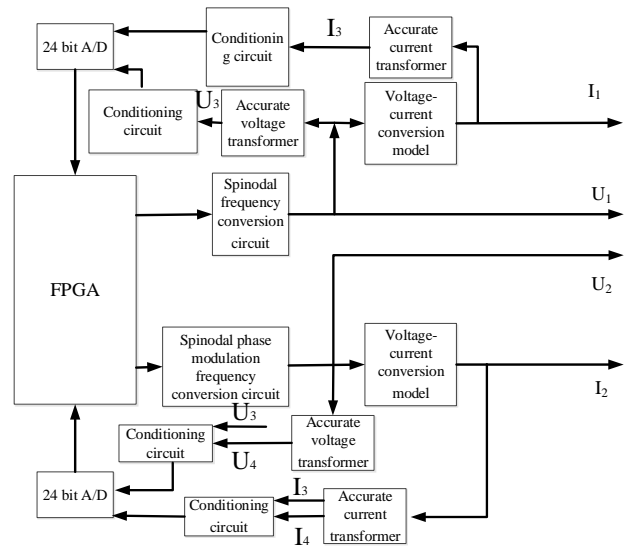


Figure 1. Principle of device

This instrument adopts the conversion between rectangular coordinate system and polar coordinate system to realize the certification of kinds of transformer calibrator. Rectangular coordinate system is used to certificate traditional transformer calibrator, polar coordinate system is used to calibrate wireless PT secondary drop test instrument [10].

#### B. Amplitude and Phase Adjustment Techniques with High Resolution

Presently, there are some problems in the application of accurate measurement by using 24 bits D/A convertor, which has the characteristics of high-stable, high-degree linearity and low-noise. This paper adopts 20 bits D/A convertor with type AD5791, resolution of ratio difference just meets the demand of design. The circuit in fig 2 is adopted to improve adjustment resolution, in which B (20 bits D/A) and E (20 bits D/A) are separately used to produce analog signal, respectively providing reference voltage of C (20 bits D/A) and F (20 bits D/A) with waveform superposition. FPGA produces wave data through parallel bus to C and F. Analog signal sum of C and F is an amplitude adjustable signal larger

than 24 bits, thus guarantee the phase adjustment resolution of signal source better than  $10^{-7}$ .

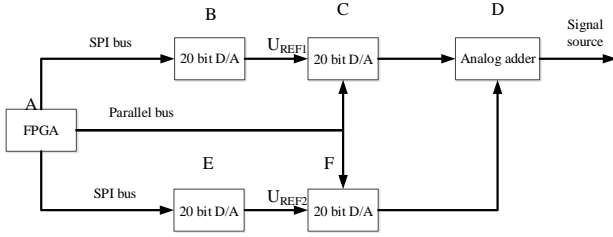


Figure 2. Principle amplitude modulation

This paper relies on the adjustment resolution of  $\Delta U$  and  $\Phi$  to make the adjustment resolution of phase difference better than 0.0001 realize.

Normally, phase difference production of two channel signals adopts phase dispersion controlling two ROM addresses and converting start time of D/A waveform. ROM of wave has the resolution with 6 in a cycle with 3 600 points. If the converting start time of D/A delays 0.3us, it would make resolution with 0.3. Under this situation, operation frequency of FPGA is 1000 MHz, 0.3 us delay is realizable, and then the phase difference resolution better than 0.0001 can be realized by adjusting resolution of  $\Delta U$ .

If the converting start time resolution of D/A controlled by FPGA achieves 10 ns, the clock jitter of FPGA will be hundreds of femto-seconds which leads to D/A converting response time problems. By adopting phase modulation principle, resolution can be improved.

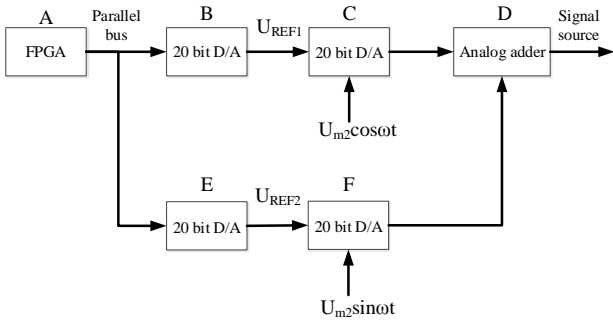


Figure 3. Principle of phase modulation

Assume the equation of second standard signal is shown as below:

$$U_2 = U_{m2} \cos(\omega t + \theta) \quad (5)$$

Expand trigonometric function:

$$U_2 = U_{m2} \cos \omega t + \cos \theta - U_{m2} \sin \omega t \sin \theta \quad (6)$$

Let  $A = \cos \theta$ ,  $B = -\sin \theta$ , put it into equation (6):

$$U_2 = AU_{m2} \cos \omega t + BU_{m2} \sin \omega t \quad (7)$$

Initial phase is:

$$\theta = \pi - \arctg(B / A) \quad (8)$$

A and B satisfy that:

$$A^2 + B^2 = 1 \quad (9)$$

So, high accurate resolution adjustable signal  $U_2$  can be achieved by accurately adjusting B ( $U_{REF1}$ ) and E ( $U_{REF2}$ ).

### C. Measurement Feedback Circuit with High Accurate

In order to guarantee the accurate of output signal, this paper adopts accurate voltage transformer and accurate current transformer both with 0.05 degree to convert and isolate the voltage. 24 bits conversion with ADS1278 is used to realize high accurate measurement with 0.005%. The error caused by waveform synthesis and signal amplification treatment can be compensated by measurement feedback technology. So the error of standard signal includes the error of accurate voltage transformer, accurate current transformer, programmable amplifier and A/D sampling, which guarantee the standard output signal meet 0.05 degree. The measurement part adopts self-calibration of amplitude and phase, together with high accurate digital instrument, solve the problem of low stability due to the electronic device drift under a long-term operation

### IV. ANALYSIS ON MEASUREMENT ERROR

The circuit of standard signal consists of accurate transformer, signal conditioning circuit, A/D, etc. this paper adopts measurement feedback circuit, therefore, the error caused by digital signal procession would not be considered in standard signal, thus the error of standard signal includes the error of accurate transformer, error of programmable amplifier and error of A/D sampling. The error theory analysis is shown as below.

The accurate voltage and current transformer adopted is 0.005 degree, which would bring with the measurement error:  $E_1=0.005\%$

Error of programmable difference signal:  $E_2=0.02\%$

Error of sampling resistance in current circuit:  $E_3=0.01\%$

Measurement error of 24 bits A/D chip, in the situation that do not consider the gain error:  $E_4=0.01\%$

In sum of above, those measurement errors are not correlative, the theoretical value of measurement error is:

Measurement error of standard  $U_1$  circuit:

$$E = \sqrt{E_1^2 + E_4^2} = 0.007\%$$

Measurement error of standard  $I_1$  circuit:

$$E = \sqrt{E_1^2 + E_3^2 + E_4^2} = 0.012\%$$

Measurement error of standard  $U_2$  circuit:

$$E = \sqrt{E_1^2 + E_2^2 + E_4^2} = 0.020\%$$

Measurement error of standard  $I_2$  circuit:

$$E = \sqrt{E_1^2 + E_2^2 + E_3^2 + E_4^2} = 0.020\%$$

From the equation above, it can be seen that, the biggest error brought by measurement system is 0.020%, satisfying the 0.05 degree of standard signal, and 0.1 degree of difference value between two standard signal.

## V. CONCLUSIONS

This paper develops a novel fully automatic transformer calibrator overall test device. This paper brings out innovations as follows compared with existing technology.

(1) Adopting technology of conversion between rectangular coordinate system and polar coordinate system, together with digital synthesis and condition, in order to solve the problem of additional error and nonlinear caused when phase error is big. The connection can be changed flexible to certificate traditional transformers and kinds of PT secondary drop test instrument. The error of measurement system is improved to 0.02%. It can also detect digital transformer calibrator.

(2) Adopting technology of amplitude and phase condition with high resolution, which can improve resolution of amplitude from 0.0001% to 0.00001%, improve resolution of phase from 0.001' to 0.0001'. At the same time, it solves the problem that the effect on phase caused by frequent through 90° phase shifter.

(3) Adopting technology of automatic measurement feedback technology to solve the problem of poor stability, low accuracy, poor adaptability, which achieves long-term accuracy better than 0.05%, guarantying the overall accuracy of 0.1%.

(4) The device can change frequent and harmonics output, it can do the test on resolution, harmonic suppression capability, and so on. It can certificate transformer calibrator in 10% to 100% operating range. These specifications exceed the requirements of existing standard.

## ACKNOWLEDGMENT

The authors gratefully acknowledge the contributions of Jiang Bo, Chen Zhongming and Zhu Chongye to the electric power industry.

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