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Converter Circuit «Voltage-Voltage» Investigation for Power Calibrator

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Abstract.The paper presents possible circuits to construct a voltage-voltage converter for the calibrator of fictitious power. The problems of circuit solutions were experimentally identified, and the ways of their elimination were found. One of the main problems of convectors is to provide small harmonic distortions and additional phase shift. The use of deep negative instantaneous value feedback helps to provide the desired level of nonlinear distortions and to reduce the phase shift. Corrective circuits are used to ensure the stability of the transducer at greater depths of the feedback; the half-period average value or rms value feedback is used to ensure the stability and accuracy of conversion. However, the accuracy of the power calibrator can be upgraded and its work for various types of loads can be ensured by means of application follower circuit with modern electronic components which are also discussed in the paper.

1.Introduction

Modern power calibrators and measuring system [1–4] comprise several main modules that perform various functions, such as generation of the reference signal, signal conversion, power amplification, etc. A simplified functional diagram of the power calibrator is shown in figure 1, and a complete diagram is considered by the authors in [5].

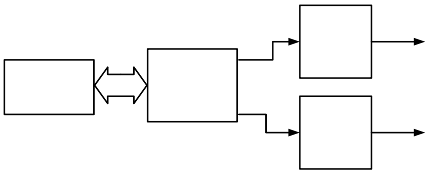

Figure 1. A simplified functional diagram of the fictitious power source.

A digital signal synthezer (DSS) generates two sinusoidal voltages with a given amplitude and phase. The required output power $P_{out} = U{\cdot}I{\cdot}\cos\varphi$ is provided by the "voltage-voltage" converter (VVC) and "voltage-current" converter (VCC). Precise setting of the required values of voltage amplitudes, current and the phase shift between them at the input of the converters is determined by the metrological characteristics of the DSG and can be currently achieved with a sufficiently high accuracy (accuracy within 0.02 ... 0.05 %), and increment in the phase shift can be provided in the range of 0.01° and a 0.02°. The calibration relative error of the power calibrator output power

$$\frac{\Delta P_{out}}{P_{out}} = \frac{\Delta U}{U} + \frac{\Delta I}{I} + \left[1 - \frac{\cos(\varphi \pm \Delta\varphi)}{\cos\varphi}\right]$$

is determined by the VVC conversion absolute error (ΔU), the VCC voltage-to-current conversion absolute error (ΔI) and additional phase shift ($\Delta\varphi$) caused by the converters.

In addition to these requirements, VVC and VCC should provide the required output power:

– for VVC, the rms voltage value is 250...260 V, and the required power is determined by the meter consumption equal to up to 10 VA according to GOST R-52323 [6], i.e. in group n meters verification $P_{out} > 10 \cdot n$VA;

– for VCC, the load is largely determined by the connecting wires and, as the experiment has shown, a voltage of 2...3 V is to be applied to the VCC output, i.e. for 60 A current, P_{out} = 120…180 W. According to the requirements in the standard [6], the permissible distortion of output signals and does not exceed 0.2 %.

Thus, the problems occurring during converter design are as follows:

– energy characteristics of the generated signals (voltage, current, power) are to be provided;

– adequate accuracy and stability of the conversion is required;

– small non-linear distortion and minimal additional phase shift of the generated signals is to be ensured.

In addition, for group calibration of the shunt static electricity meters, galvanic separation of current and voltage channels is to be considered. In this case, the output transformer is to be used in the VVC.

The stability and accuracy of conversion can be achieved using the half-period average value or rms value feedback, however, instantaneous value deep negative feedback (NFB) is to be used to provide low distortion and additional phase shift. Another problem to be solved is the stability of the converter operation.

The paper considers several diagrams for VVC used in various measuring instruments, the diagrams for converters based on modern electronics are suggested.

2. Study of VVC diagrams

Figure 2 shows the structural VVC circuits used in power calibrators of the calibration setup "Vector".

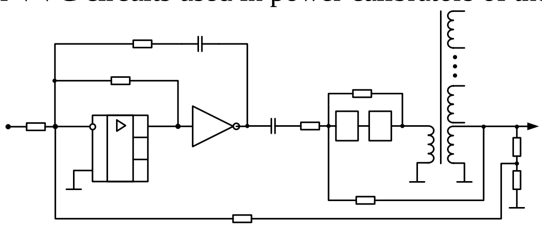

Figure 2. VVC circuits of the power calibrator "Vector".

A preamplifier with a transmission coefficient of the $K = 10$ is performed on DA_1. The positive feedback (PFB) is effected through inverter (1) and circuit elements (R_3, C_1). The voltage amplifier (VA) is designed on discrete elements and allows the output voltage of 60 V peak value. The power amplifier (PA), the follower in powerful field-effect transistors working in AB class provides power output of 100 VA. Deep voltage NFB for the VA and PA is obtained through R_4 and R_5 (DC negative feedback is 100%), which provides an insignificant zero offset at the PA output. TP_1 is a step-up output transformer which has a primary winding (W_1) and six output windings made of six bundled wires that ensure equal number of winding turns and the same transformer ratio relative to the primary winding, i.e.:

$$\frac{W_2}{W_1} = \frac{W_3}{W_1} = \ldots = \frac{W_7}{W_1} = 6 .$$

One of the output windings is connected to the common wire, and is used for local (R_4, R_6) and total (R_1, R_7, R_8, R_9) NFB. The use of this transformer can solve two problems:

– to get six galvanically isolated voltages with a given level of up to 360 V and permissible load capacity per each winding of up to 10 VA, the switching being made from the second (W_2) winding;

– to ensure the required metrological characteristics at all outputs under similar types of loading.

The required precision of the setup, stability, low distortion and small phase shift of the output voltage are provided by deep feedback. To increase the total FB depth, local positive FB is introduced in the preamplifier via inverter (1) and circuit elements (C_1, R_3).

To calculate the FB depth, we use a directed graph of the system (figure 3).

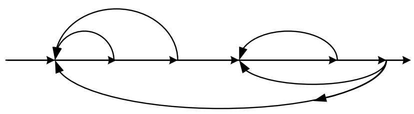

Figure 3. Directed graph of the VVC diagram of the power calibrator "Vector".

If we take the conventional values $\beta_1 = \beta_2$ and $\gamma_1 = 1$, $\gamma_2 = 1$, the VVC transmission coefficient will be determined by the expression:

$$K_{\mathrm{VVC}} = \frac{K_1 \cdot K_2 \cdot n}{1 + K_2 \cdot \beta_3 + K_2 \cdot \beta_4 \cdot n + K_1 \cdot K_2 \cdot \beta_5 \cdot \beta_6 \cdot n},$$

where K_1 is the transmission coefficient of the input operational amplifier.

When $K_1 = 10^4$, we get the following equality

$$K_{\mathrm{VVC}} \approx \frac{1}{\beta_5 \cdot \beta_6},$$

i.e. the accuracy and stability of K_{VVC} is determined by the resistors of the total feedback circuit. The feedback depth amounts to several thousand that allows for additional phase shift of less than 0.02 %.

For this feedback depth, when the loop includes the transformer and capacitive load, the problem of its stability is to be solved. In the research, different corrective circuits have been tested. Satisfactory results were obtained when using the circuit shown in figure 4 and gain and phase of this amplifier presented in figure 5.

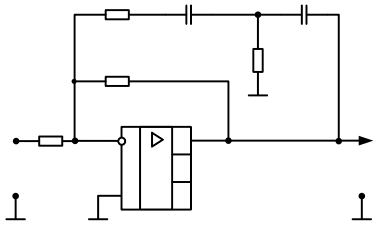

Figure 4. Example of the VVC corrective circuit.

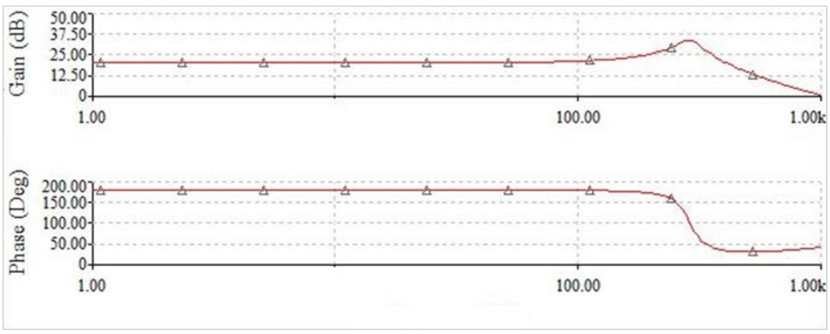

Figure 5. Gain and phase of the VVC corrective circuit.

From the graphs (figure 5), it can be seen that the amplifier operates in the frequency range of 45...65 Hz with an additional phase shift less than 0.02°. From 200 Hz, the phase shift decreases sharply by 150°. As frequency increases, the phase shift slowly grows, but the gain remains less than unity. This circuit design can be applied in the VVC input stage in the "Vector" calibrator (figure 2), and it provides stability of the system.

For group calibration of static meters, another problem has been revealed: the feed circuits of most static meters are made using half-wave rectification; therefore, the consumed current is pulsed. The input voltage circuits of the meters RIM 586.01 and SOEB-2PK/1 have been studied. Figure 6 shows the diagram of the consumed currents of the power sources for these meters.

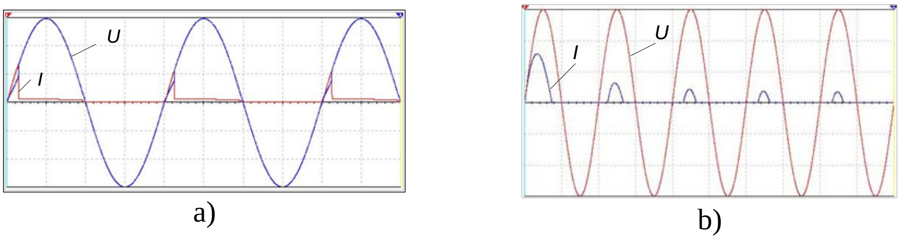

Figure 6. Diagrams of the consumed currents: IM 586.01 (a) and SOEB-PK2/1 (b).

As can be seen from the graphs (figure 6), the initial drain is several times higher than the steady-state value, which leads to protection operation or causes excitement. To avoid these problems, the slew rate of the input and, consequently, the VVC output voltage were reduced programmatically.

3. Implementation of VVC on state of the art electronic components (transformerless VVC)

Increase in the operating frequency band for VVC and VCC up to 0.5...2 kHz is required to determine additional error of the meter caused by a number of different factors (harmonics in the voltage and current circuits and subharmonics in AC circuits) according to the requirements in GOST R-52323 [6]. To solve the problem for VVC, the output step-up transformer is to be excluded from the circuit.

A number of currently produced high voltage op amps provide permissible voltage of ±(400...450) V, for example, PA89 [7], PA91 [8], PA93 [9], PA94 [10] and PA97 [11]. These op amps can be used to make transformerless VVC, but unfortunately, the output power of the op amp is not sufficient to carry out group verification of meters, i.e. a powerful follower is required. The task is complicated by lack of powerful field-effect transistors with a p-type channel (as well as p-n-p-type bipolar transistors) for permissible voltage of U_{DS} = 800…900 V. The designers have to find the solution using transistors IRF740 [12] with n-type channel only. Figure 7 shows one of the alternatives of this solution.

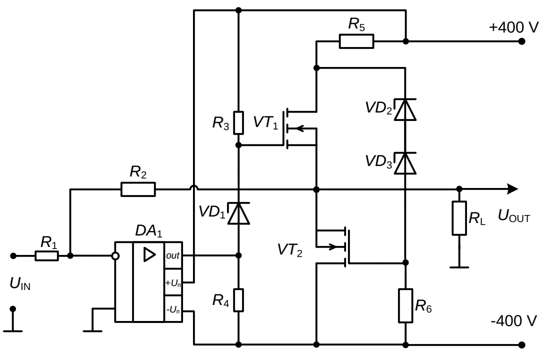

Figure 7. Circuits of the follower on single-type field-effect transistors with n-type channel.

The follower shown in figure 7 is a circuit with controlled dynamic load. The transmission coefficient of the follower is

$$K = \frac{R_L \cdot S_1 \cdot (1 + S_1 \cdot R_5)}{1 + R_L \cdot S_1 \cdot (1 + S_2 \cdot R_5)}$$

where S_1, and S_2 are the slope of the VT_1 and VT_2 transistors.

The condition of the push-pull circuit is $R_5 = 1/S_2$. In practice, the resistance R_5 is to be increased by 2...3 times to compensate for the voltage drop across the dynamic resistance of the stabilitrons VD_2 and VD_3. The studies have shown that this VVC performs well for the capacitive load as well. The disadvantage is that this follower works in class A only, hence, the efficiency = 38...45 %.

Another possible option is to make a follower on transistors of different types via series connection of two transistors IRFU 9310 [13] to p-type channel to provide allowable voltage U_{DS}. Figure 8 shows a diagram of this follower.

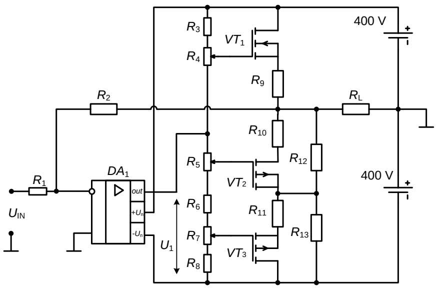

Figure 8. Circuits of the follower on different types of field-effect transistors.

Setting conditions $(R_3 + R_4) = (R_5 + R_6 + R_7 + R_8)$ and $(R_5 + R_6) = (R_7 + R_8)$ provide the voltage supplied to the VT_3 gate equal to $½ \cdot U_1$. In addition, half of the output voltage is to be supplied to the VT_3 source, which is carried out via the divider $R_{12} = R_{13}$. In order not to lose the power, high resistance is chosen.

The study of the circuit (figure 8) showed that it works well in class "AB" for active and capacitive load and is stable for standard op amp corrective circuits. Its setting is to be started with the follower, i.e. equal primary currents of the transistors are set with potentiometers, and then the op amp is connected and the overall feedback is closed. Figure 9 shows the gain and phase of this VVC for 40 gain and active-capacitive load (1 Ohm, 4 μf).

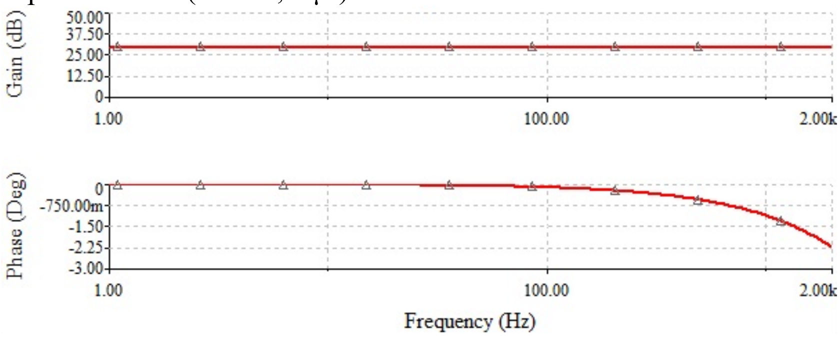

Figure 9. VVC gain and phase with active-capacitive load.

The graphs indicate that an additional phase shift up to 100 Hz is insufficient. Increase in the phase shift at higher frequencies (–2.25 degrees at 2 kHz) has a negligible effect on the overall measurement error.

It can be concluded that for group verification of static meters with this VVC design, a transformer is to be used (that is, galvanic decoupling unit); however, in this case, it is not included in the feedback loop and does not affect the system stability.

4. Conclusion

Testing of the above VVC diagrams used in various devices which require high output voltage (hundreds of volts), for example, power calibrators revealed different problems:

- additional phase shift when expanding the operating frequency;
- the stability of the diagrams in terms of deep NFB.

These problems require search not only for circuit solutions, but new electronics.

The circuit of the VVC suggested by the authors in figures 7 and 8:

- allow for a small additional phase shift, and thus improve the calibrator accuracy class;
- allow exclusion of the output transformer from the loop of the overall FB, which increases the system stability;
- work effectively not only for active, but also for resistive-capacitive load, therefore, they can be used to verify different types of meters;
- the diagram in figure8 can work in class "AB", which increases the VVC efficiency.

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