Letter

Electronically Compensated Voltage Transformer with Capacitive Reference

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We propose two schemes for improving the performance of electromagnetic voltage transformers. The first uses a high gain amplifier in conjunction with a capacitive divider that serves as a reference. The second uses a unity gain amplifier. Simulation studies and experimental results are shown in order to validate the methods.

Keywords: error compensation, voltage transformer, amplifier

1. Introduction

An inductive voltage transformer (VT) is the principal voltage sensor in any power network. Its general behavior is specified in standards such as IEC-60044-2 with accuracy classes ranging from 0.1 to 1 for metering purposes. There is an interest in designing precision voltage transformer with very low errors. For this purpose two schemes using electronic amplifiers were suggested in Ref. (1), (2). One drawback with these approaches is the need for a second identical VT. Capacitive voltage transformers (CVTs), which are also used have a limitation of poor frequency response. A method of electronic compensation of a VT was proposed in Ref. (3), which requires four variables to be adjusted and cannot be used with capacitive VTs. It would be advantageous to develop a VT which can eliminate these drawbacks and yet have high accuracy. We propose two schemes for this purpose.

2. Electronically Compensated VT

Figure 1 shows a compensation scheme using a high gain amplifier with C_1, C_2 being the reference divider. Here VT is the voltage transformer, whose error is sought to be reduced by compensation and TX is a low voltage isolation transformer. Two terminals of similar polarity, say S_1 for the two transformers and one terminal of the burden are connected together, the other end of the burden being grounded. In the absence of the amplifier (A), the burden would be connected directly across the secondary terminal of VT, one end of which would be earthed. TX would be supplying essentially the same output current and consequently having the same terminal voltage V_{2T}. The terminal S_{2X} of TX is connected to the input of the inverting amplifier of gain A, whose output is connected to S_{2T} of VT. The voltage across the input terminal of the amplifier is equal to the difference in the voltage across the burden and the secondary voltage of TX, whose secondary is essentially on open-circuit, being connected to an amplifier of high input impedance.

The amplifier provides an output voltage which acts in series with the secondary terminal voltage of VT to develop the required voltage across burden with sufficiently large gain.

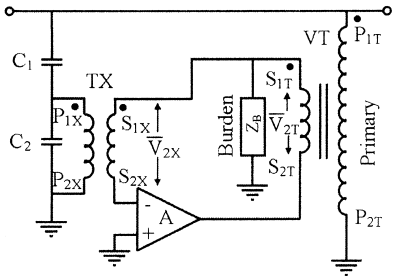

Fig. 1. Electronic error compensation for a VT using high gain amplifier

The output voltage of the amplifier gets adjusted in magnitude and phase position till burden potential approaches secondary voltage of TX, thus reducing the voltage error and phase displacement as viewed from the burden. In brief, since A is an ideal amplifier, it draws no current from the C_1, C_2 combination. Any errors in VT are corrected by an increased current from A making the error of VT small.

The second proposed scheme of voltage transformer compensation using an unity gain amplifier is shown in Fig. 2. Here two terminals of similar polarity say, S_{1X} and S_{1T} of TX and VT, and one terminal of the burden are connected together. S_{2T} is earthed, while S_{2X} is connected the input of voltage follower (VF-unity gain amplifier), whose output is connected to the other end of the burden.

In the absence of voltage follower, the burden would normally be directly across the terminal S_{1T}-S_{2T} and the voltage across it would posses considerable magnitude and phase error. These would vary with the value and nature of the burden. In Fig. 2 the voltage follower forces the voltage across the burden to assume a value equal to the open circuit voltage across C_2, independent of the value of burden, as long as the error voltage is compatible with the permissible output swing of the voltage follower. The secondary of TX is essentially open-circuited as the terminals S_{2X} is connected to the non-inverting input of the operational amplifier. Any errors in VT corrected are by an increased current from A making the error of VT small. The theory of error improvement due to the schemes are identical to those reported in Ref. (1), (2) and

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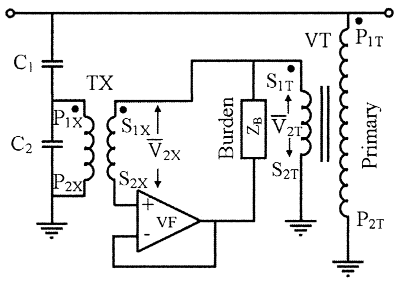

Fig. 2. Electronic error compensation for a VT using unity gain amplifier

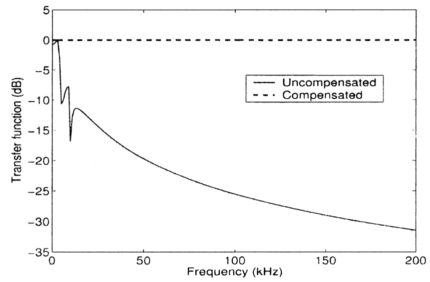

Fig. 3. Frequency response of voltage tranformer by simulation

Table 1. Simulation results at rated burden with unity gain amplifier (Ratio: 440/110 V single phase, Burden: 40 VA, Frequency: 50 Hz)

% Rated voltage	*Ratio error (%)*		*Phase error(min)*	
	Uncompen-sated	Compen-sated	Uncompen-sated	Compen-sated
120	-0.3985	0.000151	9.460	0.000414
100	-0.4008	0.000153	9.461	0.000420
80	-0.4035	0.000154	9.461	0.000423

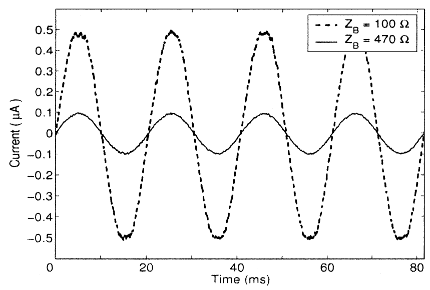

Fig. 4. Measured current through the voltage follower for scheme of Fig. 2

hence are not repeated. In both cases the amplifier supplies only the error power for the burden.

3. Validation of Scheme

We consider a 440/110 V, 40 VA VT. We initially consider a circuit simulation approach as the values of the equivalent circuit can be modeled explicitly and the error reduction theoretically established. The equivalent circuit of this VT, referred to the secondary has a resistance of 13.3 Ω, leakage inductance of 7.006 mH. The core is modeled using Jiles-Atherton model. The entire network of Fig. 2 was modeled in PSPICE software. With $C_1 = 1\,\mu$F, $C_2 = 3\,\mu$F and TX being an ideal 1 : 1 transformer and VF an ideal amplifier. The ratio and phase errors with and without the amplifier are shown in Table 1. It is evident that the proposed method can reduce errors.

4. Improved Frequency Response

In order to demonstrate the improved frequency response additional resonant elements are added to the model of the VT in the secondary (at frequencies of 5 kHz and 10 kHz). The voltage transfer function, (ratio of secondary voltage to primary voltage) are computed with and without the amplifier and shown in Fig. 3. The magnitudes are normalized such that maximum peak occurs at 0 dB. It is evident that the compensation improves the frequency response.

5. Experimental Validation

In order to experimentally validate the method a single stage low voltage amplifier and an electronic VT [4] was chosen for conceptual clarity. A VT with a secondary voltage of $1.625/\sqrt{3}$, turns ratio of 7 : 1, a capacitive divider with $C_1 = 1.67\,\mu$F, $C_2 = 10\,\mu$F and an amplifier using LF356 were designed, fabricated and tested as per Fig. 2. The current through the amplifier was measured using a P6257 Tektronix differential probe. Figure 4 shows the current through the amplifier for burdens of 110 Ω and 470 Ω respectively providing error improvement.

6. Discussion

Although the method was shown with the capacitive reference as an independent element, the method will equally work if the capacitive divider were part of the condenser bushing of the electromagnetic VT itself. This would result in a capacitive divider and voltage transformer as a single integral equipment†. Similarly, the method can be readily extended to a capacitive VT where the improved frequency response will be of use. Applications can be considered in GIS systems and medium voltage field where capacitive references are feasible.

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