Electrical Power and Energy Systems 99 (2018) 426–433

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Design of capacitive voltage divider for measuring ultrafast voltages☆

Uroš D. Kovačević[a], Koviljka Đ. Stanković[b], Nenad M. Kartalović[c], Boris B. Lončar[d,*]

[a] Faculty of Mechanical Engineering, University of Belgrade, 11000 Belgrade, Serbia
[b] Faculty of Electrical Engineering, University of Belgrade, 11000 Belgrade, Serbia
[c] Electrical Engineering Institutte Nikola Tesla, University of Belgrade, 11000 Belgrade, Serbia
[d] Faculty of Technology and Metallurgy, University of Belgrade, 11000 Belgrade, Serbia

ARTICLE INFO

Keywords:
Voltage divider
Fast pulse voltage
Ultrafast voltages
Measurement
Capacity
Inductivity

ABSTRACT

The aim of this paper is to consider and analyze design of capacitive voltage divider for measuring ultrafast voltage occurrence. Measuring pulse voltages by means of a capacitive divider in nanosecond range is affected by problems related to the construction of the divider and materials used. However, an appropriate constructive solution could minimize the budget of measuring uncertainty of the measurement pertaining to parasitic inductivity and capacitance. Consequently, the right selection of dielectric materials could offset the effects of high-voltage and low-voltage frequency characteristics of the capacitor. Four types of capacitive dividers have been constructed for the purpose of this paper. The high-voltage capacitor of each divider is a gas capacitor (intended to avoid both electrostatic and electrodynamic influence on measurement uncertainty). Ultrafast pulse response is measured by dividers constructed in this way, and compared with the corresponding response obtained from numerical simulations.

1. Introduction

For efficient coordination insulation at both high and low-voltage it is necessary to know the overvoltage (pulse voltages) in the network which is (are) usually of commutational or atmospheric origin. Appearance of overvoltage in the network is also a constant threat as a consequence of a nuclear explosion in the atmosphere. The characteristic time of the commutational origin of overvoltage is of ms rate while the atmospheric origin of overvoltage is of μs rate, and, it is of ns rate for nuclear explosion origin of overvoltage [1–4].

Compensated capacitive dividers are used most often for measuring fast pulse voltages. Capacitive dividers can be split into two groups: (1) dividers with concentrated parameters on the high-voltage side, and (2) dividers with spread parameters on the high-voltage side. Capacitive dividers with concentrated parameters on high-voltage side are considered in this paper.

These dividers consist of one capacitor of capacity C1 on the high-voltage side and the other of capacity C2 on the low-voltage side (Fig. 1a) Input voltage u1(t) and output voltage u2(t) are related by the coefficient k:

$$k = u_1/u_2 = (C_1 + C_2)/C_1 \tag{1}$$

Given that in the high-voltage and low-voltage branches of a capacitive divider parasitic resistances occur alongside with parasitic inductivities (Fig. 1b), the condition for transfer rate independence from frequency is reduced to the parity of high-voltage and low-voltage time constants. Therefore, the condition is:

$$C_2/C_1 = L_1/L_2 = R_1/R_2 \tag{2}$$

Depending on the divider's parameters certain relations between parameters play different roles. Condition given with Eq. (2) is difficult to meet when fast voltages are measured because a small value of inductivity of the low-voltage branch (i.e. small dimensions of low-voltage branch) is necessary.To get an acceptable response to the rectangular (or double exponential) pulse from the capacitive divider with unequal time constants, R_1 and R_2 are selected to secure voltage distribution – based on resistances and not inductivity – within the frequencies of the high-voltage and low-voltage branches. This can actually be achieved if $R_1 \geqslant 100\omega_r L_1$ and $R_2 \geqslant 100\omega_r L_2$, wherein ω_r denotes the frequency of voltage drops in high-voltage and low-voltage branches, and, consequently, dividing coefficient k is determined on the basis of capacitive and not inductive (parasitic) resistances. The smaller the difference between the frequencies of high-voltage and low-voltage branches, the lower the resistances of dividers. At equal frequencies, the dividing coefficient does not depend on frequency whenever resistors R_1 and R_2 are absent.

☆ This work is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia under contract no. 171007.
* Corresponding author.
E-mail addresses: ukovacevic@mas.bg.ac.rs (U.D. Kovačević), kstankovic@etf.bg.ac.rs (K.Đ. Stanković), nenad.kartal@ieent.org (N.M. Kartalović), bloncar@tmf.bg.ac.rs (B.B. Lončar).

https://doi.org/10.1016/j.ijepes.2018.01.030
Received 15 December 2017; Received in revised form 11 January 2018; Accepted 17 January 2018
0142-0615/ © 2018 Published by Elsevier Ltd.

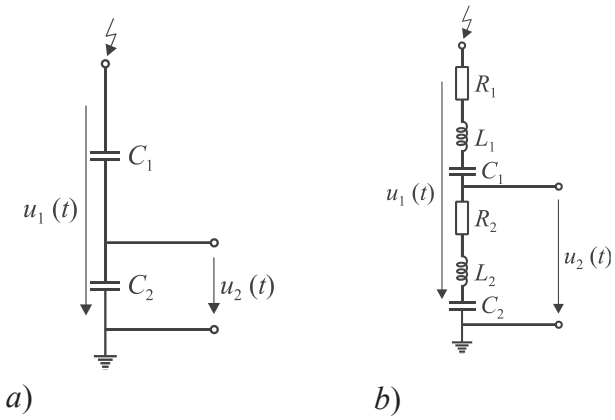

Fig. 1. Capacitive voltage divider: (a) with concentrated capacity in the high-voltage branch; k = u1 (t)/u2(t); (b) with its parasitic components.

Fig. 2. Photograph of the voltage divider housing.

Given that obtaining equal frequencies is impossible in practice, and that there is always a degree of resistance in the measuring circuit, the value of R_2 resistance is always final, but its impact could be compensated for by resistor R_1 (placed as a serial line item between the generator and high-voltage branch).

A compensational capacitive divider combined with an analog or a digital oscilloscope is usually used for measuring overvoltage [5]. In order for such measuring to be effective, i.e. to make its measuring uncertainty acceptable, the response time of all the components of the measuring system should be harmonized with the characteristic time of the generator [6]. That the dividing coefficient is frequency independent is of great importance, as is the absence of distortion in the measuring system's transfer of the measuring wave. Therefore, the measuring wave should reach the measuring spot without reflection and retraction, i.e. it should travel with no discontinuities of wave impedance. Available measuring instruments include reliable oscilloscopes for recording phenomena in GHz range (ns-range) but measuring overvoltage of ns characteristic time requires construction of a suitable divider with accompanying equipment. Therefore, in this paper different design solutions for the capacitive voltage divider for measuring overvoltage of μs and ns characteristic time are presented and assessed.

2. Construction of capacitive divider

In order to avoid unintended effects of electrostatic and electrodynamic forces, and partial discharges, a capacitor (calotte-calotte) SF6 under 5-bar pressure has been selected for the high-voltage capacitor. Four types of low-voltage capacitor have been used with the same high-voltage capacitor: Type 1 – gas trimmer capacitor with discrete 50 Ω adjustable resistance; Type 2 – plate-plate capacitor with dielectrics with electronic type of polarization with discrete 50 Ω adjustable resistance; Type 3 – calotte-calotte capacitor with different types of electronic polarization dielectrics, and waveguide 50 Ω adjustable resistance; Type 4 – parallel connection of several discrete capacitors with discrete 50 Ω adjustable resistance.

The housing of the capacitive divider is made of insulating material (sipas), 150 mm in diameter and 250 mm in height. Its inside is sleek while it is ribbed on the outside, Fig. 2.

The high-voltage capacitor has its upper electrode in the shape of a calotte, 150 mm in outer diameter and 110 mm in inner diameter. Its lower electrode is 78 mm in diameter on both its upper and lower sides, and it differs from type to type of the high-voltage capacitor. Both electrodes are made of aluminum. The electrodes of the low-voltage capacitor have no sharp edges and are polished (to reach high-gloss) to minimize the possibility of partial discharge.

The lower electrode of the high-voltage capacitor for Type 1 low-voltage capacitor is a full calotte while the upper electrode is represented by concentric circles engraved in the lower side of the low-voltage capacitor. The concentric engraving of the upper electrode of the low-voltage capacitor is matched with the engraved concentric circles in the lower electrode which has the form of a cylinder, with 78 mm in diameter and 10 mm in height.

The engraved concentric circles at the upper and lower electrode of the low-voltage capacitor match thus forming a series of connected parallel gas capacitors (trimmer capacitor). A BNC connector runs from the upper electrode of the low-voltage capacitor with a built-in 5 mm-long 50 Ω adjustable resistor (Fig. 3a).

The lower electrode of the high-voltage capacitor Type 2 has the shape of a full calotte. Its lower part acts as the upper electrode of the low-voltage capacitor. The lower electrode of the low-voltage capacitor is cylindrical with 78 mm in diameter and 100 mm in height. Mica is used as dielectric (Mica is used because it has unchangeable dielectric constant for frequencies bellow 10^{18} Hz [7]). Mica dielectric is cut out from a plate of pure mica. BNC connector runs from the upper electrode of the low-voltage capacitor and has a built-in 50 Ω adjustable resistor of 5 mm in length (Fig. 3b).

The lower electrode of the high-voltage capacitor for Type 3 low-voltage capacitor is a calotte with the outer diameter of 78 mm and inner diameter of 36 mm (made of aluminum).

The lower electrode of the low-voltage capacitor is cone shaped with the diameter of 36 mm, made of aluminum and placed in the cavity of the lower electrode of the high-voltage capacitor (Appendix). Low-voltage electrodes have the calotte-calotte configuration. The angles of the cone of the low-voltage electrode provide 50 Ω waveguide resistance. A dielectric of polyester resin is placed around the lower electrode of the low-voltage capacitor. The upper electrode of the low-voltage capacitor is wrapped in aluminum film. The polyester resin dielectrics are cast in a plaster mold to form the lower electrode. A BNC connector runs from the upper electrode of the low-voltage capacitor. A cross section of the voltage divider Type 3 is shown in Fig. 4.

Lower electrode of Type 4 high-voltage capacitor is full calotte with the low-voltage capacitor screwed onto it. The low-voltage capacitor Type 4 displays a connection of eight parallel mica capacitors. In the making of the low-voltage capacitor Type 4 particular care was taken to secure that the capacitors were parallel and compactly packed. Parallel

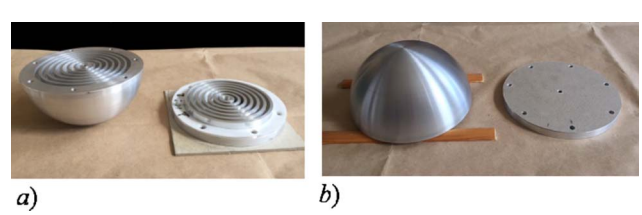

Fig. 3. Photo of the low-voltage capacitor: (a) Type 1, (b) Type 2.

Download English Version:

https://daneshyari.com/en/article/6859366

Download Persian Version:

https://daneshyari.com/article/6859366

Daneshyari.com