High Voltage Indicator with a Fiber-optic System

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Abstract – **Providing management of the power distribution grids and the equipment in the electric power system, in order to reduce the time of power outages in emergency situations, requires continuous monitoring for the presence of the respective voltage in certain points of the system.**

The work is dedicated to the development and research of a voltage indicator, designed for medium voltage grids, which is based on a sensor – voltage-to-light pulse frequency converter. The sensor gives a possibility for galvanic separation from the receiver on the basis of a fiber-optic system. This allows operation in a medium with strong electromagnetic interference, remoteness of the sensor from the receiver and additional including of a system for processing of the received result from the measurement.

Keywords – **high-voltage indication, fiber-optic systems.**

I. Introduction

The purpose of the present work is to be synthesized a device for high-voltage indication for work in grids over 1000V with a transmitter located next to the live parts under voltage and operating without the need of operational supply voltage and with a communication channel between the transmitting and the receiving parts based on a fiber optic line.

Different devices are known in the literature [1, 3, 4, 5], for indication of high voltage, which include capacitive divider, converter and indicator - a glyme lamp. Each of them has some advantages and disadvantages. In some cases disadvantages of these devices are the absence of galvanic isolation between the high voltage source and the indicator, low light indicator intensity and low selectivity at the presence of high level electromagnetic interference.

An example structure of such device for indication is shown in Fig.1, where:

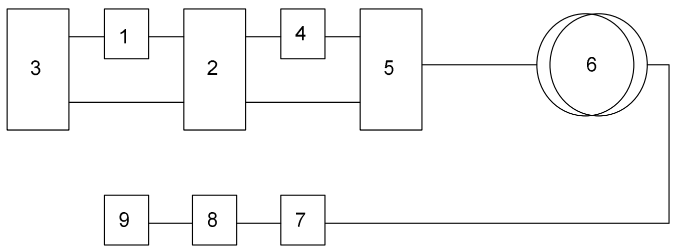

Fig.1 Schematic circuit of a device for measurement of high voltage on the base of a fiber-optic system

- 1 – ballast;
- 2 – rectifying section with accumulating capacitor;
- 3 – high voltage source;
- 4 – switching element with a fixed threshold of activation;
- 5 – emitting LED;
- 6 – fiber-optic line;
- 7 – photodiode converter;
- 8 – trigger expander;
- 9 – indicator.

The principle scheme of the transmitting part is shown in Fig.2:

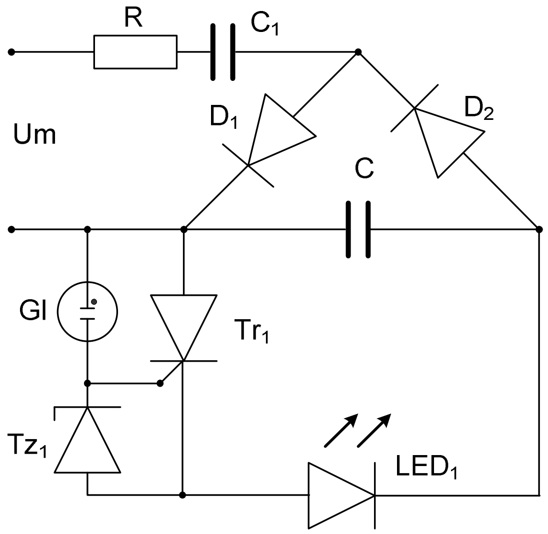

Fig.2. Principle scheme of the transmitter in a device for indication of high voltages

The transmitting part of high voltage indicator is a voltage to light pulse frequency converter. The frequency of the light pulses depends on the charging of the capacitor C to a voltage at which occurs a discharge in the glyme lamp Gl, triggering on the thyristor Tr_1 and forming a light pulse by the LED_1.

II. Experiments

In Fig.3 is shown the principle scheme of the voltage doubler.

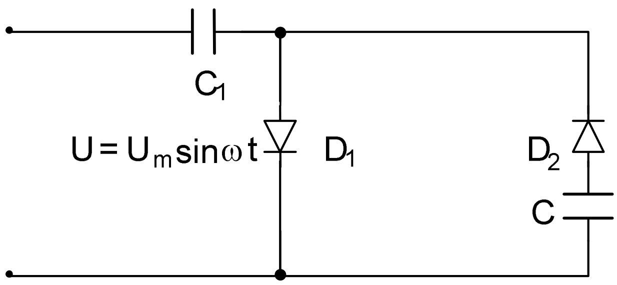

Fig.3 Principle scheme of a voltage doubler

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In Fig.4 is presented the time diagram of the voltage change in the capacitor C from Fig.3.

For a random moment in the n^{-th} pulse from the charging of C is valid Eq.1, [2]:

$$u_{Cn} + u_{C1n} = u = U_m \sin(\omega t + \varphi_n) \quad (1)$$

where: φ_n is dephasing of the moment of triggering on the diode.

After differentiation of Eq.1 is obtained Eq.2:

$$i_{3n} = C\frac{du_{Cn}}{dt} = C_1\frac{du_{C1n}}{dt} \quad (2)$$

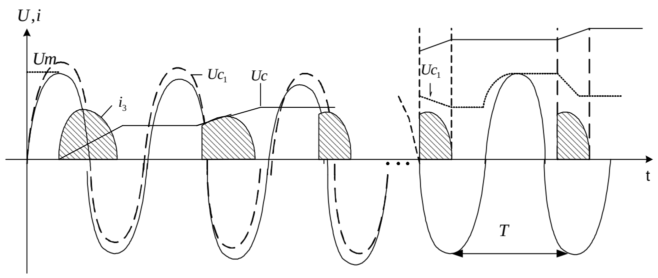

Fig.4. Time diagram of the voltage change of the capacitor C from Fig.3

Then, for the charge current through a triggered on diode D_2 is valid Eq.3:

$$i_{CHn} = U_m\omega\frac{C_1.C}{C_1+C}\cos(\omega t + \phi_n) \quad (3)$$

At the moment of triggering on the diode D_2 is valid:

$$|u_{Cn}(0)| - |u_{C1}(0)| = U_m \sin\varphi_n \quad (4)$$

At this moment $u_{C1n}(0) = U_m$, therefore:

$$u_{Cn}(0) - U_m = U_m \sin\varphi_n \quad (5)$$

from where:

$$\sin\varphi_n = \frac{u_{Cn}(0)}{U_m} - 1 \quad (6)$$

The voltage u_{Cn} at the moment of passing of the n^{-th} charge current pulse can be defined by Eq.7:

$$u_{Cn} = \frac{1}{C}\int i_{3n}dt = \frac{U_m C_1}{C_1+C}\sin(\omega t + \varphi_n) + K \quad (7)$$

Here, K is an integrating constant and is defined by the border conditions.

The charge current appears at $\omega t=0$ and vanishes at $\omega t+\varphi_n=\pi/2$.

$$\left.\begin{aligned} u_{Cn}(0) &= \frac{U_m C_1}{C_1+C}\sin\varphi_n + K \\ u_{Cn+1}(0) &= \frac{U_m C_1}{C_1+C} + K \end{aligned}\right\} \quad (8)$$

Replacing $\sin\varphi_n$ from Eq.6 in Eq.8, it can be found the increase of the voltage, to which C is charge in the n^{-th} interval of the charging process – Eq.9:

$$\Delta u_{Cn} = u_{Cn+1}(0) - u_{Cn}(0) = \frac{C_1}{C+C_1}[2U_m - u_{Cn}(0)] \quad (9)$$

After transformation of Eq.9 is obtained:

$$\frac{u_{Cn+1}(0)}{2U_m} = 1 - A\left[1 - \frac{u_{Cn}(0)}{2U_m}\right] \quad (10)$$

where: $A = \frac{C_1}{C}$. In this case:

$$\begin{aligned} \frac{u_{C2}(0)}{2U_m} &= 1-(A)^1 \\ \frac{u_{C3}(0)}{2U_m} &= 1-(A)^2 \\ \frac{u_{Cn}(0)}{2U_m} &= 1-(A)^{n-1} \end{aligned} \quad (11)$$

At a ration $C_1 : C \approx 1:1000$ the increase step of the voltage over the capacitor C - Δu_{Cn} for each period of the input supply voltage is constant and can be presented with Eq.12:

$$\Delta u_{Cn} = 2U_m\frac{C_1}{C} \quad (12)$$

At U_m=14 100V, the dependency $u_{Cn}(0) = f_1(t)$ is shown in Fig.5.

The amplitude of the charge current pulse can be defined by Eq.13:

$$I_{CHm} = U_m\omega\frac{C_1.C}{C_1+C} \quad (13)$$

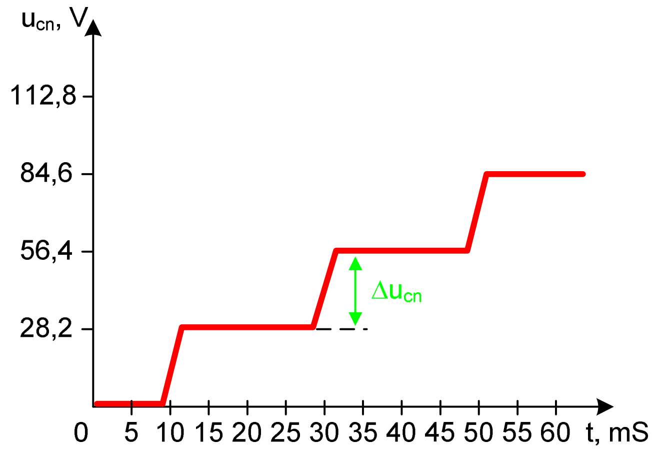

Fig.5. Change of $u_{Cn} = f_1(t)$ at $\Delta u_{Cn} = const$.

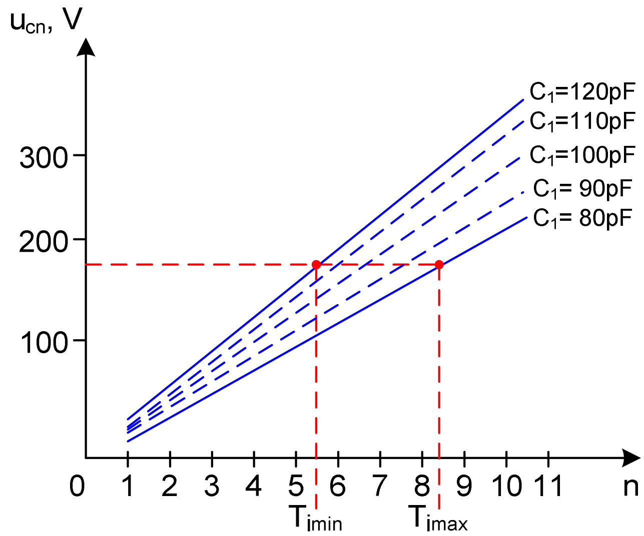

Fig.6. Change of $u_{Cn} = f_2(n)$ for C=100nF and U=10kV at a parameter C_1.

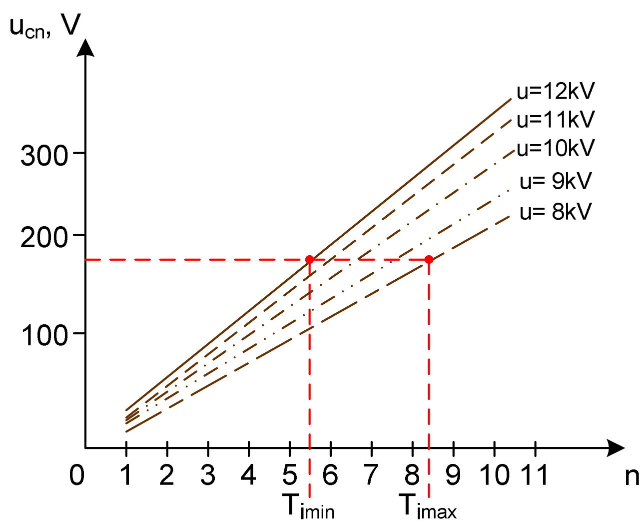

Fig.7. Change of $u_{Cn} = f_3(n)$ for C=100nF and C_1=100pF at a parameter U.

In the suggested analytical model [2] are not covered the differences in the charging process depending on which of the diodes D_1 or D_2 is triggered on during the first half wave of the charging process. It is also not considered the issue about the non-zero initial conditions for the charging process. For the proposed converter, representing the transmitting part of the high voltage indicator, the pointed limitations are not of significant matter, because at the formation of the light pulse the capacitor C (Fig.2) is discharged practically to 0V.

In Fig.8 is shown the connection of a high voltage transmitter and fiber optic line to a 20kV electric pole. This allows operation in a medium with strong electromagnetic interference, remoteness of the sensor from the receiver and safety for the operators. Here the transmitter operates without need of operational supply voltage, which is one of the advantages of the presented device.

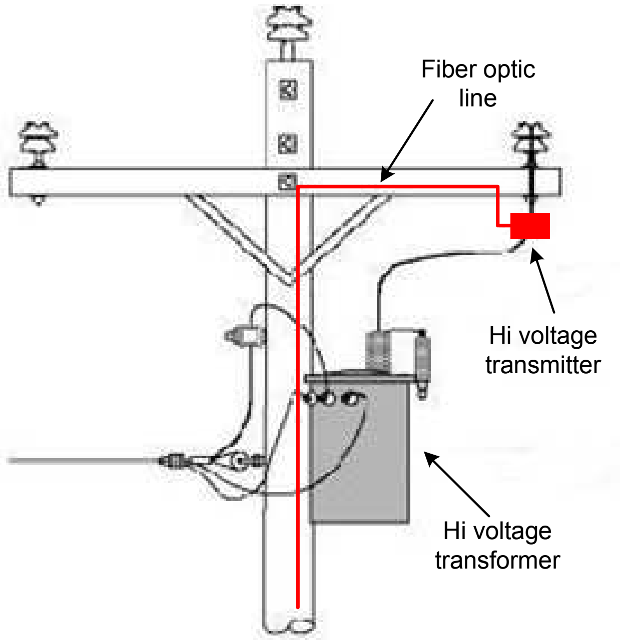

Fig.8. Connection of a high voltage transmitter and fiber optic line to a 20kV electric pole

III. Conclusion

From the conducted analysis can be summarized:

1. On the basis of the voltage-to-light pulses frequency converter from Fig.2 is possible the realization of devices for high voltage indication with a fiber-optic system with the following advantages:
   - A possibility for movement of the indicating part at a considerable distance;
   - Insensitivity to electromagnetic interference;
   - High level of the output signal.

2. Independently from the linear connection “amplitude of the input supply voltage – charge voltage of the

accumulating capacitor u_{cn}”, the application of the proposed converter for measurement of high voltages could be difficult because of the sudden increase of u_{Cn} for few milliseconds in the range of one period of the supply voltage - 20mS.

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