EXPERIMENTAL FILTER TESTS FOR AN INSULATION MONITORING DEVICE FOR IT SYSTEMS

Radi Tenev

Kardzhali Branch of the University of Mining and Geology „St. Ivan Rilski” - Sofia, raditenev@abv.bg

ABSTRACT. IT systems only work effectively with the availability of an insulation monitoring device in real time. The device is connected between the electrical network and the ground. The device's function is to disconnect the network when the insulation resistance drops bellow a preset value. This article discusses the topic of the explorations an insulation monitoring device where an active filter is attempted instead of a choke which attenuate the industrial frequency of 50 Hz. It has been measured and applied a diagram of the filter and the attached features illustrate its operation.

Keywords: insulation resistance, Sallen-Key filter

ЕКСПЕРИМЕНТАЛНИ ИЗСЛЕДВАНИЯ НА ФИЛТЪР ЗА АПАРАТ ЗА КОНТРОЛ НА ИЗОЛАЦИЯТА ЗА МРЕЖИ С ИЗОЛИРАН ЗВЕЗДЕН ЦЕНТЪР

Ради Тенев

Филиал Кърджали на Минно-геоложки университет„Св. Иван Рилски - София, raditenev@abv.bg

РЕЗЮМЕ. Мрежите с изолиран звезден център работят ефективно само при наличието на сигурно устройство за непрекъснат контрол на изолацията в реално време, включено между мрежа и земя. Устройството изключва мрежата при понижаване на изолационното съпротивление под предварително зададена стойност. Настоящата статия разглежда апарат за контрол на изолацията, където е направен опит вместо дросел да се използва активен филтър, който не пропуска промишлената честота от 50 Hz. Дадена е схема на филтъра, а приложените характеристики показват неговата работа.

Ключови думи: изолационно съпротивление, филтър на Сален и Кей

Introduction:

One of the types of insulation control devices that are used in our mining industry is the AZUR apparatus that is highly reliable and meets the requirements of standard 10880-83.

The principle of insulation monitoring is by passing a direct current from a voltage source and the circuit is closed over the ground and the insulation resistance R_F. The magnitude of this constant current is constantly monitored in the process as this is the parameter that informs about the state of R_F insulation resistance. Since the insulation monitoring device is switched on between the network that monitors and the ground, it should have a high resistance to the alternating current and a low resistance to the constant current carrying the information. This high resistance at the AZUR is achieved thanks to a choke-transformer connected to the three-phase network. The choke has high AC resistance and low for the direct current and filters the industrial frequency 50 Hz. If an insulation monitoring. device is implemented without an inductive filter, it will produce a significantly light and compact apparatus,which is significant advantage. The purpose of the study is to select a filter and to examine the parameters of the apparatus at work.

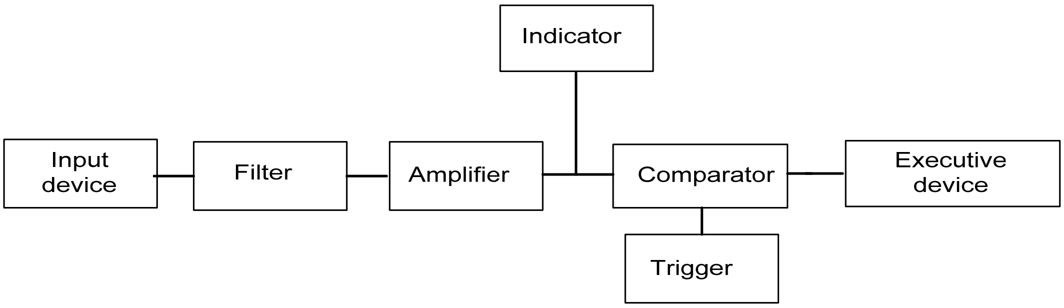

Fig. 1. Block diagram of the insulation control device

Input device:

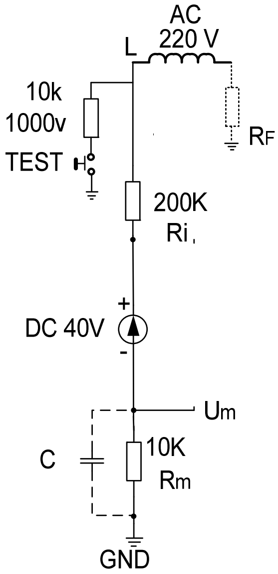

Fig. 2. Input device

The input device is powered by an operating voltage source of 40 V. The voltage source is connected to a 200 KΩ resistor to the mains and even to a ground resistance of 10 KΩ. The parameter which is monitored is taken from the resistor Rm. On the occurrence of an insulation fault the measuring circuit between system and earth closes via the insulation fault R_F, so that a DC measuring current Im proportionate to the insulation resistance results, in accordance with the following equation:

$$I_m = \frac{U_m}{R_i + R_m + R_F} \tag{1}$$

where:
Im - DC measuring current,
Um - DC measuring voltage,
Ri - Internal resistance of the insulation monitoring device,
Rm - Measuring resistance of the insulation monitoring device,
R_F - Total insulation resistance of the system.

The resistor Rm has two components, constant voltage and alternating voltage. In this case, the variable voltage is a harmful component that needs to be removed. An example: R_F=40000Ω. There are the following voltages on the Rm:

$$U_{m\sim} = \frac{220_{\sim}.10.10^3}{(200+10+40)10^3} = 8{,}8V \tag{2}$$

And for Um-is:

$$U_{m\text{-}} = \frac{40.10.10^3}{(200+10+40)10^3} = 1{,}6V \tag{3}$$

In this case Um~ should be filtered. This problem may be solved by using a suitable capacitor connected in parallel to Rm. As capacity increases, capacity resistance X_C decreases in accordance with the following equation:

$$X_c = \frac{1}{2\pi f C} \tag{4}$$

The time constant σ also increases:

$$\sigma = R.C \tag{5}$$

According to the BDS 10800-83, the trigger time must be 0,1s.[2]. But the increase in capacity reduces the speed of the apparatus, which is a requirement of BDS.

An active filter with operational amplifiers is used to filter the industrial frequency.

When the insulation resistance decreases, the current through Rm increases. If a graph is built, it is in the fourth quadrant. It is more convenient if the graph is in the first quadrant, when the insulation resistance decreases and the current or the voltage will also decrease. To achieve this, a divider of a resistor and a potentiometer is included parallel to the voltage source and the signal is taken from the divider. In this case, when Ri decreases, the measured current decreases. The potentiometer acts as a regulator for adjusting the level of the measured magnitude. Fig. 3 shows the input device finished.

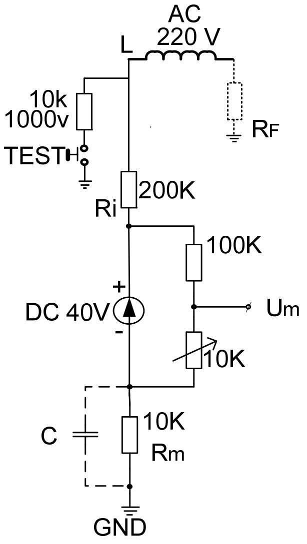

Fig. 3. The input device is complete

It performs the following functions:
1. Provides a high input impedance for the apparatus.
2. Changes the level of the characteristic for a more comfortable R_F measurement.
3. Equipped with a test button according to BDS.

Device filter:
Sallen-Key Law-Pass Filter

To find the circuit solution for this generalized circuit Fig.4, find the mathematical relationships between Ui, Uo, Up and Un, and construct a block diagram. KCL (Kirchhoff's current law) at Uf:

$$U_f\left(\frac{1}{Z1} + \frac{1}{Z2} + \frac{1}{Z4}\right) = U_i\left(\frac{1}{Z1}\right) + U_p\left(\frac{1}{Z2}\right) + U_0\left(\frac{1}{Z4}\right) \tag{6}$$

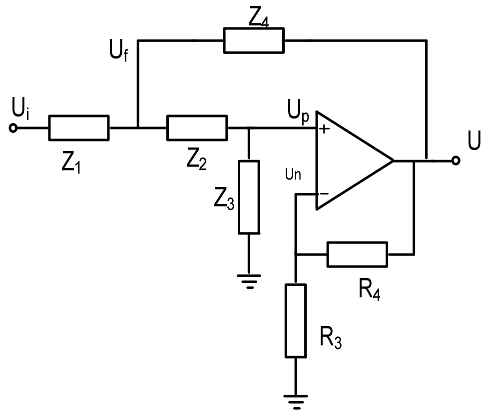

Fig. 4. GeneralizedSallen-Key Circuit

KCL at Up:

$$U_P\left(\frac{1}{Z2}+\frac{1}{Z3}\right)=U_f\left(\frac{1}{Z2}\right)\Rightarrow U_f=U_P\left(1+\frac{Z2}{Z3}\right) \tag{7}$$

Substitute Equation (7) into Equation (6) and solve for Up:

$$U_P=U_i\left(\frac{Z2Z3Z4}{Z2Z3Z4+Z1Z2Z4+Z1Z2Z3+Z2Z2Z4+Z2Z2Z1}\right)$$

$$+U_0\left(\frac{Z1Z2Z3}{Z2Z3Z4+Z1Z2Z4+Z1Z2Z3+Z2Z2Z4+Z2Z2Z1}\right) \tag{8}$$

KCL at Un:

$$U_n\left(\frac{1}{R3}+\frac{1}{R4}\right)=U_0\left(\frac{1}{R4}\right)\Rightarrow U_n=U_0\left(\frac{R3}{R3+R4}\right) \tag{9}$$

Gain Block Diagram Fig.4.:

By letting: a(f)= the open-loop gain of the amplifier,

$$b=\left(\frac{R3}{R3+R4}\right)$$

$$c=\frac{Z2Z3Z4}{Z2Z3Z4+Z1Z2Z4+Z1Z2Z3+Z2Z2Z4+Z2Z2Z1}$$

$$d=\frac{Z1Z2Z3}{Z2Z3Z4+Z1Z2Z4+Z1Z2Z3+Z2Z2Z4+Z2Z2Z1}$$

And Ue=Up-Un, the generalized Sallen- Key filter circuit is represented in gain-block form as shown in fig.5.

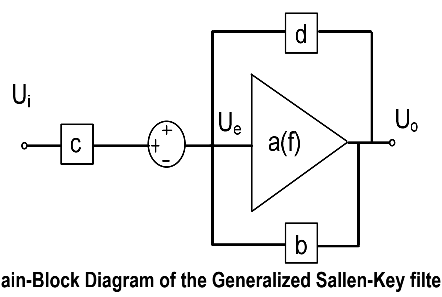

Fig. 5.Gain-Block Diagram of the Generalized Sallen-Key filter

From the gain block diagram the transfer function can be solved easily by observing, $U_0=a(f)U_e$ and$U_e=cU_i+dU_0-bU_0$ .Solving for the generalized transfer function on from gain block analysis gives:

$$\frac{U_0}{U_i}=\left(\frac{c}{b}\right)\left[\frac{1}{1+\frac{1}{a(f)b}-\frac{d}{b}}\right] \tag{10}$$

Ideal Transfer function

Assuming a(f)b is very large over the frequency of operation, $\frac{1}{a(f)b}\approx 0$, the ideal transfer function from gain block analysis becomes:

$$\frac{U_o}{U_i}=\left(\frac{c}{b}\right)\left[\frac{1}{1-\frac{d}{b}}\right] \tag{11}$$

By letting $\frac{1}{b}=K, c=\frac{N1}{D}$, and $d=\frac{N2}{D}$,where N1,N2 and D are the numerators and denominators shown above. The ideal equation can be rewritten as:

$\frac{U_0}{U_i}=\left[\frac{K}{\frac{D}{N1}-\frac{K.N2}{N1}}\right]$. Plugging in the generalized impedance terms gives the ideal transfer function with impedance terms.

$$\frac{U_0}{U_i}=\frac{K}{\frac{Z1Z2}{Z3Z4}+\frac{Z1}{Z3}+\frac{Z2}{Z3}+\frac{Z1(1-K)}{Z4}+1} \tag{12}$$

Low –Pass Circuit Fig.5

The standard frequency domain equation for a second order low-pass filter is:

$$H_{LP}=\frac{K}{-\left(\frac{f}{f_C}\right)^2+\frac{jf}{Qf_C}+1} \tag{13}$$

*Wh*ere fc is the corner frequency and Q is the quality factor. When f<< fc Ecuation (10) reduces to K, and the circuits passes signals multiplied by a gain factor K. When f=fc, Ecuation (13) reduces to –jKQ, and signals are enhanced by the factor Q. When f>> fc, ecuation (13) reduces to $-K\left(\frac{f_C}{f}\right)^2$ and signals are attenuated by the square of the frequency ratio. With attenuation at higher frequencies increasing by a power of 2, the formula describes a second order low-pass filter. Fig.6 shows the Sallen-Key circuit configuration for low-pass:

$Z1=R1,\ Z2=R2,\ Z3=\frac{1}{sC1}\ ,\ Z4=\frac{1}{sC2}$
and $K=1+\frac{R4}{R3}$

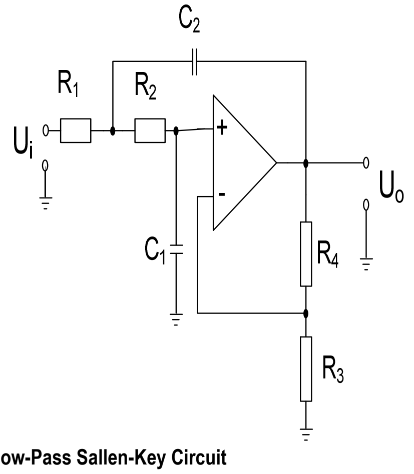

Fig. 6. Low-Pass Sallen-Key Circuit

From Equation (12), the ideal low-pass Sallen-Key transfer function is;

$$\frac{U_0}{U_i}(I_p)=\frac{K}{s^2(R1R2C1C2)+s\big(R1C1+R2C1+R1C2(1-K)\big)+1} \quad (14)$$

By letting $s=j2\pi f,\ f_c=\frac{1}{2\pi\sqrt{R1R2C1C2}}$, and $Q=\frac{\sqrt{R1R2C1C2}}{R1C1+R2C1+R1C2(1-K)}$.

Equation (14) follows the same form as Equation (13). With some simplifications, these equations can be dealt with efficiently: the following paragraphs discuss commonly used simplification methods.

Simplification 1:Set Filter Components as Ratios.

Letting $R1=mR, R2=R, C1=C,$ and $C2=nC,$ results in: $f_c=\frac{1}{2\pi RC\sqrt{mn}}$ and $Q=\frac{\sqrt{mn}}{m+1+mn(1-K)}$. This simplifies things somewhat, but there is interaction between fc and Q. Design should start by setting the gain and Q based on m, n, and K, and then selecting C and calculating R to set fc. Notice that $K=1+\frac{m+1}{mn}$ results in Q = ∞. With larger values, Q becomes negative, that is, the poles move into the right half of the s-plane and the circuit oscillates. Most filters require low Q values so this should rarely be a design issue.

Simplification 2:Set Filter Components as Ratios and Gain=1.

Letting R1=mR, R2=R, C1=C, C2=nC, and K=1 results in: $f_c=\frac{1}{2\pi RC\sqrt{mn}}$ and $Q=\frac{\sqrt{mn}}{m+1}$. This keeps gain=1 the pass band, but again there is interaction between fc and Q. Design should start by choosing the ratios m and n to set Q, and then selecting C and calculating R to set fc.

Simplification 3: Set Resistors as Ratios and Capacitors Equal.

Letting $R1=mR,\ R2=R,$ and $C1=C2=C,$ results in: $f_c=\frac{1}{2\pi RC\sqrt{m}}$ and $Q=\frac{\sqrt{m}}{1+2m-mk}$. The reason for setting the capacitors equal is the limited selection of values in comparison with resistors. There is interaction between setting fc and Q. Design should start with choosing m and K to set the gain and Q of the circuit and then choosing C calculating R to set fc.

Simplification 4: Set Filter Components Equal. Letting R1=R2=R, and C1=C2=C, results in: $f_c=\frac{1}{2\pi RC}$ and $=\frac{1}{3-K}$. Now fc and Q are independent of one another, the design is greatly simplified although limited. The gain of the circuit now determines Q. RC sets fc- the capacitor chosen and the resistor calculated. One minor drawback is that since the gain controls the Q of the circuit, further gain or attenuation may be necessary to achieve the desired signal gain in the pass band.

Values of K very close to 3 result in high Qs that are sensitive to variations in the values of R3 and R4. For instance, setting K=2,9 results in a nominal Q of 10. Worst case analysis with 1% resistors results in Q=16. Whereas, setting K=2 for a Q of 1, worst case analysis with 1% resistors results in Q=1,02. Resistor values where K=3 leads to Q=∞, and with larger values, Q becomes negative, the poles move into the right half of the s-plane, and the circuit oscillates. The most frequently designed filters require low Q values and this should rarely be a design issue.

Of the frequency characteristics, a Butterworth filter is selected whose characteristic in the bandwidth is too close to the uniform one, called the maximum flat. The slope of the transition section of the filter characteristic of Butterworth is equal to 6Db / oct per pole. There is a non-linear phase-frequency characteristic. The Butterworth filter is used in cases where it is desirable to have the same gain factor for all frequencies in the pass-band. Of the commonly used simplification methods, the forth is selected.

A filter unit is made with the following components.Fig.7.

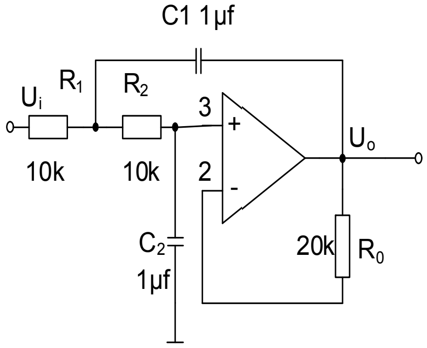

Fig. 7. Low-Pass Filter

With the components so selected, the following characteristics are obtained.

Transfer function $G(s)=\frac{10000,4}{s^2+199,996s+10000}$;
Cut of frequency fc=15,9154943 Hz;
Quality factor Q= 0,5000100002;
Damping ratio ξ=0,99998.

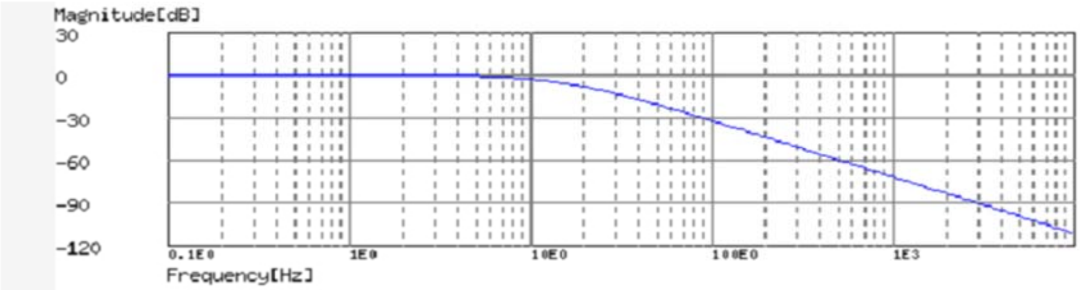

Fig. 8. Frequency response of the Low-Pass Filter

A second-order filter decreases at -12 dB per octave. Fig.8. shows the frequency response of the first filter. Each subsequent filter makes the slope of the frequency response steeper. The filter of the isolation monitoring device is three-stage. The IC LM 324 is used which consists of four operational amplifiers. The first two work as Low-Pass Filter. After the second OA follows a first order Low-Pass Filter. The third OA works as an amplifier and the fourth is a comparator. The potentiometer regulates the amplification of the DC signal.

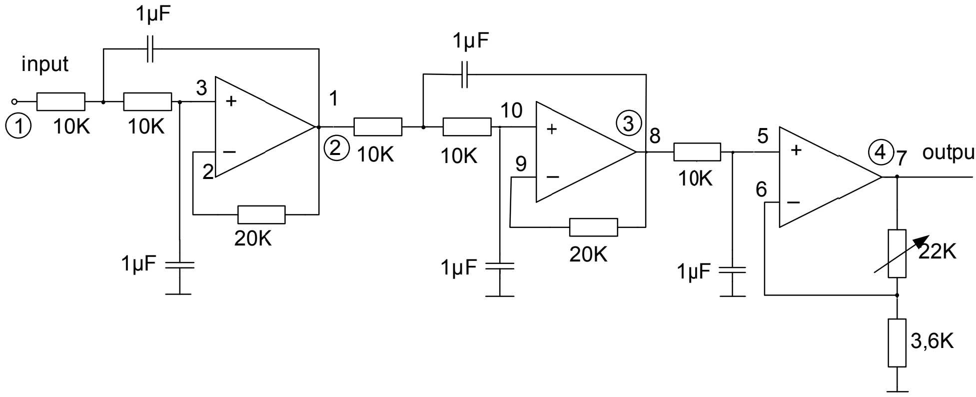

Fig. 9. Filter of the insulation control device. The measuring points are indicated

Experimental studies:

Illustrating the operation of the filter with appropriate oscillograms. A digital oscilloscope SIGLENT is used. The filter is made up of three units, see Fig.9. One unit is not enough to filter the variable component of 50 Hz. Channel 1 of the oscilloscope is connected to the input and channel 2 to the output of the unit. These are points 1and 2. of fig.9.Fig.10.is the oscillograme of the first filter unit. The second oscillogram shows the work of the first two units. Channel 1 is at point 1 and channel 2 at point 3.Fig.11. The next oscillogram, Fig.12 shows the operation of the filter and the amplifier. The ratio between input and output signal is 100 times which means that the AC signal is reduced 100 times. From the above example where U~=8,8V, U~ will be 0,088V at the output. Channel 1 is at point 1 and channel 2 at point 4, which is the output of the amplifier, and hence the signal goes once to the indicator and a second time to the comparator of the device. In addition, another oscillogram for the second unit, point 2 input and 3 output. Fig.13. It is clear that the phase shift between the input and the output signal is approximately 158^0.

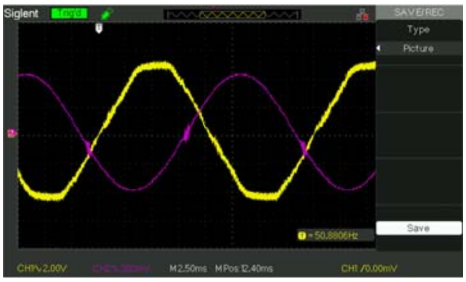

Fig. 10. The input and output signals of the first filter unit

Fig. 11. The input and output signals of the first and second filter units

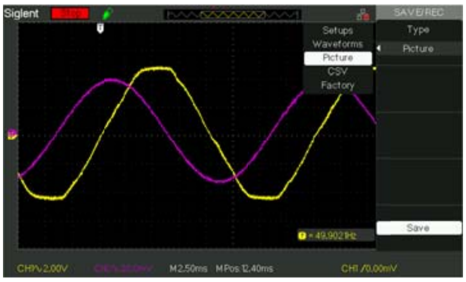

Fig. 12. Input and output signals for the entire filter

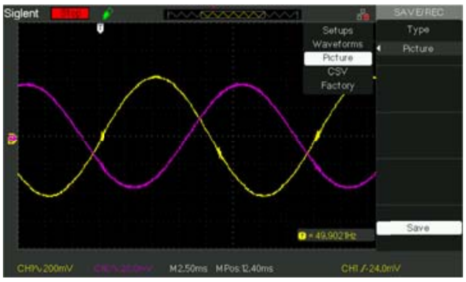

Fig. 13. Input and output signal of the second unit. The phase shift is158^0

Conclusion

The experiments were carried out with a real-made insulation monitoring device for voltage of 220 V. The results obtained show that the any inductive filter, such as a throttle, can be replaced by an active filter. Implementing active filters into Insulation Monitoring Devices will significantly reduce their mass and volume.

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