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Desgin of On-line Monitoring Device for MOA (Metal Oxide Arrestor) Based on FPGA and C8051F

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Abstract: Monitoring of metal oxide surge arresters (MOA) due to aging, moisture and other components cause increased resistive current. Through a lot of practices, it has been proved that in the early days, MOA insulation damage and current increase is not obvious. The accurate working conditions of the MOA are also not obvious but it can reflect the aging or moisture of MOA. When the resistive current of the fundamental component increases, there is no increment in the harmonic components that is the general performance of a serious or moisture contamination. In the same way when the resistive current of harmonic components increases, the fundamental component is not increased and it is the general performance of aging. Therefore, this paper designed an experiment-based FPGA and C8051F-line monitoring device. This device uses resistive current as a detection target. The main monitoring parameters are the fundamental and peak value of resistive current, third harmonic content of the leakage current, phase angle difference and power consumption. Through laboratory tests, the device can be used with a network arrester line monitoring, maintenance, reduce the economic losses caused by power outages and improve the distribution network reliability. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: (MOA) metal oxide surge arrester, On-line monitoring, FPGA, C8051F, Resistive current.

1. Introduction

The MOA with non-linear characteristics like the large flow capacity, no series gaps, small size, light weight and excellent features gradually replaced the traditional SiC arrester, so it is used in power plants, substations and transmission lines that can protect the equipments of electrical power system from over voltage. Its main role is to absorb over-voltage, operating the energy impact of over-voltage and prevent over-voltage substation to damage the electrical equipments. Under normal operating voltage, the current flowing through the arrester is few micro amps, when applied over-voltage the flow of current through the arrestor reached thousand of amps due to the non-linearity of zinc oxide varistor while surge arresters is in the conduction state [1-3]. The release of over-voltage energy, while limiting the amplitude, which badly violates the over-voltage power transmission equipment, after than we resumed the zinc oxide varistor in impedance state, so that the power system will back to normal operation. Due to continuous operating voltage arrester long-term effects, if the product has too high chargeability arrester beyond capacity, it will accelerate the aging of resistors, resistive current and subsequent increase in the power consumption that cause a crash, subsequent heat lightning breakdown or explosion. Internal moisture is caused by a lightning arrester which is important factor in accident.

According to the "preventive test code equipment DL/T-596-1996 provisions of China" [2] electricity distribution network detection system is used for preventive methods: light prevention trial period is one time in a year. There are large number of distribution arresters networks, each test consumes a lot of manpower, material resources and power outages but cannot control the light damage, so many departments have to run the test period 3 ~ 7 times in a year. In recent years, some research institutes and manufacturers launched an online monitoring system that monitor the total leakage current of MOA [4-6]. Some results show that in the early MOA insulation damage and there is not increment in the current value, it also not properly shows the working condition of MOA but it reflects the resistive current aging and moisture for MOA. The MOA is under the appropriate chargeability conditions like 10 % to 20 % of the total current, so we need to separate the resistive current from the total current in order to clearly understand its different behaviour.

In this paper, the status quo of China distribution network arrester monitoring system presents a FPGA and C8051F based on line monitoring device that monitor the distribution network of the arrester. The device uses resistive leakage current component as a detection object. By the lab experiments, we observe the operation of the online monitoring system fulfil the requirements of the arrester.

2. The Leakage Current of MOA

MOA leakage current monitoring main purpose is to monitor the MOA due to aging, moisture and other meritorious that causes increase in power consumption, heat and other parameters. The equivalent circuit of MOA is shown in Fig. 1.

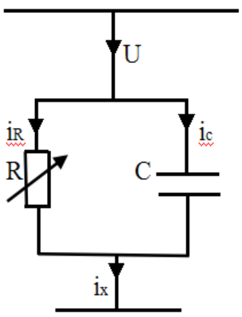

Fig. 1. The equivalent circuit of MOA.

In Fig. 1, R is the equivalent nonlinear resistance; C is a constant equivalent capacitance; i_R is resistive leakage current; i_c is capacitive leakage currents; i_x is the total leakage current; U is the operating voltage of MOA.

The main purpose of this modelling is to calculate the resistance of nonlinear resistor that is given in Fig. 1. The volt-ampere characteristics of MOA explain that the application of five polynomial fitting methods can create mathematical models for MOA under normal conditions. The equation for the resistive leakage current is given below:

$$i_R = 0.8756\,u^5 - 1.949\,u^4 + 1.601\,u^3 - 0.5401\,u^2 + 0.0894\,u \quad (1)$$

On the basis of above equation (1) and from the experimental data of [7] it has been proved that MOA aging is five times current polynomial fitting characteristics to calculate the equivalent resistance R during the nonlinear mathematical model. The equation for resistive leakage current during the MOA aging is given below:

$$i_R = 0.02082\,u^5 + 0.1108\,u^4 + 0.234721\,u^3 + 0.076\,u^2 + 0.0291\,u \quad (2)$$

On the basis of above Equations (1), (2) and by using MATLAB R2010B we can plot the average nonlinear voltage characteristics of MOA that is shown in Fig. 2. In Fig. 2, the u (u=U/UN, the unit is pu) is represents by vertical axis and i_R (resistive leakage current) is represents by horizontal axis. The results of the average nonlinear voltage characteristics for MOA are given below:

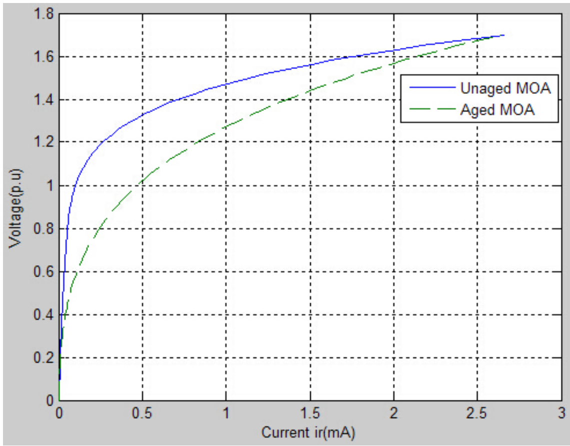

Fig. 2. The graph for MOA resistive current average voltage characteristic.

From Fig. 1, the value of i_x as follows:

$$i_x = i_R + i_c \quad (3)$$

We can set the grid voltage as follows:

$$u = U_1 \sin(\omega_1 t) + \sum U_n (t + \varphi_n) \quad \text{n=3, 5, 7} \quad (4)$$

$$i_c = i_{c1} + \sum i_{cn} \,, \tag{5}$$

where i_{c1} is the capacitive fundamental current and i_{cn} is the capacitive harmonic currents and these currents are created in the grain boundary capacitor of C by applying the fundamental and harmonic voltage. Because i_{5r} and i_{7r} are very small so ignore them. The values of i_R, i_r and i_{3r} can be calculated by the following equations:

$$i_R = i_r + i_{3r} \,, \tag{6}$$

$$i_r = i_r^{'} + i_r^{''} \,, \tag{7}$$

$$i_{3r} = i_{3r}^{'} + i_{3r}^{''} \,, \tag{8}$$

$i_r^{'}$ and $i_{3r}^{'}$ are obtained by the fundamental voltage that is applied to the resulting nonlinear resistor R. In the same way, $i_r^{''}$ and $i_{3r}^{''}$ are obtained by the harmonic voltage that is applied to the resulting nonlinear resistor R. $i_r^{'}$ and $i_{3r}^{'}$ can be used to judge the MOA's operating conditions, so it is very important for operating conditions of MOA.

We divided the resistive current in two parts that is given in Fig. 3. The R_0 and C_0 are the electrical parameters of MOA. The R and C are selected from the monitoring device.

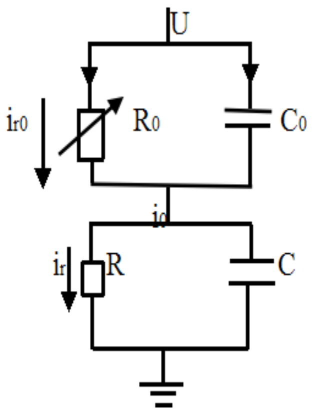

Fig. 3. Resistive current separation principle.

In Fig. 3, the frequency current flowing through the arrester is i_0, the resistive component i_{r0} and the current i_r flowing through a small resistor can be obtained:

$$i_{r0} = \frac{1/\,j\omega C_0}{R_0 + 1/\,j\omega C_0} i_0 = \frac{1}{1/\,j\omega R_0 C_0 + 1} i_0 \tag{9}$$

$$i_r = \frac{1/\,j\omega C}{R + 1/\,j\omega C} i_0 = \frac{1}{1/\,j\omega R\ C + 1} i_0 \tag{10}$$

The i_{r0} is the true resistive current and in this case its value should be calculated but the actual measured current is i_r, if $i_{r0} = i_r$, it means that $R_0 C_0 = RC$. The measured value of the current flowing through the resistive arresters has equal amplitude and same phase.

There is also need to determine whether there is a change in the access RC parallel branch after passing through the arrester leakage current and resistive components.

$$i_x = U\,(\,j\omega C_0 R_0 + 1)\,/\,R_0 \,, \tag{11}$$

$$i_0 = \frac{U\left(j\omega C_0 R_0 + 1\right)\left(j\omega CR + 1\right)}{j\omega R_0 R(C + C_0) + R + R_0}, \tag{12}$$

where i_x and i_0 both are the leakage currents as i_0 is connected to the RC branch but i_x is not. Because $R_0 C_0 = RC$, $R_0 >> R$, we can be know that $i_0^{'} \approx i_0$. There is very small change after accessing RC leakage current because the frequency equivalent impedance of MOA is greater then RC parallel impedance within a certain voltage range, as i_0 is substantially constant, so after accessing the RC circuit resistive current flowing through the arrester there will be a little change in the current that is flowing through the resistor R and it may be considered on the leakage current of the surge arrester that is the resistive component.

During the decline of the MOA characteristics, the initial resistive current changed but the whole current change is relatively small. At this point surge arresters electrical parameters remain unchanged. While R_0 becomes smaller but its frequency equivalent shunt impedance is still much larger than RC. i_0 basically unchanged.

After the MOA electrical parameters change, some parameters changed like $R_0^{'}$ and $C_0^{'}$, the current flowing through the MOA resistive component is i_{r1} and calculated value of i_r remains constant. The equations for calculating the i_{r1} and i_r are given below:

$$i_{r1} = \frac{1/\,j\omega C_0^{'}}{R_0^{'} + 1/\,j\omega C_0^{'}} i_0 = \frac{1}{j\omega R_0^{'} C_0^{'} + 1} i_0 \tag{13}$$

$$i_r = \frac{1/\,j\omega C_0}{R + 1/\,j\omega C} i_0 = \frac{1}{j\omega RC + 1} i_0 \tag{14}$$

The error exists and equation for this error is as following:

$$\Delta i_r = i_{r1} - i_r = \left(\frac{1}{j\omega R_0^{'} C_0^{'} + 1} - \frac{1}{j\omega RC + 1} \right) i_0 \quad (15)$$

Suppose normal detecting $i_r = i_{r0} = 0.1 i_0$, the parameter changed then set $i_{r0}^{'} = 0.2 i_0$, and the measured value $i_r^{'} = 0.1 i_0$. According to the above equation the error is $\Delta i_r = 0.1 i_0$ which is acceptable. During MOA critical aging, the leakage current will increase then the errors will also increase and this error is much low as compared to the full current detection method. Our main goal is to monitor the resistive current.

3. The Design of Arrester on Line Monitoring Device

For MOA automatic monitoring and testing equipment the budget is a main thing. In addition to the distribution network, some MOA are installed in more places. We also need some person who can give supply to self-test devices and timely inspect our system. So in this design i choose FGPA and C8051F to control external components and we also set up a power detection device charge section for monitoring patrol officers.

During normal operation the leakage current of 10 kV arrester is very small. When MOA insulation damage is not critical, the resistive current increases several times but there is not much increment in the full current and it can’t timely detect of an accident. Resistive current can be used to detect hidden arrester insulation, so the self-monitoring device uses resistive current as a detection target. We used some digital waveform analysis techniques like harmonic analysis and digital filtering software interference method that measure very accurate and stable results. It can also analyse the component of the fundamental and harmonic for 3~7 times, overcome interference and correctly measure the resistive current of arrester. You can also determine the resistive current percentage over total current and in this way you can judge the MOA’s initial operating conditions. The vertical comparison method can be used historical data to better reflect the operation of the tin oxide surge arresters. MOA-line monitoring device principle block diagram in Fig. 4.

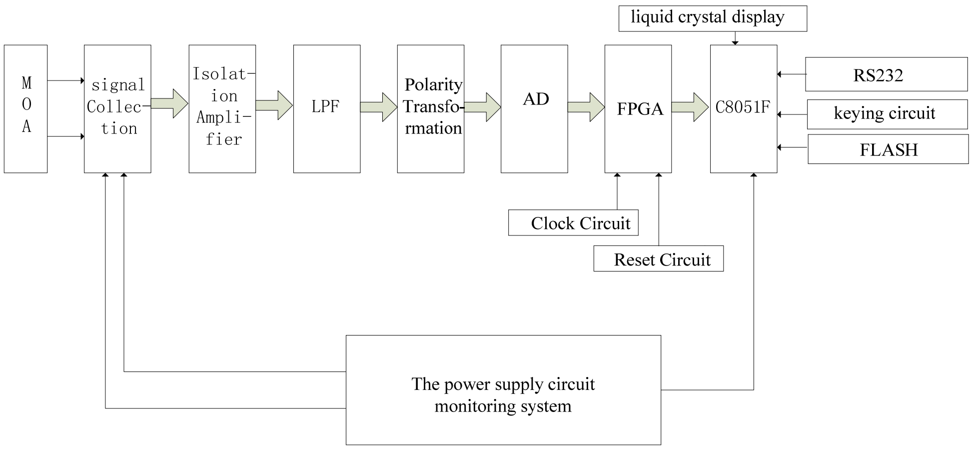

Fig. 4. MOA-on line monitoring device.

The Hardware system consists of three parts: signal conditioning circuits, signal processing circuit and system power circuit. A signal sampling circuit and a voltage transformer have a small current and they connected the sensor to obtain the voltage and current of MOA. Isolation amplifier circuit is to filter the signal and the internal circuit is to isolate MOA monitoring system, so that no interference and the current signal amplification system is using active filter. It can remove the high frequency noise and prevent aliasing but after filtering a small part of the harmonic components of the signal also exist that can be eliminated by digital filtering and interference method. We used an external 16-bit AD converter for converting the analog signal into digital and then passed through FPGA [8] control and handling. We can get good data processed by the incoming C8051F120 processor. This processor sends the date to the resultant data storage and we can see the current measured data on the LCD with the help of button. Monitoring the final results and by using the RS232 uploaded all data to the main control room of the host computer.

4. The Results of MOA-line Monitoring

We used the MOA of 10 kV (HY5WS-17/50 type) for our laboratory test, this device can test the effectiveness and motion effects, the wiring of laboratory is shown in Fig. 5.

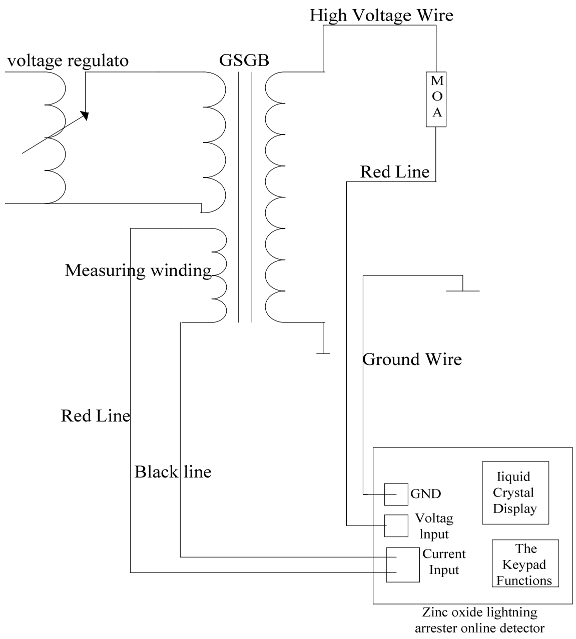

Fig. 5. The circuit of MOA-line monitoring in the laboratory tests.

Through testing transformer can adjust the voltage on the arrester; the testing transformer variable ratio is 500:1. The data of MOA in the laboratory of MOA is shown in Table 1. This data is an average and shows the relationship between the voltage waveform, full current, resistive current that is shown in Fig. 6.

Table 1. The results for different voltages.

	The results for different voltage		
U (KV)	7.60	8.40	9.20
P (W)	0.05	0.06	0.07
i_x (mA)	0.078	0.085	0.093
ϑ (°C)	85.4	85.4	85.4
i_R (mA)	0.006	0.007	0.007
i_c (mA)	0.078	0.084	0.093
I_R (mA)	0.114	0.123	0.133
i_{3R} (mA)	0.000	0.001	0.000
i_{5R} (mA)	0.001	0.001	0.001

Depend on the above tests, we obtained some results that are as follow:

1) In the system voltage, the full current is 0.078 mA and the resistive current component is 0.006 mA. We can see that the resistive current is only 13 % of full current. Some researchers explained that the resistance current is about 10 % ~ 20 % of the total current under the normal conditions, if the test values will be in this range then it shows that MOA is working well. If resistance current is about 25 % ~ 40 % of all current then that will increase the testing frequency and pay close attention to transformation, do data analysis and judgment. If resistance current is more than 40 % of all current, it is consider out of operation.

2) Through above data we observed that the value of the resistive current for current is very small and the total content of capacitive current is very large.

3) By testing we observed that the performance of MOA is good, so in this case the i_{3R}, i_{5R} and i_{7R} are consider 0.

4) Interphase interference affects the result of the test but didn't affect the validity of the test results. We can use the historical data of the longitudinal comparison method that can better reflect the working status of MOA.

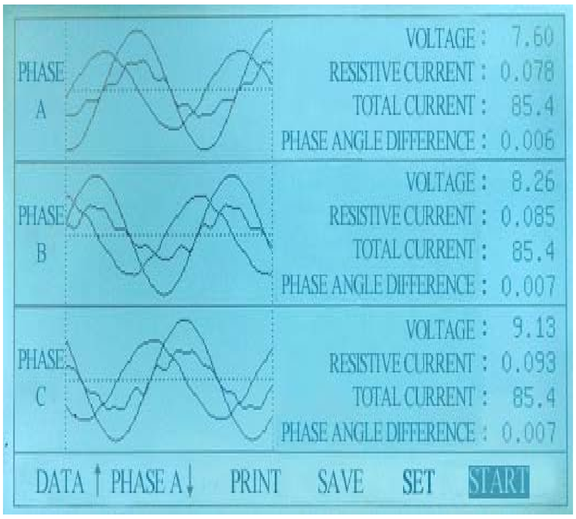

Fig. 6. The relationship between voltage, full current and resistance.

5. Conclusions

The MOA of 10 KV is used in the laboratory for on-line monitoring testing, it can be detected during MOA aging, moisture and resistive current component that can be used to detect hidden arrester insulation in time. The resistive current component is consider as detection target for auto-monitoring device, using a digital waveform analysis technique, such as harmonic analysis and digital filtering software anti-interference methods to make the measurement results accurate and stable. It can accurate analysis the fundamental wave and harmonic content for 3 ~ 7 times, overcome the interphase interference effects and correctly measure the resistance of arrester current. Based on these values of longitudinal and transverse comparison, we concluded that the arrester is in aging or may be affected with damp. This can determine whether or not to stop the working of MOA and reduce the damage for electric power system.

Acknowledgements

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