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An Online Monitoring System of Corona Loss of High Voltage Transmission Lines Based on Metalized Membrane Method

***Abstract**. An online monitoring system of corona loss of high voltage transmission lines based on metalized membrane method is developed in this paper. The system includes 3 components: the upper computer, the conductor voltage acquisition module and the corona leakage current acquisition module. The corona leakage current acquisition module is set on the high voltage line. The transmission line is covered by a certain length of thin metalized membrane . The sampling resistance is put paralleling between metal layer and bundle conductor. The conductor voltage acquisition module is set in transformer substation. The two modules are synchronized by the rising edge of Pulse Per Second (PPS) emitted by Global Position System (GPS), and the data is sent to the public port of mobile telephone network by General Packet Radio Service (GPRS). The remote upper computer gets the data and calculates corona loss of each bundle conductor by visiting public port. The experiment results show that the system can monitor the corona loss accurately. The whole study is helpful in the further research of UHV transmission line's corona in different environment and weather.*

***Streszczenie.** Zaprezentowano metodę monitorowania strat powodowanych ulotem (wyładowaniem koronowym) w liniach transmisyjnych wysokiego napięcia. Do tego celu wykorzystano metalizowaną membranę. Układ składa się z trzech modułów: komputera, systemu akwizycji napia) ęcia i systemu akwizycji prądu ulotu. Linia transmisyjna jest pokryta na pewnej długości cienką metalizowaną membraną. Do lokalizacji ulotu zastosowano moduł GPS a do transmisji danych moduł GPRS. (**Monitorowanie on-line strat ulotu w liniach wysokiego napięcia bazujące na wykorzystaniu metalizowanej membrany**)*

Keywords: Metalized membrane method; corona loss; online monitor; synchronous.
Słowa kluczowe: prąd ulotu, wyładowanie koronowe, linia wysokiego napięcia.

Introduction

It is meaningful to make further study on the corona loss of power transmission line in different atmosphere and environment[1,2]. It is helpful to design transmission line reasonably, keep the electrical system reliable, save investment of ultra high voltage (UHV) constructions and protect environment.

There are many factors which affect corona loss of transmission line a lot, such as the voltage, the surface condition and the atmosphere around the line. All these lead difficulties on studying corona loss[3~6]. The research of corona loss began in 1910s with the advent of power transmission line[7]. In the past years, numerous researchers tried to find the relationship between corona loss and other influence factors by experiment method, and some experiential formulas were summarized from experiments. The representative method are high voltage bridge method, low power factor meter method, head end resistance method, coupling antenna method and etc. But these methods only applies to on-load lines. In fact, the current of on-load line is always several tens kilo Ampere, and there are few reports and researches about the influence and difference of corona discharge between electrostatic and electromagnetism field.

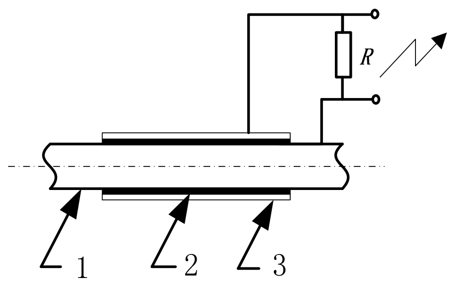
In order to monitor corona loss of on-load transmission lines, this thesis designs an online monitoring system of corona loss based on the metalized membrane method[8]. It can be used in monitoring corona loss of AC/DC transmission line. Comparing with sampling resistance method, the system is more accurate in measuring corona loss. What's more, besides AC/DC line, the system can be used in both no-load and on-load line.

The working principle of this monitoring system

The corona loss of transmission line is calculated by instantaneous power method here which needs the the line voltage and the corona leakage current of the line which is covered with metalized membrane. These two electrical parameters have great effect on the accuracy of the system.

The terminal voltage of transmission line can be got from PT or voltage divider installed in substation, and the voltage of testing line can be calculated by the equivalent circuit of transmission line with the length of the whole transmission line and the position of testing point. If the influence of capacitive rise effect is slight, we can use terminal voltage directly in engineering. For there is phase difference between testing point and terminal point, the voltage of testing point can be corrected by phase coefficient.

The leakage current can be got by the sampling resistance between transmission line and metalized layer as shown in Fig.1. The surface of transmission line is covered with metalized membrane. The two sides of metalized membrane are composed of different material: one side is called metalized layer which is conductive; the other side is called insulated layer which is made of polypropylene. When the insulated layer adhered to transmission line, the three parts which includes transmission line, insulated layer and metalized layer constitute a capacitance. Because the metalized membrane is extremely thin, the electric field of metalized layer is nearly the same as that of bare transmission line. The corona leakage current can be captured by paralleling sampling resistance between transmission line and metalized layer.



1-transmission line; 2-insulated layer of membrane; 3-metalized layer of membrane; R-sampling resistance
Fig. 1 Transmission line covered with metalized membrane

Actually, on-load transmission line plays two roles: one is transferring current to the load, the other is forming leakage current through discharging in the air around transmission line, and it is difficult to divide corona leakage current form complex current in this condition. However, metalized membrane method can divide these two roles. Transmission line covered with membrane uses to transfer current to the load, outer metalized layer discharges to the air around. There is only corona leakage current in no-load transmission line, so the corona leakage current can be measured by sampling resistance at the beginning of the transmission line. Therefore, the results measured by sampling resistance and metalized membrane should be the same in this condition.

The structure of the monitoring system

From the analyses above, on-line corona loss monitoring system of transmission line based on metalized membrane method includes three parts: upper computer, conductor voltage acquisition module and corona leakage current acquisition module.

A. Acquisition module

There are 3 phases in AC transmission line, and the line of UHV usually uses 8 bundled conductors. Therefore, the acquisition card of acquisition module is designed to sample data in 4 channels synchronously. In this way, the conductor voltage acquisition module uses one card, while the corona leakage current acquisition module uses one or two cards according to the number of bundled conductors. Comparing with current of pulse discharge, corona leakage current of fundamental frequency mainly causes corona loss. Considering the two factors above, the system finally selects acquisition card with sampling rate of 2MS/s.

The monitoring module of corona leakage current works in outdoor environment, so the system selects solar-cell panel and lithium battery as power source of module. Also, the module can control the power source in order to save energy.

The distance of two acquisition modules (conductor voltage and corona leakage current) may be far away. In order to assure the precision of system, the two modules are synchronized to sample by the rising edge of Pulse Per Second (PPS) emitted by Global Position System (GPS), and the testing result shows the error of synchronism is only in ns grade.

B. Data transmission

On-line monitoring system uses technology of General Packet Radio Service (GPRS). Internet and base station of mobile communication providers are master stations, while the two acquisition modules of monitoring system are slave stations. Upper computer sends out sampling orders by visiting public port supplied by mobile communication providers. Similarly, upper computer calculates corona loss with the data stored in public port. Once the slave station receives orders sent from master station, the acquisition data will be sent to public port [10]. In this way, on-line monitoring system is able to work in the area covered by mobile communication.

The functional diagram of on-line monitoring system is shown in Fig.2.

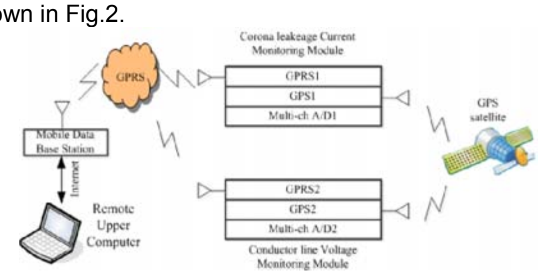
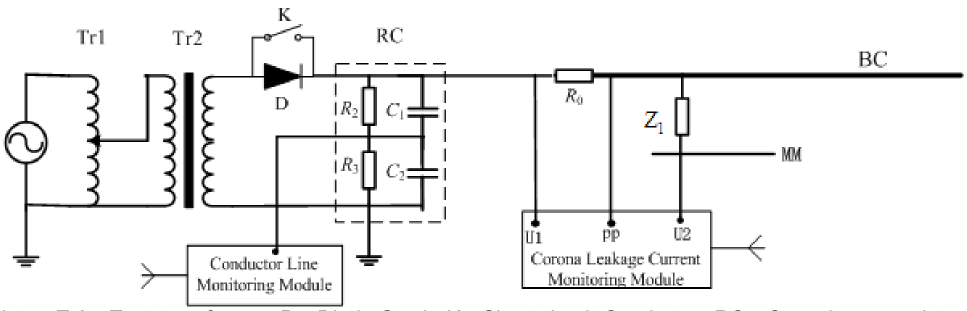


Fig. 2 Functional diagram of on-line monitoring system

Construction of lab platform

The electrical connect graph of test platform of corona loss and measuring system is shown in Fig.3.



Tr1—Voltage regulator; Tr2—Test transformer; D—Diode Stack; K—Short-circuit Conductor; RC—Capacitance-resistance voltage divider; R0(40Ω); R1(200Ω); BC—Bundle conductors; MM—Metalized membrane; pp—Public Potential

Fig. 3 Electrical connect graph of test platform and measuring system

In Fig.3, R0 is the sampling resistance at the beginning of the transmission line, and we can judge the feasibility of metalized membrane method by comparing with sampling resistance method which is generally accepted. The value of R0 is 40Ω. Z1 is called sampling resistance, and its value is 200Ω. Transmission line is steel cored aluminium stranded wire, and its sectional area is 300mm2 while its length is 30m. There is a silicon stack and a short-circuit guide bar inside casing pipe of the experiment transformer. Inserting and pulling out the guide bar can change the output of transformer from AC to DC. The real figure of the test platform is shown in Fig.4. Acquisition module of corona current is set in the metal tube, for the module won't affect the electric field outside.

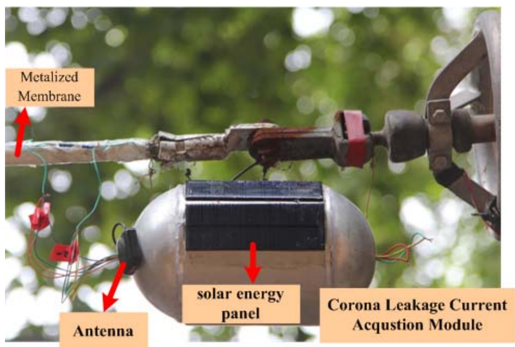
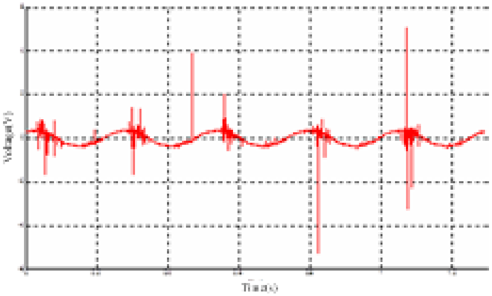


Fig. 4 Test platform and measuring system of corona loss based on metalized membrane method

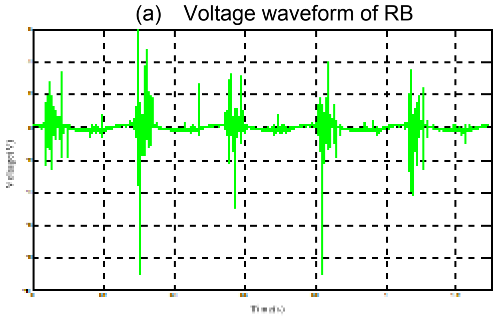
Measurement results

Based on the test platform and measuring system shown in Fig.4, the author did contrast experiment of sampling resistance method and metalized membrane method.

While the voltage of transmission line is 40kV (AC), the voltage signal of sampling resistance at the beginning of transmission line (RB) and sampling resistance in membrane (RM) are shown in Fig.5.



(a) Voltage waveform of RB



(b) Voltage waveform of RM

Fig.5 Voltage waveforms of sampling resistance (AC 40kV)

We can get the relationship between corona loss and voltage of transmission line in AC condition by changing the voltage of transmission line and measuring the value of corona leakage current and corona loss, as shown in Fig.6.

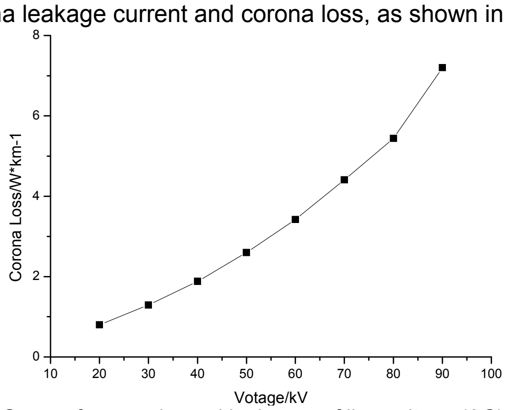


Fig. 6 Curve of corona loss with change of line voltage (AC)

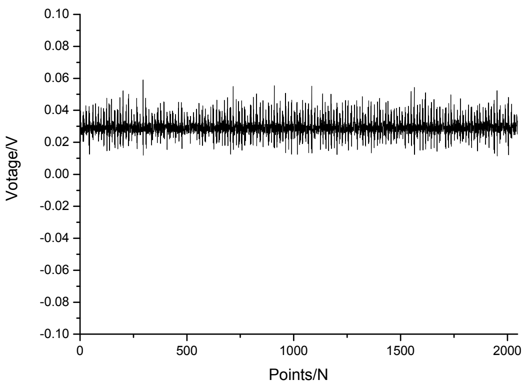


Fig. 7 Voltage waveforms of sampling resistance (DC 40kV)

From Fig.6, it is shown that the corona loss becomes larger while the line voltage becomes higher, and the curve of corona loss has the same characteristic with quadratic function. This is similar to the result of literature.

Similarly, the result of corona leakage current in DC condition is shown in Fig.7.

There are some fluctuations if we amplify the signal shown in Fig.7. This is because there are no filters in the system, and the quality of DC power source isn't good enough.

Similarly, we can get the relationship between corona loss and voltage of transmission line in DC condition by the same way as AC, and also, the curve of corona loss in DC condition has the same characteristic with quadratic function.

Analysis of results

The feasibility of metalized membrane method can be proved through comparison with experiment results of sampling resistance at the beginning of transmission line. Due to two methods have the same voltage signals when calculating corona loss, so the consistency of corona loss can convert to the consistency of corona leakage current. The consistency put forward above can get from the comparison of correlation, time delay and leakage current per unit length between the leakage current measured in two methods.

A. Analysis of correlation

Suppose there are the arrays X and Y, and they all have N samples. The correlation coefficient of the two arrays is:

(1) $$R=\frac{\sum XY-\sum X\cdot\sum Y/N}{\sqrt{\sum X^2-(\sum X)^2/N}\cdot\sqrt{\sum Y^2-(\sum Y)^2/N}}$$

The calculation results with the leakage current measured at the positions of sampling resistance at the beginning of transmission line and metalized membrane by formula (1) is 0.99. The result represents the good correlation of two methods.

B. Comparison of time delay

Time delay can be calculated by cross spectrum method. The theoretical foundation of this method is that there is time delay information existing in cross power spectrum between two signals [11]. Suppose signal x(t) and signal y(t)=x(t+τ), and τ is the factor of relative time delay. The Fourier transform of x(t) is shown as below:

(2) $$X(f)=\int_{-\infty}^{\infty} x(t)e^{-j2\pi f\tau}dt$$

The Fourier transform of y(t) has the same form with formula (2), and the cross power spectrum of x(t) and y(t) is:

(3) $$Z(f)=X^*(f)Y(f)=|X(f)|^2 e^{j2\pi f\tau}$$

The phase angle of Z(f) is:

(4) $$\phi=2\pi f\tau=\arctan\frac{\mathrm{Im}[Z(f)]}{\mathrm{Re}[Z(f)]}$$

Time delay factor τ can be calculated by formula (4). Time delay of two waveforms is nearly zero after calculation with the leakage current got at the positions of sampling resistance at the beginning of transmission line and metalized membrane. The results of correlation coefficient and time delay prove that leakage current of two positions has a high correlation. Of course, the result above is only the characteristic of transmission line for short distance. When transmission line is long enough, there will be phase shift between the leakage current measured in the two positions.

C. Comparison of leakage current per unit length

Suppose the voltage of sampling resistance R0 at the beginning of transmission line is U1, and the leakage current through R0 is I1, while the voltage of sampling resistance at membrane R1 is U2, and the leakage current through R1 is I2. The length of membrane is 2m. If leakage current per unit length of two methods is equal, the formula below should meet:

(5)
$$\frac{U_1/R_0}{U_2/R_1}=\frac{U_1}{U_2}\times\frac{R_1}{R_0}=\frac{I_1}{I_2}=\frac{30}{2}$$
$$\Rightarrow\frac{U_1}{U_2}=\frac{30}{2}\times\frac{R_0}{R_1}=\frac{30}{2}\times\frac{40}{200}=3$$

After test, the voltage at the beginning of transmission line is nearly 3 times by that at the position of metalized membrane. This result shows the corona leakage current per unit length of two methods is equal, namely that corona loss is proportional to the length of transmission line.

From the three analyses above, we can see that metalized membrane method is feasible to measure corona loss of transmission line.

Discussion of errors in practical measurement

Some elements may lead errors when measuring corona loss of practical transmission line. Generally, voltage acquisition device such as PT is usually set in substation and metalized membrane is placed on the transmission line far away from substation. In this condition, there will be some differences of the voltage phase between the two measurement points. This problem needs to be corrected by the phase coefficient of transmission line.

When metalized membrane is placed far away, the value of power frequency voltage will arise. Corona loss is proportional to the square of line voltage. When capacitive rise effect is 5%, the corona loss error will be only 0.25%, and it is much smaller than other methods.

What's more, synchronization problem of the monitoring system can also cause calculation error. Phase voltage and leakage current of metalized membrane are collected distributively, so it must ensure their synchronization with hardware which mainly includes trigger pulse of collection. This problem can be solved by the rising edge of second pulse signal which sent by GPS in this system.

Conclusions

An online monitoring system of corona loss based on metalized membrane method is developed in this thesis. It is effective in either no-load or on-load line besides AC/DC line.

The online monitoring system includes 3 components: the upper computer, the conductor voltage acquisition module which is set in transformer substation to sample the conductor line voltage and corona leakage current acquisition module which is placed on high voltage line to sample voltage signals transformed from corona leakage currents. The two modules are synchronized to sample by the rising edge of Pulse Per Second (PPS) emitted by Global Position System (GPS), and their data is sent to the public port of mobile telephone network by GPRS wireless telecommunication. The remote upper computer calculates corona loss of each bundle conductor with the test data by visiting public port.

Comparing with experiment results at the positions of beginning of transmission line and metalized membrane, the feasibility of metalized membrane method can be proved through the comparison of correlation coefficient, time delay and leakage current per unit length.

Based on the test platform and measuring system, the author did some researches on corona loss of transmission line in both AC and DC condition. The experiment results shows that the corona leakage current and corona loss become larger while the line voltage is higher, and so as the curve of corona loss. They all have the same characteristic of quadratic function. This is similar to the result of former researches. The experiment results show that the system can monitor the corona loss accurately. The whole study is helpful in the further research of UHV transmission line's corona in different environment and weather.

This work is funded by National Engineering Laboratory for Ultra High Voltage Engineering Technology (Kunming, Guangzhou）

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