Study of PD Location in Generators by PD Pulses Propagation

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When a partial discharge takes place at the stator of a generator, the electrical pulse will propagate along the stator bars and the capacitor chains formed by the end part of the stator winds. On the first path, the pulse propagates as a travel wave at slow speed. On the second path, the pulse propagates at quick speed. Based on the data of the experiments on a real 50 MW steam generator, the author has found the pulses can propagate by magnetic field of the stator winding. It was studied that how to locating the partial discharge by signals coming from the different paths, including the features of signals on the two paths at time domain and frequency domain, the measurement frequency rang of the signals, the blind area, the advantage and disadvantage of this method.

Keywords : Generator, Insulation, Location, Partial discharge, Propagation, Travel wave

1. INTRODUCTION

The partial discharge detection technology for stator insulation of large generators has been developed for several tens of years[1], but still been far away from accurately decision of the type, severity and position of partial discharges. The measured signals from high-voltage bus of generators or from neutral point of generators have been changed by propagation path, so research on the propagation law of partial discharges in stator windings is the crux of detecting actual partial discharges and locating discharge source. Because this propagation law is very complex, nowadays there are few research results. Besides, such complex law can not be used effectively to deal with partial discharge location problem[2,3].

It is well known when a partial discharge takes place at the stator insulation, an electrical pulse will propagate along the stator windings and the capacitor network formed by the end part of the stator windings. On the first path, the pulse propagates as a travel wave at slow speed. On the second path, pulses propagate at very quick speed. If measured the partial discharge signals at the high voltage bus bar, we can calculate the distance of partial discharge resource by multiplying the time interval that the pulse signals arrive the sensor along the two different paths and the speed of the travel wave[4,5].

By experiments carried out on a real 50 MW turbo generator, we have found that the pulses can also propagate by magnetic field of stator windings. The coupling mechanism, frequency bands and propagation rules of the three propagation paths, such as along the stator windings, along the capacitor chain and through magnetic induction among windings, were studied. It was found that the quick wave and slow wave location method has a blind area, and is easy to be effected by pulses from stator magnetic induction.

In this paper, it was studied that how to locate the partial discharge by signals coming from the different paths, including the features of signal at time domain and frequency domain, the decision of the detection frequency rang, the application condition and the blind area, the advantage and disadvantage of this method.

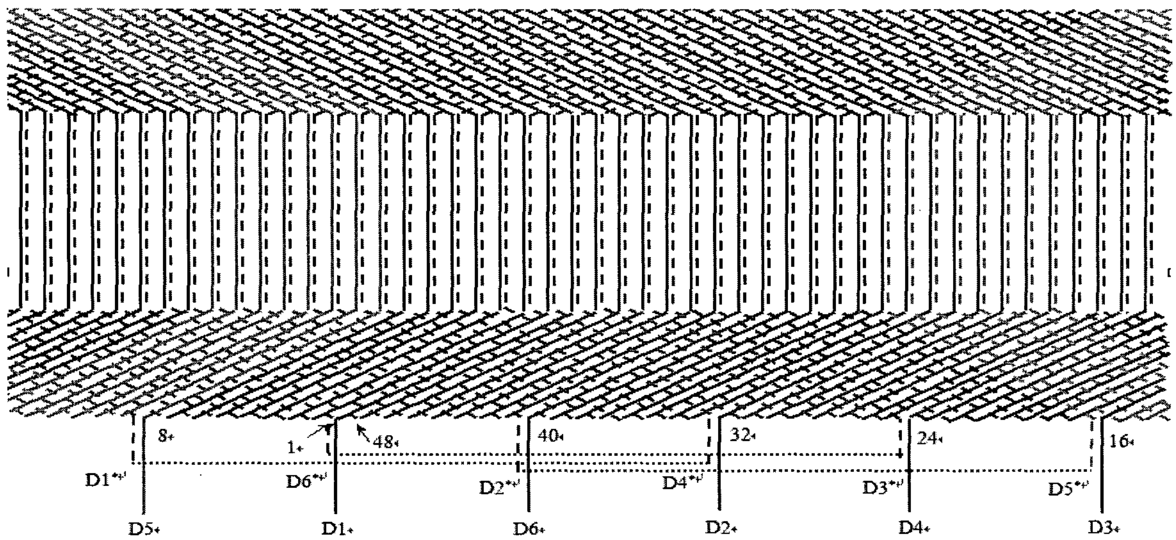

Fig. 1. The structure of the stator winding of the generator and the number of up bars.

2. EXPERIMENT ON REAL GENERATOR

We have carried out experiments on a real 50 MW steam generator stator at manufactory. This stator has 48 slots, double layer lapping over windings. The structure and slot number are shown in Fig.1. In this figure the real lines are the up layer bars, and the dash lines are the down layer bars. The out port terminal of three phases windings were named as D1~D6. Among them D2 and D5 belong to phase A, D1 and D4 belong to phase B, D3 and D6 belong to phase C. The up bars were numbered as No. 1~No. 48. In our experiments, the terminals D5, D1 and D6 were usually used, and they consisted with the stator bars No. 9, No. 1 and No. 41 respectively.

The content of our experiments were: a) injecting signal at up bars in turn and measuring it at the three phase terminals; b) injecting signal at the three phase terminals and measuring it at up bars in turn. The square wave we used were generated by Agilent 33250A signal generator, and measured by DL-5104 digital oscilloscope at 100MSPs sample speed through tin foil pasted at the parallel junctions, looking as Fig. 2.

The square wave is shown in Fig. 3. It has 20 V of amplitude and 20 ns of rising edge. It has most frequency range of normal partial discharges.

3. PROPAGATION IN DIFFERENT FREQUENCY

When injected signal at each bars in turn and measured it at three phase terminals, we obtained the response of different length of propagating path. That is, we have get the propagating rule of the signal. At first, the response in 2~6 MHz was no attenuation in propagation. Some responses at D5 were processed by 2~6 MHz digital filter and the result is shown in Fig. 4. In Fig. 4 the curve named No. 5 is the result when the signal was injected at bar No. 5, the same as other curves The curves were added a different base value in order to show them in one figure clearly. Obviously, only curve of No. 9 (which is exactly the bar of D5) has bigger amplitude. Other curves have approximate amplitude. There was no time delay in the response.

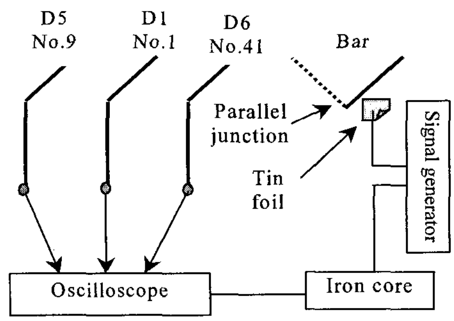

Fig. 2. The sketch of test circuit.

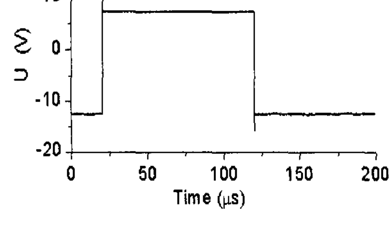

Fig. 3. The waveform of square wave signal.

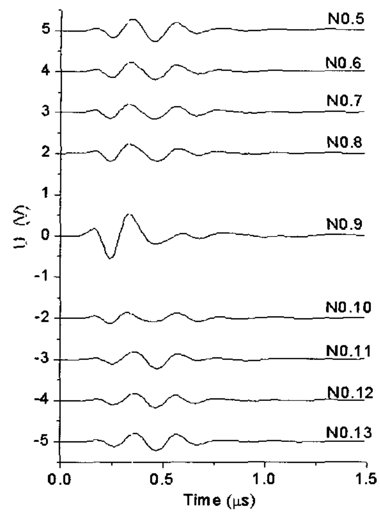

Fig. 4. Response at D5 in 2~6 MHz.

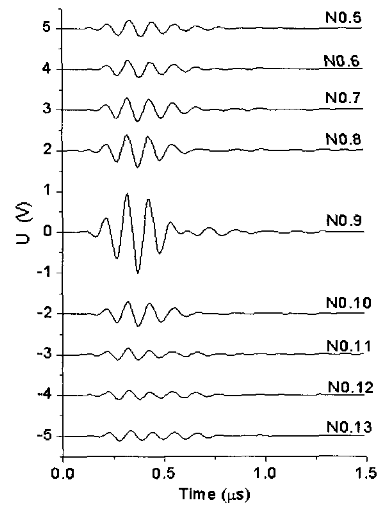

Fig. 5. Response at D5 in 7~12 MHz.

Secondly, the response in 7~12 MHz was variable with different injection position and attenuated quickly in propagation. Some responses at D5 were processed by 7~12 MHz digital filter and the result is shown in Fig. 5. Obviously, the more far the injection position, the smaller the response at the terminal was. There was no time delay in the response.

Thirdly, the response in 0~2 MHz was also attenuated quickly in propagation. Some responses at D5 were processed by 0~2 MHz digital filter and the result is shown in Fig. 6. Obviously, the curves had two kinds of components. One was the residue of the response above 2 MHz looking as a narrow peak. The other was the response within 2 MHz. The more far the injection position, the smaller the response in 0~2 MHz at the terminal was. At the same time, the response in 0~2 MHz existed at D5 only when the signal was injected at the bars of phase A. Further more, to the response within 2 MHz when the injection position was more and more far away, its rising edge was more slower, its frequency was more lower, and its time delay was more bigger.

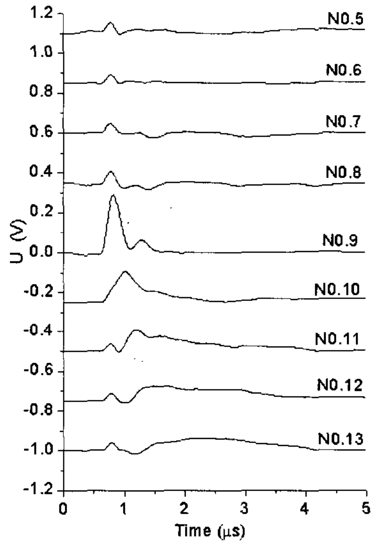

Fig. 6. Response at D5 in 0~2 MHz.

4. TIME DELAY IN THE PROPAGATION

According to above analysis, the response above 2 MHz had no time delay in propagation. We believed that it was propagating along the capacitor chains at the end part of the stator windings and it was the quick wave. The response in 0~2 MHz had obvious time delay in the propagation. We believed that it was propagating along the whole stator winding and it was the slow wave. If using a threshold value to decide the arrival time of the slow wave, we can get the time delay at each injection position, looking as Fig. 7. The signal had about 3.4 μs time delay when it traveled through 7 coils.

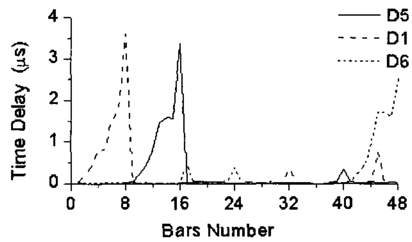

Fig. 7. Time delay of the slow wave.

But the time delay was no easy to decide at sometimes When the injection position was near the terminal, some response within 2 MHz can also propagate to the terminal

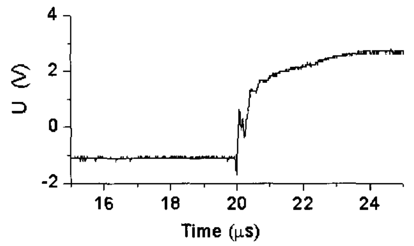

Fig. 8. Response at bar No. 34 when injected into D2.

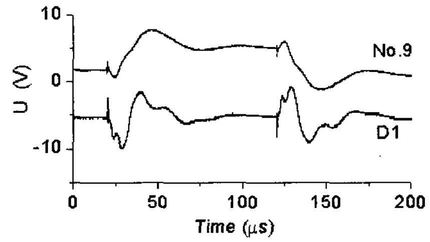

Fig. 9. The slow wave and magnetic induced wave.

by the capacitor chains. And some response above 2 MHz can also propagate to the terminal along the bar windings. So, the slow wave and the quick wave lapped over at time domain and frequency domain. It was difficult to distinguish them. When the square wave signal was injected into D2 (consists with bar No. 33), the total waveform of the response at bar No. 34 had this kind of situation, looking as Fig. 8. In the response at No. 35, the slow wave and quick wave can be distinguished. So, the time delay has a blind area of one coil (two bars). Of cause, this conclusion was come from the 50 MW generator.

5. THE MAGNETIC INDUCTION IN LOW FREQUENCY

From the experiments, we found a new propagation path of low frequency signal. That is, when the low frequency signal travels along the stator windings, it will produce a magnetic field. This magnetic field will produce induced voltage at the stator windings. Because only low frequency signal can travel along stator windings and has small attenuation, the induced voltage should be low frequency. According to our analysis, it was below to 1 MHz. In Fig. 9, the response at No. 9 and D1 were shown together when the square wave was injected into D2.

Because D2 and No. 9 belonged to the same phase, the response at No. 9 had a shape of square. The D1 belonged to another phase, so its response had only slow wave and small quick wave. Before the rising edge of the response of No. 9, there was a low frequency wave at negative polarity. It was the magnetic induced response, because the polarity and amplitude of this kind of response changed with the distance of injection position and measurement position according to the magnetic induction principle. The magnetic induced response was also no time delay. It brought with the difficulty to decide the arrival time of the slow wave.

6. PARTIAL DISCHAGRE LOCATION

Partial discharge pulse has wide frequency spectrum. Its high frequency component will propagate along the end part of stator windings without time delay. And its low frequency component will propagate along the whole coils with obvious time delay. So, if we get the time delay of and the travel speed the slow wave, we can calculate the distance of partial discharge resource from the measurement point by multiply them.

The quick wave can be used to decide the occurring time. Because the response in 2~6 MHz has no attenuation in propagation, the measurement of the quick wave should be in 2~6 MHz. To other generators, this frequency band should be measured.

When deciding the detection frequency band of the slow wave, the magnetic induction and energy attenuation in slots should be considered. On the one hand, in order to obtain accurate rising edge of the slow wave, the measurement frequency should be high. But it should also lower than the quick wave frequency. To above 50 MW generator, this frequency should below 2 MHz. On the other hand, the slow wave has great attenuation brought by iron core loss and bars heating, especially to high frequency component. So the measurement frequency band of slow wave should be low. But it should higher than the frequency of magnetic induced voltage. In our experiment, the component below 0.5 MHz had completely attenuated after traveling through 16 bars. If the partial discharge resource is within 16 bars form the measuring terminal, the detection frequency band of the slow wave can be choose as 0.5~2 MHz. If the partial discharge resource is out of 16 bars, the detection frequency band of the slow wave can be choose more lower such as 0.1~2 MHz. But the effect of magnetic induction is bigger than that of 0.5~2 MHz. And the pulse resolution is lower than that of 0.5~2 MHz.

The travel speed of the slow wave varies with the pattern of each generator and the measurement frequency. It should be measured at field. When the speed and the time delay are obtained, the distance of partial discharge resource from the measurement point can be obtained by multiply them.

7. CONCLUSION

When a partial discharge takes place at the stator insulation of a generator, the component above 2 MHz will propagate along the end part of the stator windings and become the quick wave at the measurement point and decide the time of partial discharge happened. The component below 2 MHz will propagate along the bars and become the slow wave. Its time delay and speed can be used to calculate the distance of the partial discharge resource.

The measurement frequency band of the quick wave should be choose to make the attenuation of the quick wave lightly in propagation, such as 2~6 MHz. The measurement frequency band of the slow wave should be choose as 0.5~2 MHz or 0.1~2 MHz, thinking about the iron core loss, the effect of magnetic induction and the pulse resolution.

This method of partial discharge location is easy to realize at field and can get the accurate place of partial discharge resource. But it has a blind area about one coil. And the frequency of slow wave is too low to be effected by the magnetic induced voltage and to have enough pulse resolution.

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