現場でのロータリマシンの部分放電計測応用

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On-site Partial Discharge Measurement on Rotary Machine

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はじめに

一般にロータリマシンとは発電機及びモータを指しますが何れにしても其の一方に事故が発生すれば直接又は製品納期の遅れによる間接的な損害の発生は免れません。一旦事故が発生すれば系統のリライビイリイティの低下等の欠陥も生じる、其の防護策として定期検査よりも其の早期検出の必要性がある道理です。

目前ロータリマシンの一般的な絶縁診断技術では例えば振動常態の監視及び，電気絶縁特性試験等が含まれますが。其の内の最後の一項目以外はオンラインでの試験が可能です、即ち機械的な診断効果の良いモニタリングは可能ですが、然るに電気絶縁不良発覚の暁には既に電気絶縁が破壊されているのが現状です，故にこの様な伝統的手法では完全にこの様な事故は排除出来ません。この為現段階では最も有効だと認められる部分放電試験技術の導入、応用は最も有効な手段だと結論が下されます。

因って本文は実例でもって現場での部分放電量の測定をオフライン及びオンラインでの測定を比較し、最後に実例で以って如何にして其れをリスク　マネジメントへの応用を可能にしました。

Abstract

The failure of rotary machine would cause production loss immediately or indirectly. Moreover, the manufacturing period of rotary machine is relative long, and it implies that the system reliability would be decreased. Therefore, in order to keep system reliability, the early warning system would be necessary and the preventive strategy is the adoption of condition-based maintenance to substitute time-based maintenance.

The common diagnostics for rotary machine includes vibration analysis, temperature monitoring, and insulation diagnostics. Excepting the last one, all of them could be done without outage, and the mechanical condition could be monitored continuously. However, the electrical insulation breakdown occupies high proportion of the failure events, and the traditional insulation diagnostics do not satisfy the request of condition-based maintenance. Hence, the most effective insulation diagnostics, partial discharge measurement, is introduced to the condition-based maintenance.

This paper takes real cases to introduce on-site partial discharge measurement on rotary machine, including off-line and on-line partial discharge measurement, and a risk assessment is also illustrated in the end.

1. Introduction

Rotary machine could be generator or motor, once they fail, the generator will cause outage, which might lead to be fined for no power producing, and the motor will cause production suspension, which might induce production loss. Besides possible production loss, the system reliability would be decreased. Therefore, it is an important to prevent rotary machine from breakdown, and the early warning system is necessary.

According to experience, the common failures of rotary machine are involved with bearing system, overheat, and electric insulation. For mechanical issue, the vibration analysis is adopted to diagnose bearing system; for overheat, there are resistance temperature detectors (RTD) installed inside the machine; for electrical insulation, insulation resistance test [1], dielectric power factor test [2], and off-line partial discharge measurement (PDM) [3,4] are utilized to assess the insulation condition. Among them, the first two methods could be achieved without power outage, and the execution of last one still need to be power outage, which means that the insulation condition can't be monitored on-line.

Therefore, the mentioned insulation diagnostics for rotary machine is obviously insufficient to fulfill the requirement of preventive maintenance. Because PDM shows good performance in insulation diagnostics and could be achieved without power interruption by different approach, it could be utilized for the insulation condition monitor to achieve the goal of preventive maintenance. This paper addresses different applications of PDM on rotary machine including off-line/on-line PDM on generator, and risk assessment of high voltage motor.

2. Off-line Partial Discharge Measurement

Because rotary machine is a kind of capacitive equipment, the required capacity of test power source is proportion to the capacitance of the machine and the square of test voltage. If the capacity of power source is insufficient, the frequency of test voltage would be decreased to lower down the required capacity, and the alternative power source is very low frequency (VLF) power source and damping alternating current voltage source (DAC).

This section takes two examples to show the on-site PDM via portable power source and DAC.

2.1. Power AC

Accords to [4], the connection diagram is shown in Fig. 1. As shown in Fig. 1, the stator winding is taken as filter, so test voltage is applied on one side and measured on the other side. Figure 2 show the measured phase-resolved partial discharge pattern (PRPD) at rated phase-to-ground voltage. The measured data shows that there is slot discharge phenomena in S-phase winding.

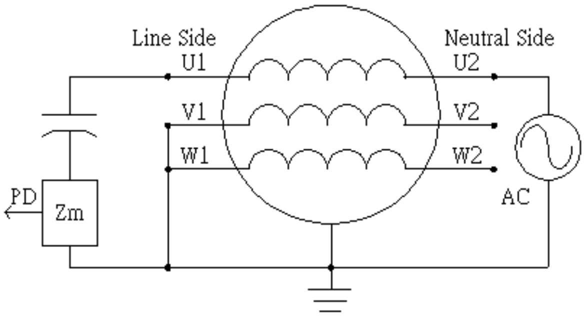

Fig. 1 The connection diagram of off-line PDM on rotary machine [4]

Figure 2 shows the trend of PD level in past 7 years. It reveals that the PD level of S-phase is stable as measured on line side, and the PD level increases gradually as measured on neutral side. The recommendation is to keep tracing PD level and to install monitoring system if possible.

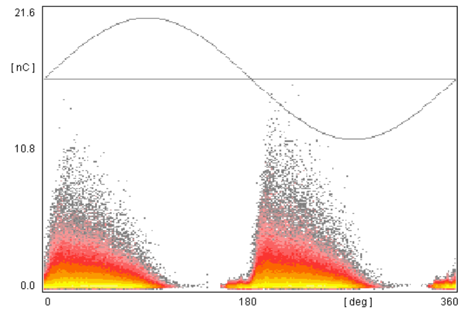

Fig. 2 PRPD of S-phase measured on line side and test voltage on neutral side

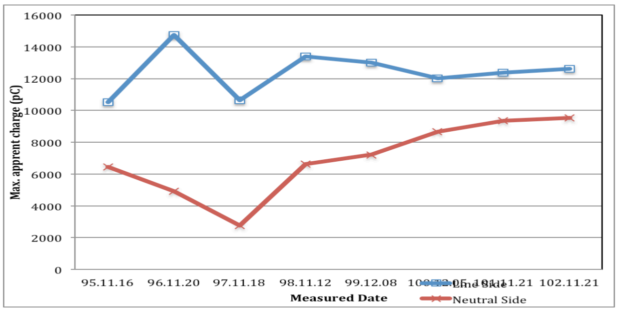

Fig. 2 The trend of PD level in 7 years

2.2. Damping alternating current voltage

The oscillating wave test system (OWTS) is taken as DAC source, and the configuration is shown in fig. 3. The DC source will charge the object under test (OUT) to the test voltage, and then IGBT closes quickly to form a resonance circuit (capacitance of OUT and inductance of OWTS). The measurement circuit is already integrated inside the system. Therefore, the OWTS has the advantage of small capacity requirement and the similar result to power frequency.

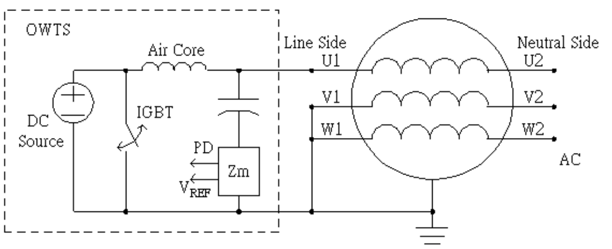

Fig. 3 Configuration of OWTS

Figure 4 shows the test procedure, and the step voltage is 2 kV_{RMS}. The amount of shots is 10 times for every step and is 50 times for the highest voltage.

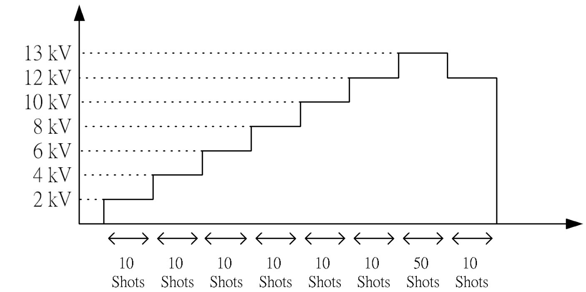

Fig. 4 Voltage Steps

Figure 5 shows the measured result at rated phase-to-ground voltage, and the reading is 252 pC. According to PRPD, the PD phenomenon is kind of slot discharge. Because the generator is hydrogen-cooled and the hydrogen was released, the insulation media of the generator was air during test. Hence, the 252 pC reading is normal and no recommendation was made.

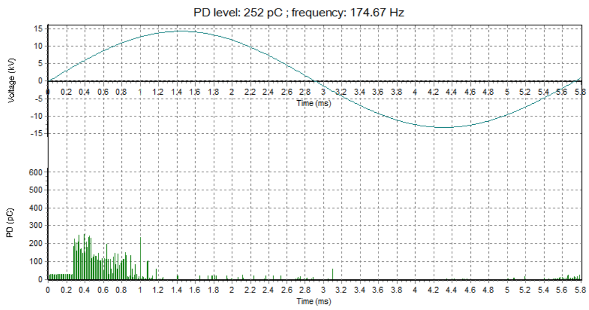

Fig. 5 PRPDs measured by OWTS

3. On-line Partial Discharge Measurement

Because off-line PDM should be carried out during a scheduled outage, the operation condition is different with normal condition and the period between two measurements is long. Therefore, the result of off-line PDM can only roughly assess insulation condition.

Therefore, on-line PDM is an alternative method to assess the insulation condition, and could be carried out continuously. In order to suppress the interference of high background noise, the measuring frequency is usually raised. This section introduces two common approaches for on-line PDM.

3.1. Coupling Capacitor

As the measuring frequency is raised, the coupling capacitor could be miniaturized and could be installed inside the panel, as shown in fig. 10. Therefore, the on-line PDM could be achieved without power outage.

Because the installation cost of coupling capacitor is relative high, it is usually adopted in generator and is not common being adopted for high voltage motor.

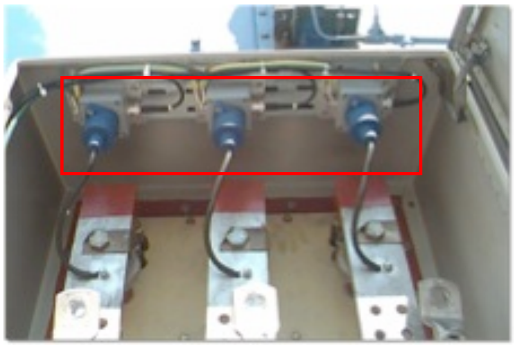

Fig. 5 The installation of coupling capacitor

3.2. Magnetic Sensor

Once PD occurs, the pulse current will also be accompanied, and travel along the conductors. Therefore, the inductive PD sensor, such as high frequency current transformer and Rogowski coil, could be adopted to couple the transient magnetic field caused by PDs. Figure 6 shows one kind of inductive PD sensor, called as bushing type PD sensor. Figure 7 shows the measured PRPD via bushing type PD sensor of the generator mentioned in section 2.1, and the measured results show different PRPD due to different measuring frequency.

Because the inductive PD sensor does not attach to high voltage parts, it is more safety than coupling capacitors.

Fig. 6 The installation of bushing type PD sensor

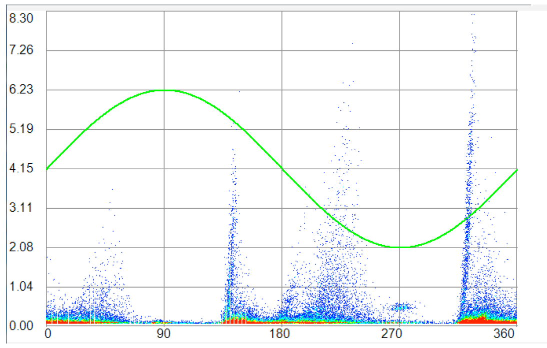

Fig. 7 Measured PRPD via bushing type PD sensor

4. Risk Assessment

Because the trend of PD level shows the tendency toward the insulation deterioration, the trend of PD level would be effective approach to assess risk of insulation breakdown. Based on field experience, the PD level would fluctuate time by time, and the ± 25 % variation of average PD level would be acceptable, and the risk of insulation breakdown increases as the PD level increases dramatically.

Figure 8 shows the installation of UHF PD sensors for high voltage motor, and fig. 9 shows the trend of PD levels over 2 years (on-line PDM twice per year). From fig. 9, the PD levels of Motor #4 and Motor #5 increased dramatically in the 2nd and 3rd on-line PDM, and the recommendations of immediate repair were proposed. After repair of Motor #4 and #5, the 4th on-line PDM shows good insulation condition of them.

Fig. 8 Installation of UHF PD sensors

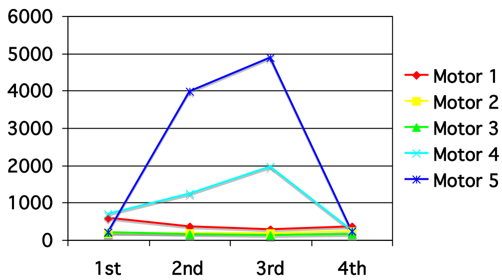

Fig. 9 The trend of PD levels for 5 motors

Fig. 10 Defects causing PDs of Motor #4

Fig. 11 Defects causing PDs of Motor #5

Figure 10 shows that there is serious partial discharge at the leading wire of Motor #4, and fig. 11 shows that there is serious partial discharge at the end-winding of Motor #5.

5. Conclusion

For rotary machine, PDM is an effective insulation diagnostic, which can be applied on-line/off-line. However, there is no standard dealing with acceptance level of PDs. According to field experience and benefited by the adoption of wider measuring frequency band, frequency analysis could be utilized to assess the risk of insulation breakdown. The low frequency band indicates the existence of PD phenomenon, and the high frequency band indicates the risk of PDs.

Besides the frequency analysis, the trend of PD levels would be another reliable index of insulation deterioration. The risk of insulation breakdown increases as the PD level increases dramatically.

6. Reference

[1] IEEE Std 43-2000 Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

[2] IEEE Std 286-2000 Recommended Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation.

[3] IEEE Std 1434-2000 Trial-Use Guide to the Measurement of Partial Discharges in Rotating Machinery.

[4] IEC 60034-27 Rotating electrical machines – Part 27: Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines.

[5] 李長興、邱敏彥、黃智賢、顏世雄, "常用線上局部放電感測器之特性分析", 2007 第 28 屆電力工程研討會。