Bushing Technology of the future – Resin Impregnated Fiber over Conventional Bushings

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Abstract- **Transformer Bushings play a critical role in power system network. Bushing technology has evolved considerably over the last decade. This paper compares the various technologies that has evolved over the years namely OIP, subsequently RIP and introduces to a fairly new technological advancement in this field which is Resin Impregnated Fiberglass based bushing. It also addresses one of most important aspect of in-service condition monitoring. This provides advance information for replacement of bushings thus pushing towards a very reliable power system network.**

I. INTRODUCTION

Bushings are an essential part of the power transformers [1]. Bushings mechanically support external conductors and provide insulation from earth as the conductors are fed into the transformer tank [2]. In principle they couple transformer winding and a switchyard through conductive and dielectric functions [1]. Their role is very crucial for the successful operation of the transformer. It is fair to state that the bushing is one of the highest electrically stressed components of the power transformer due to the proximity of the conductor to earth [2]. Literature suggests typically 25 to 30% of large power transformer failures are in principle due to bushing failure. As transformer bushings have only stationary components, most failures are attributed to insulation deterioration typically from moisture ingress and discharges. Analogous to HV insulator in a power system the bushing represents only a small fraction of the power transformer cost however their failure is often catastrophic. Damages due to failure not only limits to transformer but can often cause significant damages to equipment in the proximity and consequently significant power disruption [2].

II. TYPES OF BUSHINGS

A. OIL IMPRENAGTED PAPER BUSHING (OIP)

Conventional transformer bushings employed Oil Impregnated Paper (OIP) as the main insulation [3]. Their insulation body is formed by winding alternate layers of insulation paper and conducting layers which is impregnated with oil. Typically the outer insulation material is porcelain [4]. The reason for its use over the years include its low cost, its behaviour under various conditions of operation is reasonably understood and finally in general, its overall dielectric and thermal performance was satisfactory [3]. However with time it has been realized there are numerous issues with OIP. The presence of insulating oil, is a potential fire hazard, and has a lower temperature class of operation. Further concerns include a weak mechanical disposition and difficulty in positioning the bushing at any desired angle on top of the transformer. Also need arises for enclosing the active part of the bushing by an outer ceramic casing, even for an indoor application [3]. On the manufacturing front this type of bushing, requires a number of sealing procedures; hence the operation of these bushings demands specific periodic maintenance to ensure constant oil tightness. Most importantly if an insulation fault initiates there is a risk of rapid and undetected propagation to intense failure, which sometimes could end up in explosion [4]. Figures 1 and 2 shows some classical examples of failures that could arise out of OIP usage.

Figure 1: A 110-kV OIP bushing failure caused this 80-MVA transformer fire [5]

.It has been observed that transformer fires are a result of predominantly OIP bushing failures of all other reasons. In practice, 2.4% to 4% of all transformers can be expected to cause a fire during a 40-year service life which is significant considering the impact it causes [5]. This was one of the primary reason for the development of RIP Bushing.

Figure 2: An OIP bushing failure on the 400-kV, 100-MVAR reactor caused this reactor fire [5]

B. RESIN IMPRENAGTED PAPER BUSHING (RIP)

In late 1980's Resin Impregnated Paper (RIP) bushing evolved as an alternate dry type to OIP bushings. RIP condenser cores are made by winding insulating paper and conducting layers. They are subsequently impregnated with epoxy resin before curing stage, which eliminates the need for the insulating oil. Hence in principle an RIP bushing is eventually an all-solid system. Despite the overall complexity involved in the manufacturing of RIP bushings it has still shown good performance. These bushings were developed with superior thermal and electrical performance. The RIP technology evolved with all the advantages of OIP and aimed at solving the drawbacks of OIP. However there are genuine concerns with RIP also as summarized here. RIP condenser bodies have weaker mechanical strength, hollow porcelain or composite insulators must be used outside the bodies as outer insulators. This necessitates the need of another filling medium that has to be added between the hollow insulators and the insulating bodies ensuring the insulating performance of the interface. Hence sealing procedures have to be included in the design. Given this scenario, like OIP, reliability would again depend on the sealing robustness and the stable condition of insulating material (paper). However it is important to note that the insulating paper is sensitive to moisture, and even more so if phenolic resin is applied. Hence due to this for the oil side of RIP bushings (i.e. fitting inside the transformer) additional care is needed during transportation and storage with a protective sleeve typically filled with dry nitrogen. Finally with the cost factor under consideration RIP option is considerably more expensive than OIP [4, 6]. The considerable technically unresolved challenges with RIP laid the path for further improved technological evolution of Resin Impregnated Fiberglass (RIF™) bushings.

C. RESIN IMPRENAGTED FIBERGLASS BUSHING (RIF™)

Reasonable satisfactory performance was obtained from both OIP and RIP over years. However as the transformer assets age paper deterioration of these bushings would eventually lead to failures and could be even catastrophic. RIF™ bushings, introduced in early 2000's, are of a new dry-type transformer bushings. Simpler manufacturing processes with shortened lead times is a highlight. The construction of RIF™ involves paperless condenser bodies wrapped with fiberglass-based composite and conducting layers before curing. The outer insulation is typically made of silicone rubber (SIR) directly fitted on to the condenser structure's core, with no gap between the two components. These bushings have very high mechanical strength, and requires a very limited sealing procedures. For above mentioned reasons it is fair to expect field operation would demonstrate a distinctive robustness and repeatable reliability which is seen in reality. Figure 3 shows the construction of RIF™ bushings [4, 7].

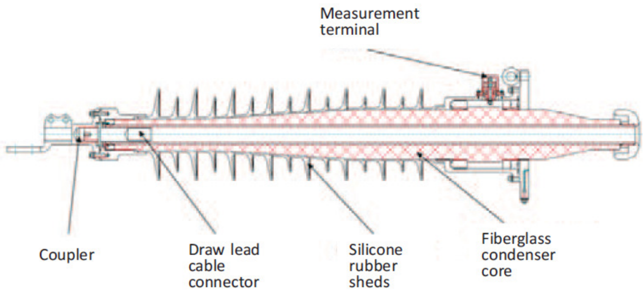

Figure 3: RIF™ Bushing construction [4]

III. RIF™ UNIQUE FEATURES

A. INSULATING MATERIAL, MECHANICAL STRENGTH AND SEISMIC PROPERTIES:

The main dielectric materials in RIF™ are an epoxy resin-fiberglass composite, which is significantly stronger at resisting moisture absorption than paper-based types. Unlike RIP bushings RIF™ doesn't need to be protected by nitrogen-filled sheaths during transportation/storage. Most importantly liquid-free insulation translates to non-requirement of sealing and thereby eliminating any concerns about leakages [4, 7]. The epoxy resin/fiberglass core composite is mechanically very strong. Literature shows for a 252 kV bushing cantilever load test failing value obtained is about three times the IEC requirement. To supplement this, as there is no porcelain (which is brittle non elastic material) for outer insulation, the bushings have higher seismic resistance capabilities with silicone housing [4, 7].

B BEHAVIOUR UNDER POLLUTION, MAINTENANCE REQUIREMENTS AND PERFORMANCE TRACK RECORD

Use of hydrophobic property of the silicone rubber to prevent flashover related failures in transmission and distribution network is well proven. Additionally uniform electrical field gradient which is resulting from the solid and very finely graded condenser core would further help. RIF™ bushings which are oil-free, much lighter provides an option of maintenance free as neither oil levels or internal stress measurement are needed. Detection of water ingress is not necessary with RIF™ design making maintenance purely optional. Literature published in 2014 shows an excellent track record of performance of RIF™ bushing. To be specific in the period from 2002 to 2013, over 10,000 units of 15 to 252 kV RIF™ bushings have operated safely in the grid. No failure was reported and thus delivering the reliability which is the need of the hour [4, 7].

IV IMPORTANCE OF CONDITION MONITORING

Condition monitoring (particularly electrical equipment) is extremely important as timely replacements can prevent catastrophic failures. As mentioned earlier bushing failures are one of the main causes of failures in transformers. It is well known that on-line monitoring of transformer bushing's insulation conditions can greatly help the cause. Technically the insulation condition can be monitored accurately by observing the changes of capacitive current of the condenser structure. If insulation faults can be detected early, and addressed in time, catastrophic failures such as fire/ explosions can be prevented. In summary a very safe operation of the grid is ensured when bushing insulation monitoring can be performed continuously and reliably. There are conventional methods used to perform the above operation but the lack of accuracy in these methods severely impaired the overall decisions. However a much improved new methodology is implemented in RIF™ bushings case. It was considered necessary to develop a special terminal for insulation monitoring of RIF™ bushings. It is obvious to ensure the accuracy is not compromised [4, 7].

A FEASIBILITY OF MEASUREMENT

In general, if a bushing capacitance is intensely affected by temperature, measurement errors of capacitive currents would occur and the bushing's insulation condition cannot be accurately evaluated. Literature shows even for RIF™ bushing monitoring the insulation conditions by means of capacitive current measurement is the method employed. However it is important to note that for RIF™ bushings they exhibit a weak sensitivity to temperature variation and hence this methodology would work accurately. In other words it can be interpreted as RIF™ bushing's capacitance, under large changes of temperature, varies within a short range, and also progressively [4, 7].

B PRINCIPLE OF OPERATION OF RIF™ - INSULATION CONDITION MONITOIRING

The core technology of on-line insulation monitoring device is based on the design/fabrication of voltage-grading capacitors in the bushings. Figure 4 shows the principle employed in this technique.

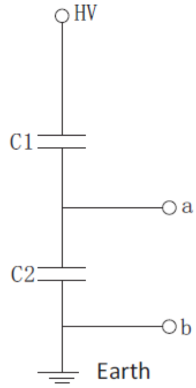

Figure 4: On-line insulation condition monitoring

Please refer to Figure 4 shown above. HV is the high-voltage end that is connected to the grid, C1 is the capacitance of the bushing's main insulation whereas C2 is the capacitance of the added grading layer. It is to be noted that C2 has a much larger value than C1. Both *a* and *b* are monitoring terminals connected to the two layers of C2, and further to intelligent equipment that performs insulation monitoring. Capacitors C1 and C2 are connected in series so as to withstand the voltage applied to bushing. As capacitance C2 is much higher than C1, externally connected monitoring equipment will under no scenario affect the bushing's main insulation, even in case of short-circuit and open-circuit. At the same time, determination of C2 takes into account impedance of the external monitoring equipment so as to ensure that almost all the capacitive current passing through C1 also reaches monitoring equipment. Thus, in the case of a core insulation fault (in which breakdown is to the first layers), the C1 capacitance increases, the capacitive current increases, and the monitoring equipment detects the increased capacitive current to trigger an early warning [4, 7].

The monitoring terminal in N-RIF is externally connected to an indicator light. No external power source is required for the indicator. The light is off when the bushing is in normal operation and will turn on only when a breakdown happens to a predetermined number of capacitive layers. This is shown in Figure 5. The maintenance crew would have enough time to conduct testing and investigate the cause without a sense of urgency and act upon it [4, 7].

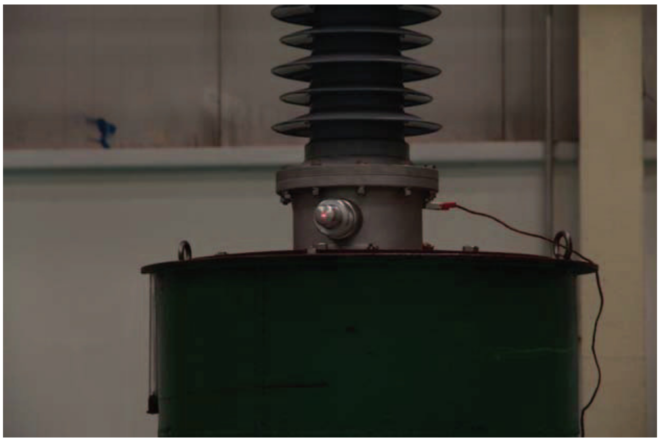

Figure 5: Insulation monitoring LED light ON.

- Safety

The distinctive characteristic features include its design of being highly safe and accurate even under scenario of extreme situations like short circuit fault or open circuit conditions occur [4, 7].

- Interference Resistance

Since the current sensed in general is weak, in conventional cases the signal received by window-type current transformers can be degraded to microampere levels and can easily suffer from interferences. However literature shows monitoring devices on N-RIF bushings, have excellent anti-interference capability as they receive milliamp class capacitive current directly from the additional layer [4, 7].

- Ease of connection

As N-RIF bushings can use the insulation monitoring terminal as the interface for output, users can easily connect the on-line bushing monitoring system to their IT platform to obtain real- time condition tracking, from any point in their network [4, 7].

- Track record of performance and future prospects

Literature highlights N-RIF bushings have been in use starting in 2011, and about 20 transformer manufacturers have been using them. Currently there are about 200 products from 72.5 to 252 kV which are in functional in demanding environment without any issues that are reported [4, 7].

Given this situation, it can be definitely expected that N-RIF bushings will progressively inspire users/suppliers to consider new approaches for safer operation of transformer bushings. Another important point to be noted is although they are typically installed on transformers at present, they can also be installed on other power equipment such as circuit breakers and Gas Insulated Switchgears (GIS) [4, 7].

CONCLUSIONS

This paper provides a clear overview of the conventional bushing technologies of OIP and RIP. However there were still several issues that both these technologies are failing to address. The introduction of dry-type RIF™ resin impregnated fiberglass condenser bushings have distinctive advantages over conventional OIP and RIP bushings, and is the single technical solution. RIF™ bushing technology has matured over the last 15 years and has an excellent proven track record. To further supplement, N-RIF bushings have been developed that provides a safe and reliable on-line insulation monitoring. As the failure of insulation is not instantaneous it provides sufficient time to deal with any fault detection. This makes the installation and operation of bushings much easier. Most importantly protects the monumental investment made in power transformer by providing a robust tool to avoid bushing generated transformer failures. Finally N-RIF bushings ensure safety and reliability of the power system network making it the choice of the present and future.

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