FAST RECOVERY ADAPTABLE TRANSFORMER FOR RENEWABLE GENERATION

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ABSTRACT

Nowadays, renewable generation companies are requested to prepare detailed contingency plans, to efficiently manage temporary grid unavailability in case of a transformer failure. The main strategy to meet these challenges is to use adaptable recovery transformers with regards to compact, fast recovery and multi-voltage solutions — showing proven reliability under most demanding emergency conditions. This is the latest trend today after some years of development in materials, OEMs design rules and close collaboration with end users.

The use of fast recovery adaptable transformers can significantly reduce reaction time — i.e., a compact single phase unit can be shipped and put into operation in just a few days. It would take weeks or even months to mobilize a large spare standard three phase transformer. The use of the right transformer technology, together with the use of high temperature material (as per IEC 60076-14), will allow to obtain reduced dimensions for such shipping activities. In this particular paper, a real case for a recovery shell-form adaptable transformer for renewable generation, having semi-hybrid insulation system, will be discussed. Both, compact shell and core form technologies are used for fast recovery applications. Selection of a design depends on the particular application, transportation limits and existing substation space limitations.

INTRODUCTION

This paper will deeply describe the characteristics of a single phase mobile semi-hybrid multivoltage shell transformer with OLTC. In particular, this development took place after client requested to dig about the possibility of counting with an extremely polyvalent unit that would enhance any previous reference. It should be used as an emergency back-up mobile transformer in fourteen different substations spread over an approximate 1000 km^2 area and should be provided with a significant amount of voltage taps plus an on-load tap changer (OLTC).

Therefore, the development consisted of a 550 MVA three phase bank, composed of modular semi-hybrid insulation single phase units, with multi-voltage capacity for different voltage ratio configurations by means of 400-220/220-138-66/33-20 kV rated voltages. These are the world's first mobile single phase transformer units tested at 420 kV with full voltage range and capacity OLTC of ±10% in HV. In the following figure, it can be observed the available main voltage levels provided, apart from the ones included in the OLTC typical range.

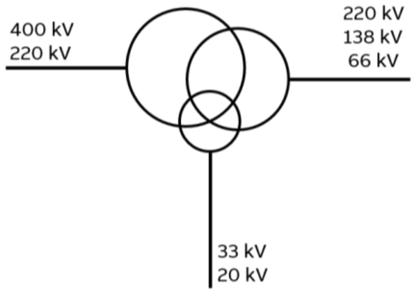

Figure 1: Fast recovery transformer main multivoltage taps

The paper will present as well the performed tests, measurements, collected data and main conclusions with regards to the calculated extra power that this transformer can provide under certain conditions, based on temperature rise limits provided by IEC 60076-14. This extra power requires to check also the ancillary equipment capabilities, like bushings, OLTC, magnetic shunts and current transformers.

As previously commented, in the past, some mobile multivoltage transformers counting with hybrid insulation system have being successfully designed and manufactured [1], however, this is the largest unit, in power per phase, that includes such a an OLTC. To finish, digitalization of this type of transformers will be also discussed; the main benefit is to know the loss of life rate under the above operating conditions and the available overload to keep transformer life expectancy at a certain level.

TECHNICAL DESCRIPTION AND RELATION WITH IEC 60076-14 STANDARD

Because of the type of the application of this transformer where every metric ton of shipping weight can really make a difference, during preliminary design stage of the unit several options were considered, including comparison between a standard full cellulose insulated transformer and the use of high temperature insulation as already acknowledged by IEC Standard IEC 60076-14 [2].

Based on the above and by using high temperature insulation only on the insulation of winding conductors, which is named semi-hybrid insulation winding based on

[2], it was possible to achieve a transformer with a shipping weight around 7% lower than the case of the same transformer only with cellulose material. The insulating fluid of this transformer was mineral oil.

The below Figure 2 shows one of this compact single-phase transformer during final testing. As it can be noticed, cooling equipment was made of air coolers also in order to make the unit more compact.

Figure 2: Transformer fully assembled during final testing

At this point it is important to remark that as part of the design, the unit was requested to allow on load voltage regulation, and therefore the transformer needed some extra windings and space to allocate the requested regulation and OLTC

One of the main challenges from design point of view of this type of units is to have accurate calculation of transformer temperatures, mainly windings hot spots, as those will be insulated by high temperature material but at the same time very near to standard cellulose material, that in case of reaching higher temperatures may lead to gases generation. For those reasons, manufacturer know-how and adequate tools that include CFD simulations (computational fluid dynamics) are of paramount importance.

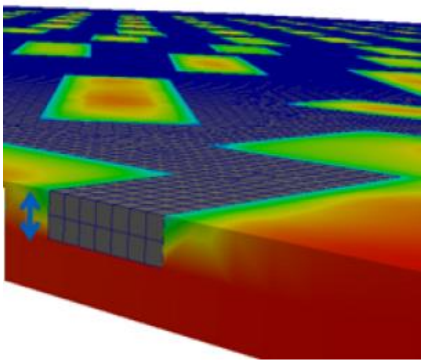

Figure 3: Example of 3D CFD modelling on a coil

Based on [2] the temperature limits agreed with the client for this unit were the following:

- Top Oil: 60ºC.
- Average Winding: 75ºC.
- Hot Spot Winding: 90ºC.

For validation purposes and because of the novelty of the unit, several fiber optic probes were installed in the windings during manufacturing in order to have a direct measurement on the windings hot spot.

VALIDATION TESTS AND OVERLOAD CALCULATED CAPABILITY

Because of being a new design and the thermal challenges mentioned in the previous paragraph, a thorough set of validation tests were performed, including temperature rise test with one cooler at 65% of the load (119 MVA) and with the two coolers at full load (183.3 MVA) taking thermal pictures and measuring winding hot spot during these test. Recorded values can be shown in the below graph:

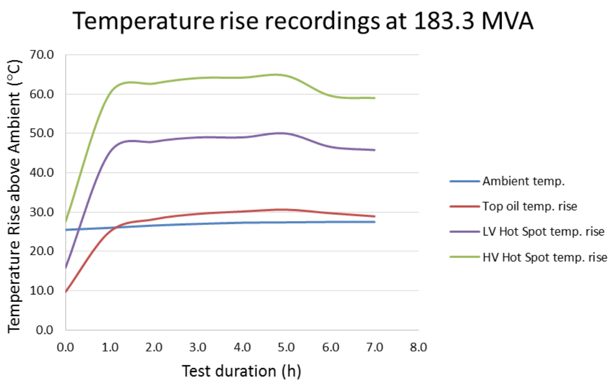

Figure 4: Temperatures recorded during tests

From temperature rise test two direct conclusions could be taken: transformer successfully passed the tests and the values were lower than guaranteed values, which means that these units had some flexibility for permanent overloading without going beyond IEC limits.

No abnormal gas generation was observed after the test. As part of the validation, thermal pictures were also taken as shown below:

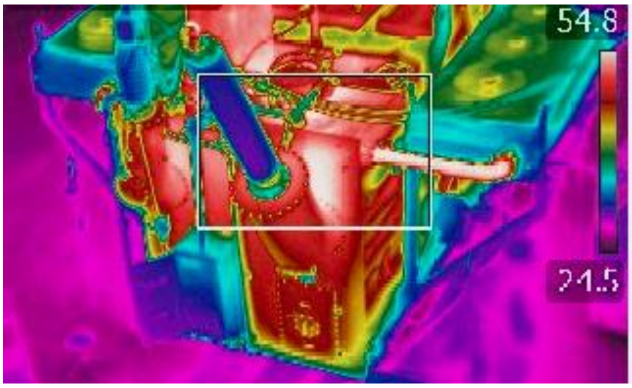

Figure 5: Thermal picture during temperature rise test

Taking into account the margin between guaranteed values and measured ones, it was considered useful to evaluate how much extra power can be obtained from the unit. After several extrapolations the conclusion was that the unit could reach 15% higher keeping temperatures below guaranteed values for permanent operation, which means from 183.3 MVA to 210 MVA.

To confirm the above it is also necessary to review loading capability of main current-carrying components and other metallic areas affected by the load, namely:

- Bushings and current transformers.
- OLTC.
- Tank walls and its magnetic shunts.

In this case all the above mentioned elements had enough margin so the power increase would still be valid.

DIGITALIZATION

The management of these overloads during transformers emergency operation, as well as transformer life expectancy information, must be properly evaluated by the user to take the right decisions regarding performance and units' reliability during their life.

Therefore, in order to provide the user further knowledge and management decisions inputs with regards to consequences of these possible overloads, as well as expert service collaboration with OEMs, a four step approach is recommended for all transformers generally speaking.

First, data gathering, sensors for measuring and data storing with digital communications should be provided to be able to run some data interaction, as for example, electronic winding temperature indicators, electronic oil temperature indicators, fibre optic sensors, DGAs, electronic Buchholz relay and pressure relief devices,… etc. Modbus communication protocol is recommended due to its reliability.

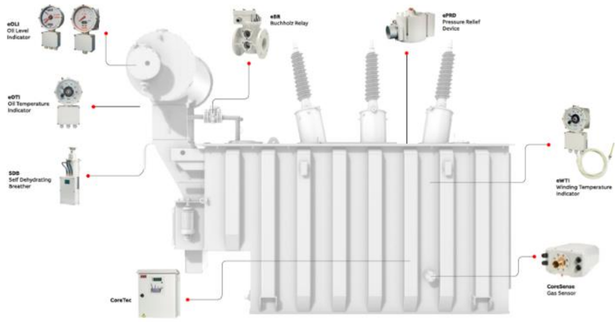

Figure 6: Full transformer monitoring devices

Secondly, data aggregation, electronic monitoring and diagnosis equipment should be included to efficiently manage the acquired information by the sensors in step one, this will allow to follow up the evolution of critical parameters and to set alarms when needed.

Third step, data analysis, is related with the main consequence of digitalization, what means, to practise detailed data analysis in order to simulate, optimize, automate and in summary, predict the equipment behaviour based on patterns to enhance the asset performance management. And finally, last step recommended is about close collaboration between user and OEM. By involving the service activity in the evaluation of the particular analysed data, consultancy and advisory activities can take place to optimize all the process and to improve the delivered product for future applications, therefore, allowing to keep growing the development of customized solutions like the one here-in introduced. Figure 7 below summarizes the whole process:

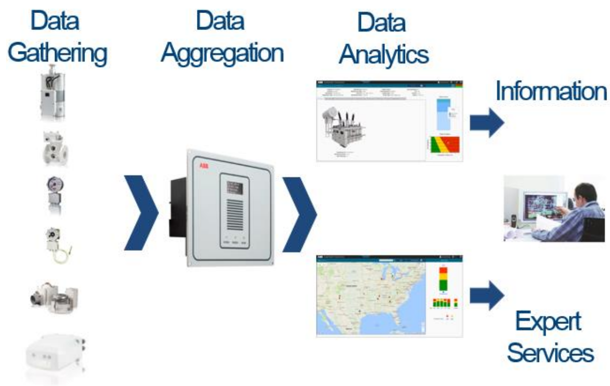

Figure 7: Step by step process

CONCLUSIONS

The development described in this paper shows that the feasibility of exceptional multivoltage mobile large transformers provided with OLTC is proven for the first time.

In other words, up to six main different voltages ratios are available in this compact 183.3 MVA 1Ph shell transformer by including two main high voltage levels and three main low voltage levels. Additionally to this, OLTC can provide ±10% voltage variation to fully adapt to life voltage adaptation demands during service.

Also, semi-hybrid insulation system as per IEC 600076-14 at 420 kV is proven as an efficient way to rationalize the use of costly high temperature insulation material.

Regarding the overload performance, it is stated the available theoretical overload would be 210 MVA, +15% compared to nominal rated power, keeping temperatures within guaranteed values. This can provide the user a safety temporary extra load during emergencies without extra loss of life, where the standard grid power flow may have suffered also from possible alterations, and robustness and reliability of emergency spare equipment is mandatory.

To finish, a simple 4 step process has been introduced to illustrate the digitalization of transformers, especially where the life expectancy and dynamic overload capability must be properly understood to efficiently manage the equipment performance during its life.

REFERENCES

[1] M. Cuesto et al, 2013, "Fast-deployable HV network transformer with hybrid insulation: a solution against mayor events", *CIGRE 2013, 54-PS3.*

[2] IEC 60076-14. “Liquid-immersed power transformers using high-temperature insulation materials” (Ed. 1.0 2013-09).