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A2 – Power transformers and reactors
PS3 – Best Practices in Transformers and Reactors Procurement

RTE's experience on transformers and reactors procurement

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SUMMARY

RTE, one of the largest utilities in Europe, operates a fleet of more than 1,300 power transformers for 245-kV and 420-kV grids with rated power from 100 to 600 MVA. It also operates neutral earthing transformers, substation auxiliary supply transformers, a few HVDC converters transformers and some phase-shifting transformers.

All these assets are expected to have a long service life as well as withstanding grid events such as short-circuits without endangering workers, the general public and neighbouring equipment. The equipment is also specified to ensure homogeneity of maintenance procedures even with transformers of different designs.

To achieve these goals, RTE indeed writes a detailed specification but has also set up a comprehensive qualification process to ensure quality throughout the manufacturing stage. The qualification process is conducted hand in hand with the purchasing department and the auditing department if needed. With this approach, manufacturers are evaluated from the factory – engineering, production, test facilities– to onsite installation services and after-sale service…

KEYWORDS

Power transformer – Reactor – Qualification – Factory – Manufacturing – Quality – Design

Introduction

Purchasing a power transformer or a reactor is an important investment for a Transmission System Operator (TSO) as they are costly assets and have a long-lasting impact on the grid. They take part, among other things, in power quality, reliability of the grid and enable the TSO to answer the users' needs.

RTE, the French TSO, operates a fleet of more than 1,600 power transformers and shunt reactors for the 245-kV and 420-kV grids with rated power from 100 to 600 MVA. It also operates shunt reactors at 24 kV, 245 kV and 420 kV as well as substation auxiliary transformers rated 24 kV, 250 kVA. In addition, RTE's assets include earthing transformers for the 63-kV delta-connected network. The French network also encompasses HVDC converter transformers at 420 kV AC side and phase-shifting transformers of all voltage levels between 72.5 and 420 kV.

Each type of unit serves a different purpose: for example 600-MVA, 400-kV autotransformers connect the 400-kV to the 225-kV networks. 500-kVA, 63-kV earthing transformers ensure that delta-connected networks are grounded and supply power in RTE's substations through smaller auxiliary transformers.

While all of them are power transformers according to international standards such as the IEC 60076 series, they all have their particularities which should be taken into account. Therefore, since RTE wishes to buy reliable and energy efficient transformers with lifetimes greater than 60 years, it has to adapt its procurement strategies to meet its diversity of needs.

This paper will describe the technical aspect of procurement; that is the qualification processes that RTE has set up, from the initial technical assessment of manufacturers to the final factory acceptance tests (FAT) and the question of subcontractors, design reviews and warranty.

Factory qualification

RTE favours framework contracts for its usual range of transformers and reactors. That is, 90% of transformers and reactors purchased by RTE are bought on such contracts. Notable exceptions include, but are not limited to: HVDC interconnections, transformers for offshore projects or offshore platforms, and unique pieces tailored to very specific needs such as phase-shifters or series reactors, which are all purchased on spot contracts.

Call for tenders are opened to all factories that have been previously screened in a process called "factory qualification". It is important to note that RTE has chosen to qualify factories and not brands, and this choice dates back decades ago. It is widely recognized that Large Power Transformers are mainly handmade, which therefore give the manufacturing workforce a heavy weight to the overall quality of the transformer. This choice is also in accordance with the definition of type tests as per IEC 60076-1 [1], which limits the validity of type tests to a single factory. Any factory that wishes to provide RTE with power transformers can apply to the qualification process. Figure 1 provides an overview of the procedure.

Applicants are assessed on their abilities to design, manufacture and test transformers [2]; but also their environmental impact and corporate social responsibility (CSR). The factory assessment includes also the R&D capability and the autonomy of the manufacturing plant. As transformers may face deviations during their manufacturing process, it is crucial that the workshop have immediate access to technical skills for efficient and safe resolution of non-quality problems.

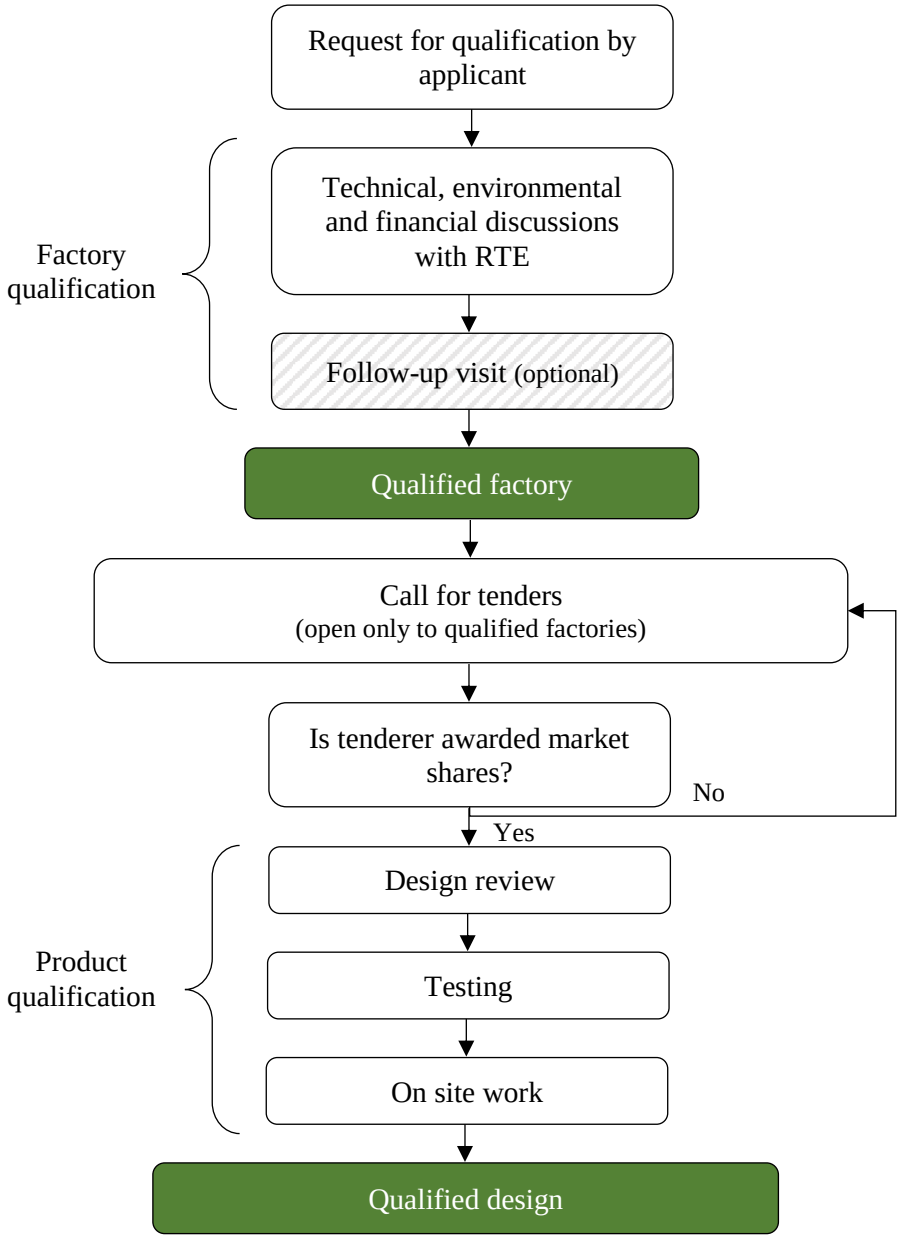

Figure 1 - Overview of RTE's qualification process

Manufacturers shall choose one or more categories[1] among the following:

- Medium power transformers with Um ≤ 36 kV
- Large power transformers with 36 kV < Um ≤ 145 kV
- Large power transformers with 145 kV < Um ≤ 245 kV
- Large power transformers with 245 kV < Um ≤ 420 kV[2]

- Phase-shifting transformers and quadrature boosters with Um ≤ 245 kV
- Phase-shifting transformers and quadrature boosters 245 kV < Um ≤ 420 kV

[1] Medium and large power transformer categories are defined according to European regulation EU/548/2014 [5] and its update 1783/2019.
[2] The French network does not have voltage levels above 420 kV.

- Shunt reactors with Um ≤ 52 kV
- Shunt reactors with 52 kV < Um ≤ 245 kV
- Shunt reactors with 245 kV < Um ≤ 420 kV

- Large power transformers for HVDC LCC
- Large power transformers for HVDC VSC

Then, detailed questionnaires are sent to the applicant: one for technical questions, one for environment and CSR and one financial for the procurement department.

Technical questions may range from the number of workers at the factory to the ability to provide customer service and spare parts. Questionnaires are the same for all but requirements may differ from one category to another. For instance, testing facility expectations are different depending on maximum voltage Um. Not only does this recognizes the extent of the state of the art, but also the necessary adaptation of requirements to the risks caused by the transformer when in operation.

For environment and CSR, RTE may look into: number of accidents over the last five years, CO_2 emissions, energy consumption, waste management, recycling, biodiversity, selection of subcontractors... This distinct form has been recently added to reflect RTE's focus on global environmental issues and its efforts to reduce its environmental footprint. With this comprehensive set of questions, RTE wants its suppliers to be involved in the approach. Data submitted by manufacturers are used by RTE to perform life-cycle analyses, evaluate the grid's impact on the environment and recommend certain choices to decision-makers.

Questions are also asked on training of workers: as large power transformers are mostly handmade, regular good quality training is of utmost importance. Knowledge sharing ensure reliable transformers are manufactured and long lifetime assets will be installed on RTE's network.

All the applicant's answers are then compiled and graded. If needed, a follow-up visit can be organized to take a closer look at some specific points.

In the end, if the applicant reaches a certain threshold and has provided no eliminating answer, the factory is qualified. Factory qualification lasts for as long as there is no significant change, either in the process or in the equipment that may have an impact on the manufacturing quality – and allows manufacturer to answer RTE's call for tenders.

To make sure manufacturing quality remains the same throughout the years, RTE has set a goal of auditing all of its suppliers over the duration of a 5-year framework contract. If auditing results are deemed poor, qualification status may be questioned and manufacturers asked to fill in qualification questionnaires again.

Product qualification

Design review

Once call for tenders is answered and contract is awarded, a new phase begins with the qualification of the actual design of each successful tenderer. RTE calls this time frame "product qualification". It starts with the design review.

Kick-off meetings are organized and several design reviews may be held. Some manufacturers would rather meet once and go through all technical points whereas others prefer to split up the process with one electrical design review and one mechanical. To ensure a durable design of power transformers, RTE is actually ready to take part in as many technical sessions as needed.

In the meantime, a lot of documents are exchanged back and forth between technical teams. To allow for in-depth discussions with manufacturers, RTE has developed its own calculations tools. Such tools

span all aspects checked during a design review: sound levels verification, temperature rises, estimation of losses, ability to withstand short-circuit, etc. [3]

They may not be as precise as actual design tools like 3D modelling of thermal behaviour but provide coherent orders of magnitude. With these values, RTE makes sure key points are in line with the specification and that no blind spot remains in the design. During this phase, RTE must have access to sensible information and confidentiality is ensured.

At this stage, manufacturers also propose a list of subcontractors for accessories: bushings, current transformers, Buchholz relay, pressure relief device… RTE has chosen not to directly qualify subcontractors and to leave to the main supplier the responsibility to provide references complying with RTE's specification. Nevertheless, RTE requires all type and routine tests of components be supplied for review. The experience (good or bad) on some vital equipment is shared with the manufacturer, and extra tests may be required from unknown or badly known suppliers. Besides, RTE regularly remains its suppliers of their obligations in terms of CSR.

Design reviews are also a good time to discuss tests that will be performed on the transformer or the reactor. RTE follows the guidelines of IEC 60076 but may choose to apply additional conditions to better account for the reality of the transformer operation or to add extra security margins. For instance, RTE has chosen to limit the hot spot temperature rise to 75 K instead of the 78 K proposed by IEC 60076-2 [4]. More information about test procedures will be given later in this paper. As a key player in the standard elaboration, RTE recognizes that the standards are the result of consensus that may not always fulfill the requirement of a utility, while providing a good working basis for all.

General documentation is examined during the qualification process as well. Complete and well-prepared documents must be provided for operation and maintenance teams as well as for technical departments. After all, they shall be used during the entire life of the transformer. They may also be of critical importance in case of transformer failure if repair must be undertaken. Especially if the manufacturer no longer exists or has disappeared without any legacy. RTE actually suffers from poor data on old transformers which make repair and upgrade very difficult and risky by lack of design details, for instance on electrical field control around bushing tails.

In addition, the ability to provide good quality documentation demonstrates the manufacturer's know-how and is often a guarantee of quality for the device. Besides, the construction of asset management policies is facilitated when the fleet is well documented.

When every detail is cleared and the design is finalized, the first unit can be built. At this point, the design is "frozen" and any change shall be submitted to RTE for approval. If minor modifications are requested (e. g.: modification of the numbering of the terminals), they can be integrated immediately in most cases. For more significant modifications of the transformer design (e. g.: sound levels, connection symbol, rated voltage, rated power, design of the active part), RTE prefers to wait for the renewal of the contract. These types of modification shall indeed lead to a new qualification: design studies, type and routine tests.

Changes in subcontractors, even minor ones, shall also be submitted to RTE for approval and the relevant documentation shall be updated accordingly. This is of crucial importance for maintenance and spare parts. RTE has decided for long to centralize spare parts and reduce to a minimum the number of them. Any new parts not ensuring interchangeability must be evaluated.

Manufacturing checks and Factory Acceptance Tests

Due to the duration of the design review, it usually takes a few months before the construction of the transformer begins. Before testing, some TSOs carry out on-site manufacturing checkpoints. RTE has chosen to do otherwise and to rely on the tests to confirm the quality of the design eventually. As the factories have been assessed for quality previously, RTE trusts the manufacturer and does not plan to attend manufacturing operations.

However, RTE has set up a payment term system allowing to carry out general verifications during the manufacturing process. They require the supplier to submit documentation as it is ready. For example, receipts of essential raw materials such as copper and steel sheets are controlled to ensure compliance with the design. The validation of raw material receipts triggers part of the payment for the transformer. Other steps include submission of extensive test reports, documentation and completion of work on site.

Besides type and routine tests, first units are tested for short-circuit in the vast majority of cases.

According to its own records, failure rate of short-circuit-tested design units are 3 to 7 times lower than those of non-short-circuit tested designs. This justifies to test any first unit of a series. Experience has showed that even renowned manufacturers with extensive experience on short-circuit tests can fail. Short-circuit testing is a key parameter in tightening and keeping straight the manufacturing process. The short-circuit test allows to recalibrate the design parameters and is the only way to ensure that the transformer will not trip during an external event. For network application it is not allowed that a transformer trips on external event. The lines and busbars are protected by themselves and their own protection shall isolate the fault without violently impacting the transformer.

No other means than actual test can provide evidence that the Buchholz relay or the PRD will not operate under short-circuit conditions.

RTE asks that all tests except the short circuit withstand ability test be organized in the factory. It is a good opportunity to assess the test bay of the factory and again, the quality of the work done. The type-tested unit is fully equipped during the type tests to correct any deviation before it is detected during installation.

Just like the design review, RTE has developed internal tools to compare results with testing teams. It is also an efficient way to check whether the transformer or reactor passes the tests or whether the guaranteed values are met without waiting for the official test report.

Such tools use raw data from tests sensors (e. g.: data from sensors during temperature rise tests) and are used by RTE to draft its own internal report. They also enable technical discussions and a fair exchange of information should any problem happen during the tests.

RTE usually does not witness routine test of repeat units. RTE does not accept test report showing only final corrected values: all measured data shall be part of the report in order to repeat or perform extra calculation if needed.

Validity of design

If the transformer passes the test and after the report is verified, the last phase needed to finally pronounce the qualification is the onsite installation. If everything goes well, the product qualification is awarded to the manufacturer. A year may have passed since the signature of the contract. RTE, with optimization in mind, keeps a transformer qualified (design in line with specifications, validated type tests, including short-circuit test) for as long as necessary provided new specifications do not call into question its active part.

It means that identical designs can cover several contract periods. This allows for flexibility in orders and project planning.

However, the evolution of energy efficiency regulations has recently pushed RTE to qualify new references. On a related note, changes in capitalization values also trigger the qualification of new designs, all things being equal.

Once completion of work onsite is done, the transformer is guaranteed for 5 years. Paint and anti-corrosion coating are guaranteed for 7 years.

Conclusion

RTE's technical procurement strategies can be divided into two stages. First, manufacturers go through qualification factory and then, product qualification. Each step of the procedure is an opportunity to have in-depth technical discussions and to ensure RTE will be able to purchase durable units.

Having reliable and quality transformers and reactors is imperative for RTE to fulfill its missions as a TSO, answer its clients' needs and develop coherent asset management policies and these demands are passed down to its suppliers.

From the training of workers to the verification of receipts for raw materials and a thorough design review, RTE tries to check as many aspects as possible on the design and production to ensure the quality of transformers and to build long-lasting working relationships with its suppliers.

With decades of experience with power transformers qualification, this method has yielded great results so far with RTE benefiting from a reliable grid and accumulating deep technical knowledge about its assets.

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