MANAGING CRITERIA APPLIED ON EXISTING MEDIUM SIZE DISTRIBUTION TRANSFORMERS

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1. SUMMARY

Starting from the nineties, the Italian market has undergone drastic changes mainly due to the privatization process of the former public energy authority (ENEL).
These changes have involved both private energy producers and users resulting in a global characterization of the local market philosophy which has rapidly adopted the new market concepts.
The reduction of the prices and the strong cut in investments, with regard to new equipment, have resulted in the necessity of approaching, with new concept, the "service activity" devoted to the existing units.
In this frame, one significant example of activities regarding re-powering of existing transformers, carried out in co-operation with ENEL, is examined in detail.

2. THE CHANGING ON THE ITALIAN MARKET

Starting from nineties, the Italian transformer market began to change the strategic criteria related to the purchase of new units and the managing of old units that had characterized a long period before.
Even thought this changes were mainly initiated by ENEL that, at that time, began its internal privatization process, the resulting criteria were rapidly adopted also by private energy producer and big electricity users so resulting in a global characterization of the Italian market.
Anyway, the situation is not different in other European and world countries where the electricity companies are undergoing similar processes.
As a consequence we deem that the example given here below, even if related to Italian companies, could give proper and significant information to all people involved in the managing of existing transformers.
The traditional Italian market, mainly regarding to public company, was characterized by:

- continuos flow in the purchasing of the new units,
- redundancy in the quantity of the purchased transformer this reflecting the managing criteria at site were the units were exploited between 50 to 70% of their rated power,
- firm prices with automatic updating based on changes of the cost of raw materials and manpower,
- acknowledgment to the supplier companies of a proper production margin (the minimum return below which the activities are not profitable enough to be continued),
- competition limited to a reduced number of approved suppliers (i.e. companies able to supply transformers in accordance with prototype units that undergone positively all type and special tests including also short circuit test at full scale).

The above market frame, even if periodically affected by recurrent crisis, gave to the supplier a considerable bases to elaborate their developing strategy as well as to define the employment plans.
This stable market situation has been forced by following events:

2.1 Opening of the Italian market to other EC countries

This event changed the Italian situation from a closed (and partially protected) market to an open to all main European transformer producers one.
This leads to a considerable price reduction (about 35% in three years) which is far below the "production full cost" of most the Italian suppliers. The relevant reaction of suppliers was the extreme rationalization of the productive process characterized by the reduction of manpower (very strong problem in Italy due to trade union power) and by the application of innovative criteria.
The innovations involved not only the technological aspects of the production (means, tools and process) but also a complete re-engineering of the design aimed at an apparently insoluble goal: i.e. the reduction of the material cost and the simplification of the manufacturing solutions (this resulting in a lowering of the man-hours) respecting at same time the technical specification in force which increased significantly the required quality level.

2.2 Drastic cut of investment

The privatization process of the public authority was accompanied, since the beginning, by considerable

reduction of the purchase of new transformers. This was required by the necessity to cut the investment and was made possible by the redundant asset of the Italian grid.
Such a situation leads the more organized transformer manufacturer to approach the merging markets of Far-East, Africa and China, so as to compensate the local lack of orders. Locally the alternative was found in new idea regarding the maintenance activity of old units that the present paper deals with.

2.3 Revision of the managing criteria of the electrical power plant

In parallel to the above events, one testifies the modification of the central authorities in taking any decision with economical value: the decision comes off directly by the person in charge for the specific business (production plant or interconnection station) so resulting in a decentralization of the decision maker.
In this frame the decision makers need to properly balance the risks and the economic convenience for any possible solution. Thus resulting in the need to supply with more detailed information as well to go in deep also with regard to the technical content of different solutions.
Even though the decentralization of the decision may lead to a different valuation for the same situation, this depending on the capacity of the responsible to assume risks or his prior experience for similar events and of the urgency to restore the service. It resulted in an increase of the local managing capacity and in a better economical results for the company.
Even if the result of the present market's situation has entirely influenced the strategy of the transformer's supplier, in the present paper only the influence on service activity is taken into consideration. This will be done mainly through the following example involving the former public authority. Anyway at the end of the paper we will synthetically mention another more complex example (involving a large private producer) that is very significant in the frame of innovation since the whole repair and refurbishment activities have been carried out directly at Customer site.
Anyway before going into detail, we would like to underline that, in this market frame, the service's supplier should not only have adequate solutions but also is required to "put one's cards on table" this mean to supply in a "transparent way" all economical and design data for the purpose of a proper evaluation.

3. DESCRIPTION OF ONE SPECIFIC CASE

The case that raised in the urban area of Rome was a consequence of ENEL's decision to abrogate the existing 8,4 kV secondary network in order to have the standard value of 20,8 kV, as in the rest of Italy. This, beside other modification, should have required the replacing of the existing 150.000 ± regulation/ 8,4 kV transformers with new standardized units of 25/31,5 or 40/50 MVA (ONAN/ONAF).
According to ENEL file, thirty units in the range of 16 to 40 MVA, manufactured in the years from 1955 to 1987 (being 20 in service and the other stored in the substation areas as spare or faulty) were involved in such a problem. Significant differences were reported between these transformers (supplied in accordance with the technical specification in force when manufactured), and the new standardized units. These differences are not only in term of secondary voltage but also in terms of other functional characteristics (i.e. short circuit voltage, noise level, losses, short circuit withstanding tests, new type of accessories).
Such situation, plus other considerations, lead ENEL, to state that, any proposal related to the refurbishment of old transformers, should have included following conditions:

- the refurbished transformers to be in full accordance with the Italian standards as well as with the latest ENEL DT 1092 technical specification including the withstanding of the short circuit stresses and with the only exception to maintain the existing regulating scheme since this was a precondition to re-use the existing On-load tap-changers only with a special maintenance,
- refurbished activities on **"full service"** bases, i.e. the proposal had to include all foreseeable activities starting from the site removal and transportation to factory up to the re-energization after the refurbishment,
- **"inclusive price"** for each single activity, i.e. the supplier should assume all risks for any unforeseen or not completely evaluated event,
- **only one company responsible** for all service activities (including main supplier responsibility also for third party auxiliary services
- free access for ENEL and supplier to data necessary for carrying out the analysis of economical convenience. Such analysis should have to include also the capitalization of relevant losses.

As a consequence of the above condition, it was decided not to take into consideration the oldest units (manufactured before 1976) due to high losses values.

3.1 Technical data of transformer after refurbishment activities

According to ENEL pre-requisite the existing transformers after the refurbishment activities should have the following characteristics:

Rated power	[MVA]	the original one (25 or 40)
Rated voltage	[kV]	150 ± 8x1,5% / 20,8
Frequency	[Hz]	50
Connection		star /star with neutral
BIL	[kV]	650 / 125
Type		ONAN

Other data in accordance with ENEL DT 1092 technical specification, including the ability to withstand and to be tested at a full-scale short circuit tests. It should be kept the OLTC regulating scheme based on coarse plus fine regulating windings (if actually existing) instead of reversing switch regulating scheme as required on DT 1092.
For each transformer it has been included the option for the eventual uprating to ONAF condition (by adding the required number of fans and auxiliary components) with an increase to 1,25 of actual rated power (OFAF rated power to 31,5 or 50 MVA respectively).
In addition, also all guaranties data for both situations, before and after the refurbishment, have been supplied for each transformer under consideration.
See here below an example for a specific 40 MVA transformer:

Guarantee data		**Before refurb.**	**After refurb.**
No load losses at Vn	[kW]	**37,3**	**30**
On-load losses at 150/LV kV	[kW]	**163**	**180**
Vcc at 150/LV kV	[%]	**12,5**	**15,5**
Noise level	[dbA]	**69**	**60**

3.2 Extension of activity included on "full service" proposal

The main activities included in "full service" proposal comprised the followings:

[a] Preliminary inspection at site to define the status of the specific unit
[b] Removing of the transformer from service bay and transportation to factory
[c] In case of need decontamination from PCB at supplier factory.
[d] Refurbishment of the unit at supplier factory (including rewinding, maintenance of the OLTC and other accessories, treatment and acceptance tests)
[e] Return transportation to service site and re-energization

Even thought, for each item of the above activities, a detailed list of activities and time schedule has been submitted, in the present paper we would like to underline only some specific and "non traditional " aspects.
No particular evidences are to be underlined with regard to transportation activities of item [b] and [e] since the units into consideration are generally transported fully assembled and filled with oil.
With regard to the preliminary inspection at site [item a], we underline that it was aimed at defining the present status of the individual transformers (through visual inspection, information related to bushings type and supplier, number of OLTC operations, collection of an oil sample for laboratory checks, mapping of any oil leaks, registration of eventual anomalous events or faults and with particular relevance to specific special maintenance activities, etc.) as well as their actual location for transportation aspects.
Anyway, with regard to other activities some particular aspects are more clearly explained below .

3.2.1 Some additional details regarding to activity [c] "Case of PCB (polychlorobipheniles) contamination"

In case of units contaminated by PCB over the legal limit (50 ppm for PCB contamination census and 25 ppm for oil vast) the first activity to be carried in the factory is the decontamination from PCB of the whole transformer. This operation is required not only for economical reasons but also for factory safety and health regulations for the manpower.
The PCB decontamination is normally carried out by a specialized chemical dealogenation process that consists in the continuos circulation of the transformer oil in an external closed equipment that is capable to extract the PCB from the oil. In series to this specific equipment the oil undergoes a traditional degassing and filtering process. The duration of the process depends on both oil mass and PCB level content.
At the end of the process the oil and the transformer are then classified "PCB free" i.e. with a PCB content in the oil and in solid materials below 5 ppm.
From the economic point of view, the opportunity to carry out this process as first activity is connected to the following reasons:

- In case one decides to go-on with the refurbishment activity up to its completion, the oil and all internal components of the old transformer can follow the normal process steps and production cycles without starting up with very expensive actions to avoid the contamination of the factory's equipment and of the new units under process.
- In case, after the visual inspection of the active part (see item below), one decides to scrap the transformer (being judged not convenient to refurbish) the oil could be re-used in other units and the metallic parts of the transformer can be sold as scrap in order to balance not only the cost of the decontamination process but also a part of the other costs already paid out.

3.2.2 Some additional details regarding to activity [d] "Refurbishment of the unit at supplier factory". This is a classic repair/refurbishment activity but, in the present case, the following particular steps should be underlined since they are quite out of standard.

[a] All design activity has been carried out before the arrival of the transformer to the factory, i.e. same procedure as for new units. In fact a preliminary design has been carried out during the bids phase thus allowing to supply ENEL with the price relevant to all possible alternatives (replacing of one or more: HV windings, LV windings plus all possible other combinations).

Then upon issue of the Order by ENEL, the final design has been completed in advance so giving the possibility to issue the preliminary orders for the supply of the materials and shorten the delivery time. This is possible because ABB has in its files the design information relevant to about 85% of the transformers installed in Italy and pertaining to 21 different companies that in different time merged together and finally merged into ABB.

[b] The final decision whether to continue the activity is jointly taken after the inspection of the active part. In fact this operation together with the information collected during the on site inspection and on the basis of the inclusive price issued during the biding offer, allows ENEL to decide to:

- recuperate the unit since this operation is technically feasible and economically convenient
- scrape the transformer being this operation in the cases of the inclusive price included in the offer resulting in an economic balance of the costs incurred till this moment (visual inspection on site, transportation, decontamination activity and active part extraction).

In conclusion we underline that the whole refurbishment activity (starting from disassembly up to the final tests) undergoes the same quality level of the new transformer being in fact applied both quality procedures and main equipment (winding machine, vapor phase system treatment, test room, etc.) in force for new units.

3.3 Criteria adopted for valuation of economical convenience

ENEL, to define the economical convenience to go on with refurbishment, stated very ambitious targets, based in a % of the full price of the equivalent new unit, as follows:

- refurbishment activity on its basic solution (as described on above items without PCB decontamination)
  target = less than 60%
- as above but including one or more of the optional activities (re-painting of the transformer, repair and touch-up of the radiators, replacing of the HV bushings, re-making of the control circuit plant)
  target = less than 70%
- uprating by inclusion of the OFAF solution
  target = plus 10%
- PCB decontamination: fixed prices depending of PCB content and oil volume

The full prices for new and old units have been evaluated according to the terms highlighted in the following table.

New transformer		**Refurbishment**	
Element for full price evaluation	**Value**	**Element for full price evaluation**	**Value**
Purchasing price	**An**	Refurbishment price	**Ar**
Transportation price	**Bn**	Return transportation price	**Br**
Capitalization of losses price	**Cn**	Price for capitalization of losses	**Cr**
Old transformer residual value	**Dn**	Value of scraped copper	**Dr**
Old transformer scraping value	**En**		

New transformer full price = [An + Bn + Cn + Dn - En]

Refurbishment full price (basic solution) = [Ar + Br + Cr + Dr]

We underline that the capitalized price of the losses was calculated on the basis of following figures:

- transformer service life 20 years
- rate of interest 8 %
- actual cost of no-load losses 7.200.000 L/kW
- Actual cost of on-load losses 1.100.000 L/kW

At the present a group of four transformers have been refurbished being two already re-energized and other two in preparation at factory for final acceptance tests.

4 SHORT CONSIDERATION ON REPAIR / REFURBISHMENT AT CUSTOMER SITE

In some situation the economic evaluation for consistent repair/refurbishment is deeply affected by transportation costs (from site to factory and back to site). This is not the case of the example analyzed in the previous item since it deals with transformers located near the repair factory (distance of a maximum of 20 km) and that do not require special transportation wagon; consequently the transportation costs do not influence greatly the full price of the repair.

Anyway when the distances from site to factory are larger and one deals with heavy transformer's weight the transportation costs impacts heavily on the total repair cost. In such a situation the repair carried out at site results in a very significant money save.

Our Company has been successfully involved in a specific case that raised on the extreme south of Italy near a large private producer of energy (500 MW plant) i.e. about 500 km from any transformer's factory with proper capacity for the transformers in consideration.

The repair/refurbishment activity involved three 100/100/30 MVA, 220/75/10,5 kV units from different suppliers and manufactured in different times but with identical characteristics being two normally in service and one out of service because failed. The refurbishment activity included the substitution of all windings with

changing of the value and regulating range on MV side (this to obtain a significant raise of the plant productivity) and; in addition to this, the new plant lay-out required the modification of the existing HV bushing assets (traditional oil-to-air assets) to oil-to-oil bushing for direct connection to cable end termination.
Anyway it should be underlined that to be successfully in a so consistent repair activity at site the following main steps must be followed:

[a] to manufacture the complete sets of new windings at the supplier factory. (the winding sets were fully assembled, tested and treated i.e. impregnated with oil under vacuum at factory so resulting in a component ready to be installed at site directly on the relevant core leg).The sets were than fastened with vertical tie rods to grant a safe transportation and the maintaining of the axial dimension according to the design and wrapped in a sealed bag to avoid any contact with the atmosphere.

[b] Implementation of the required degree of cleanliness on the operating area at site. As known the achievement of the required quality level in the manufacturing of a transformer requires a high degree of cleanliness in all the manufacturing steps.
It means that, in addition to the direct exposure to atmospheric agents, it is also mandatory to avoid any direct or indirect contact of all transformer components and mainly of the insulating structures with dust, fumes, metallic particles and with every kind of polluting agents.
For these reasons even though, at site, a closed building equipped with adequate lifting means was available, being not considered sufficient the degree of cleanliness of such area, it was decided to install an additional closed box to house the transformer's active part and the working area. The main dimension of the box when completely closed, were: 11 x 6 m x 5 m height.

[c] On site dielectric and routine tests. As in the factory the final tests are aimed at giving to the Customer:

- the guarantee of the integrity of the transformer's insulation characteristics
- the fulfilling of the guarantee data in term of losses, no load current and short circuit voltage
- the assurance that the transformer can be re-energized without any problem.

Anyway one should underline that such on site acceptance tests are not always and easily feasible on site because this requires proper equipment as well as the availability of voltages and power adequate for feeding the various winding during on-load and no-load tests.
In the specific case for dielectric test it was employed a mobile 130 Hz laboratory composed by:

- moving and transportation equipment consisting in a diesel tractor (360 CV) and in a 13 m length trailer on which all laboratory component are housed
- Hz feeding and supply circuit consisting in a motor-generator-dynamo system with two transformers able to elevate the secondary voltage up to 200 kV
- the control and measuring laboratory equipped with computerized system of digital signal related to partial discharges and other test values.

With regard to no-load and load measurements it was used standard laboratory instruments and a local existing feeding 10 kV line. The no-load energization of the tertiary side of the transformer (i.e. 10 kV winding located near to the core column) required a proper study to avoid problem connected to the inrush current phenomena.

[d] Proper treatment equipment and procedure. This is a very important task since it may result decisive in the final exit of the repair activity. Anyway it should be considered that such activity is not so easy to be carried out since, at site the equipment used on transformer factory (mainly based on vapor phase system) is not available. Anyway by employing proper equipment and mainly by applying proper procedures one may meet the same degree of active part's dryness as in factory (below 0,5%).

5. FINAL CONSIDERATIONS

The privatization process of electrical utilities boards and, in general, the greater sensibility towards the economical aspects, lead to a substantial revision of the traditional concepts of investment.
This introduces therefore a new scenario as regards to the management of maintenance and refurbishment activities, where the decision makers assume a very active role and an high degree of responsibility.
In such a situation the customer needs to require a new approach far from to the traditional criteria.
The above examples show how the decisional and operating processes are composed of many technical and economic moments that require e deep evaluation of different solutions with regard to technological and diagnostic new criteria.
In this frame, positive results are obtained through a trustworthy and open relation between supplier and Customer, mainly during the preliminary stage, aimed at searching the best and less expensive solution.