RISK ASSESSMENT CONSIDERATIONS IN LIFE CYCLE ANALYSIS

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ABSTRACT

The need of an integration between Risk Assessment (RA) and Life Cycle Analysis (LCA) methodologies is considered one important objective in all major companies environmental policy. ABB Ricerca, the Italian branch of ABB Corporate Research, has recently introduced the environmental analysis and RA procedures as a priority target of its own research activities: during the development of resources and environmental analysis, applied both to single operations and to "cradle to grave" systems, risk considerations have emerged as a complementary element to be investigated. While LCA methodology refers to normal conditions of a production system, RA considers also the effects of possible events with a low probability to occur. The use of both methodologies in a systematic procedure provides therefore a more complete set of information to make value judgments about resources conservation, pollution prevention, health and environmental safety. The application of this procedure in the design stage of an electromechanical system is here briefly presented in order to show, in an operative, way problems and advantages of the combination of these techniques.

INTRODUCTION

The recent publication of the ISO 14.000 series has increased the support to the efforts of all those companies, mainly large and multinational, in the field of respect of the environment.
All the initiatives should be defined according to the particular features of the company: electromechanical industries, for instance, are at present chiefly committed to study the environmental burdens associated to the use and post-use phase of the products, which are generally characterized by a long life-time. In some cases, environmental improvements were directly obtained from the results of LCA studies: low voltage switchgears, electrical engines and power transmission lines are some examples of systems investigated at ABB. Since all these systems are characterized by processes with simple assembling stages and by a long life-time, the design phase is considered the critical stage, responsible of possible impacts to the environment. In the same stage, some other parameters such as economic, risk, reliability, technological performances, and dimensions, can't be ignored. A multicriteria analysis seems therefore the right approach to obtain a comprehensive set of information to be used in the decision making stage. The attempt to implement RA and LCA procedures using a

multicriteria analysis can be a first step of this new approach and the case of a power transformer is here presented.

LCA-RA OPTIMIZATION TECHNIQUE

The optimization of a system in terms of minimization of environmental impact and risk during the life cycle consists of the search of a set of values X={x1, x2, x3, ...} that minimizes the consequent global environmental burden and the global risk associated to the system itself. In a simplified approach, the environmental impact categories (GWP, ODP, AP,..) and the risk factors (Explosion Risk, Fire Risk, Fume Risk, ...) can be considered a direct function of X:

$$F(X) = \{E,R\} : \Omega \rightarrow \Re^n \quad (1)$$

where $\Omega = \{X \in \Re^m\}$ is the domain for X; n is the total number of impact categories E and risk factors R; m is the dimension of the X vector and F(X) is the function to be minimized. Minimization of F(X) can be obtained within a constrained framework. Various methods have been defined to look for the minimum: Linear Programming, Quadratic Programming or iterative numerical methods.

Applying this procedure to the liquid-filled power transformers, it was possible to obtain some interesting results. The RA study gave different useful information first about the relevant components of F and then about some relevant components of X. It was also seen that, while the X components, which are relevant in RA, range in an almost discrete set of values and they consist in the choice of different materials, the X components, which are relevant in LCA, are defined in a continuos set and they consist of quantity of materials and design criteria.

TRANSFORMERS APPLICATION: LCA APPROACH

Liquid immersed power transformers are made mainly by steel, aluminum and copper components, magnetic sheets, insulators and insulating fluids. The assembling stage is generally a simple process and the main environmental impacts has to be investigated during the upstream operations(raw material mining and transformations) and the life-time (energy losses, spills of the dielectric fluid).The information coming from the LCA could address, for instance, the material selection and design criteria, but to improve the general performances of power transformers, a parallel RA study should be also performed.

TRANSFORMERS APPLICATION: RA APPROACH

When a RA is performed, first of all it is necessary to understand the possible developments and consequences of dangerous situations. In some cases a good support to RA may also come from experimental simulations to reproduce dangerous situations. The risk parameters have to be described in detail and they have to be related to quantitative factors in order to be implemented in equations as R.

Identification of risk parameters

RA on power transformers started with the collection of data on failures and dangers in general. It has been assessed that the risk analysis of liquid-immersed power transformer should be concentrated on the main risk parameters, FIRE and EXPLOSION, strongly connected and usually both present when a strong failure of the transformer occurs.

Description of risk parameters

A fire situation depends on the combination of FUEL, OXYGEN and IGNITION. Usually inside a transformer the presence of oxygen is very poor. A significant consideration is that the flammability of the transformer is usually theoretically defined by the flammability of the coolant/insulating liquid. Fire experiments on real transformers have shown that this definition is not sufficient for a correct judgment of fire risk: the fire point is important only for the starting phase of fire but also the developing phase and the consequences of fire (smokes and flame) have to be taken into consideration. In particular, a transformer can be involved in a fire in two ways:

A) The transformer is a source of fire. Generally two effects may heat up the insulating liquid in a transformer, and they are both linked with a failure of some parts of the system:

A.1) Internal high current arc, that causes a local heating of the liquid.

A.2) External short circuit that causes a high current in the conductor of the windings.

B) Transformer is a victim of external fire.

Identification of quantitative risk factors

The risk analysis should be done according to the different phases of fire and it consists of the identification of some physical quantities which describes the liquid or the design. The risk factors affect both the choice of materials and the design criteria of the transformer. The most important factor is the insulating liquid but the RA showed that not only the fire point has to be taken into consideration. The choice of a different insulating fluid has strong consequences on the design, being this material one of the basic materials whose dielectric and cooling properties determine the design and dimensioning criteria of the transformer itself. In conclusion, the RA gives two possible ways of improving the performances of a transformer with respect to the risk factor:

- changing design but leaving the same materials;
- changing materials, i.e. insulating liquid, with strong consequences also on the design.

The second choice can give the best results, but it takes a much stronger effort, both for the choice of the proper material and for the re-designing of the transformer, tailored on the new material chosen.

TRANSFORMERS APPLICATION: LCA-RA OPTIMIZATION

In practice, the RA and LCA optimization on a transformer can be seen as a dynamic process, schematically shown in fig. 1. The initial dominion Ω, which includes theoretically every material, is first restricted by RA in a discrete number of possible materials. The optimization function can to be applied to this new dominion, as illustrated in fig. 2

As said above, the insulating liquid is crucial for determining the design and overall performances of the whole transformer: moreover, changing the liquid means a "*jump*" in the allowed values of the relative X components, so if the projection on these X components space is done, it is possible to see that it is discrete. The projection on the remaining X components (those relevant mainly for LCA) is usually continuous. The domain is made therefore of continuous parts, each one relative to a certain choice of the insulating liquid: in every subdomain, F can be calculated and optimized separately and then eventually a comparison can be done with the values obtained in other domains (i.e. for other liquids).

This approach in the peculiar application gives the following advantages:

- the considerations linked to RA are well defined and identified, with respect to those linked to LCA: this gives a better knowledge of the problem on the two sides and in its whole complexity;
- the liquid, that has resulted to be the crucial point for RA, is also a strategic choice for other reasons, like economic aspects, clients specific requests and so on: separating the variables connected to the liquid choice from those more related to design gives the possibility of taking the other constraints into account in an easier way.

The success of this approach is mainly due to the fact that, in the specific case of liquid-filled power transformer the subset of X components is discrete for its nature and it has only few sets of values (not many insulating liquids exist on the market).

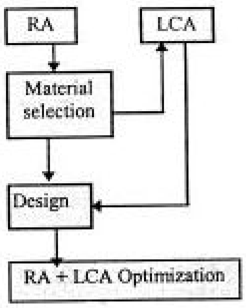

Figure 1: *RA + LCA optimization approach*

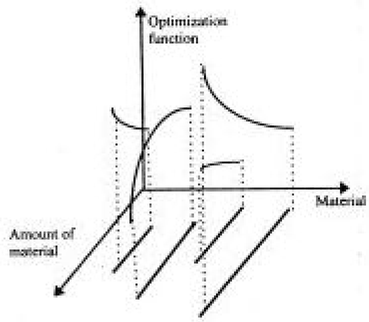

Figure 2: *Objective function application to the defined domain*

CONCLUSIONS

The system boundaries of LCA evaluations of electromechanical products should necessarily include the use phase. The use phase is affected by different parameters like maintenance, risk and costs. An optimized design should be performed according to the search of a minimum of an objective function: while LCA can be performed with a direct link with the Objective Function, RA, in some case, requires a not-continuous approach. Performing RA for the various (discrete) set of input data, it is possible to define the domain for the Objective Function where Environmental burden is the quantity to be minimized.

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