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Energy efficient EAF transformer – a holistic Life Cycle Cost approach

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Abstract

As steel industry is a major energy consumer, huge improvements in EAF's energy efficiency has already been performed; thus, additional progresses are difficult. The main opportunity is to adopt a holistic approach considering all the relevant process components, especially the electric transformer, since all the melting energy pass through it. EAF transformers are exposed to more critical conditions than power transformers. The best solution should be designed evaluating the LCC: i.e. purchase, energy losses, cooling and maintenance costs. In the present work, a model and a numerical example are proposed to determine the total cost of ownership of EAF transformers.

Keywords: Transformer; EAF; LCC; cooling system; real losses; maintenance

1. Introduction

Steel production process consumes a huge amount of resources such as electrical and chemical energy (oxygen, natural gas, oil, carbon) and it is well recognized as one of the most energy-intensive process. Steel industry is one of the largest energy consumers in the manufacturing sector. Moreover, the energy consumption is expected to additionally increase: by 2050 steel use is projected to increase by 1.5 times to meet the needs of the growing population [1]. The production of primary steel is more energy intensive than the production of secondary steel due to the chemical energy required in reducing iron ore to iron using reducing agents. Consequently, electric arc furnaces (EAF), which are a common method of reprocessing scrap metal to create new steel, has acquired increasingly relevance through the years, especially for the higher competitiveness of the process. Aiming at improving efficiency and quality of the melting process, in the past decades huge improvements in terms of energy efficiency of the EAF have been introduced (see [2]), in order to: maximize stability of the arc during the different stages of the whole melting process;

- reduce electric disturbances (flicker) on the power supply network during melting process;
- increase productivity;
- reduce electrode consumption and optimize the cost of EAF equipment and of its operating costs.

Despite of the sophisticated energy management systems and the developments in terms of energy efficiency of the steelmaking process performed in the past decades, energy still represents a significant portion of the cost of steel production. Thus, further improvements in the process energy efficiency (and related reduction of production costs) will generate relevant savings and thereby improve the competitiveness. However, until the focus was mainly directed to the furnace, it was easy to get results, i.e. reduction of power off and tap-to-tap times, use of chemical energy, use of foamy slag, electronic regulation of the electrodes, higher voltage and use of reactors

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in series, etc. The specific energy, mostly used today to melt a tonne of steel in an electric arc furnace, is virtually a parameter under control, very closed to the theoretical limit. Consequently, additional progresses without considering other components of the process are now difficult to be achieved as they have always been considered of secondary relevance. Thus, in order to improve the global efficiency of the process, the main opportunity is to adopt a holistic approach by including all the relevant parts. The main focus should be especially on the electric transformer, since all the power required for melting scrap, ferroalloys and other materials flows through it and its correct working is crucial for operations efficiency. Because of the relatively large capital expenditure involved when purchasing a transformer, most steelmaker are generally very well aware of the economic factors and savings that can be achieved at this stage of the transformer's life cycle. However, the other components of the total cost, which are not always taken seriously in industrial processes (e.g. costs due to energy losses and maintenance), represent a relevant share during the lifespan of the transformers. They can reach even the 70-90% of the lifetime costs and, thus, they should be considered in the purchasing decision. Consequently, the optimal transformer should be design evaluating the life cycle cost (LCC) taking into account all significant cost components and not only purchase price. Saving in quality only means postponing a capital expenditure to a future time. For that reason, companies' commitment is in investing in products of excellence that are tailored to meet the different requirements specific to every steel mill.

At the present, several study on the life cycle cost approach applied to the transformers have been performed ([3], [4]); however, all of them are focused on power and distribution transformers, while the steel making setting is not yet considered. Steelmaking process is characterized by severe conditions [5], such as EAFs requires dozen of interruptions a day and they are characterized by time-variant and non-linear loads. In addition, the instability of the arc creates relevant power quality problems such as unbalanced voltages and currents, voltage flickers as well as odd and even harmonics (due to the low voltage and high current AC power flow). Moreover, during the melting process, the melting iron sometimes causes shorts in the electrodes, which results in violent shocks to the power source. As EAF transformers are exposed to specific and more critical conditions than power/distribution transformers, it becomes crucial to consider real operating conditions and to extend the LCC approach to this specific context.

The present work has been developed in collaboration with Transformer Electro Service Srl. (TES), an important reality in high power and special transformers market, with a high specialization in the production of tailor made EAF transformer. The aim is to propose a LCC approach for EAF transformers: throughout the developed model it is possible to select the best design solution for the specific load cycle load and operating conditions, improving the energy efficiency of the global system and thus, increasing the energy transferred to the metal. Moreover, as an additional and relevant aspect introduced in the proposed model, the impact of real operating conditions and maintenance activity related to any single auxiliary component and equipment (e.g. smart cooling system, OLTC, etc.) have been included in the analysis.

2. LCC model for EAF transformer

Since EAF transformers operate connected to a system controlled by the operation of the furnace, they are subject to more critical conditions compared with power and distribution transformers: i.e. very high secondary currents and low secondary voltage, heavy current fluctuations and unbalanced conditions, switching transients, harmonics, short circuits, mechanical stress, frequent overloading conditions, vibrations, high ambient temperature, pollution and dust. For that reason, a holistic approach, which considers all the system components and not the only transformer, is necessary. Consequently, in order to achieve customer satisfaction, the challenge for suppliers is to design products that meet operation requirements, but at the same time they are reliable and cost competitive: such a goal can be reached by optimizing acquisition, ownership and disposal costs. A transformer with high efficiency and therefore low life-cycle cost would be expected to have low losses. In fact, since losses (in the form of heat) cause damage to the insulation over time, higher efficiency means a longer lifetime and reduced system degradation, i.e. lower failure rate. Moreover, a transformer with high efficiency reduces the amount of cooling power generation needed to accommodate the losses (both core and coil). Usually, EAF transformers are expected to operate about 20 years or more: thus, the procurement decision encompassing only the initial cost seems to be uneconomical. Since the transformer design affects all relevant performance, i.e. safety, reliability, maintainability, maintenance support requirements, etc., purchasing choice should be influenced not only by the product's acquisition price but also by the expected ownership cost, i.e. losses cost, cooling system cost and maintenance cost. Consequently, the analysis of the transformer costs over its lifespan through the life-cycle cost (also called "total owning cost") approach leads to a better economic evaluation. As stated in [6] and in accordance to IEC 60300-3-3 "Dependability management Part 3-3: Application guide – Life cycle costing" [7], the lifecycle of a product should consist of the following six cost-causing phases: (a) concept and definition, (b) design and development, (c) manufacturing, (d) installation, (e) operation and maintenance and (f) disposal. In order to develop an aggregated analysis, the different cost components can be grouped into investment or acquisition cost (concept/definition, design/development, manufacturing, installation), operating or ownership cost (operation, maintenance) and recycling or disposal costs. The LCC analysis provides important inputs in the decision-making process: product suppliers can optimize their designs by comparing competing alternatives on the same basis and by performing trade-off studies; they can also evaluate various operating, maintenance and disposal strategies and assess whether it is convenient or not to replace an old transformer. As disposal costs are relatively insensitive to the type and design of the transformer, as in the considered setting,