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Product-Service Systems across Life Cycle

Product-service system for sustainable EAF transformers: real operation conditions and maintenance impacts on the life-cycle cost

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Abstract

Steel industry is one of the largest energy consumers in the manufacturing sector and covers a great share of the total energy consumptions in the world. As in recent years, energy efficiency has been a top priority for the European Commission, which set a reduction of 20% as a target for the energy consumption, so that great improvements in energy performances are required. Many improvements have already been introduced in the Electric Arc Furnace (EAF) process and additional progresses are very difficult to be achieved. Consequently, the main opportunity consists in the improvement of other system components, especially of the transformer's performance, as it is an expensive component with a strategic relevance for EAF operation. A more energy-efficient transformer can make a valuable contribution to European energy savings: lower energy losses substantially correspond to lower running costs. However, recent EAF transformers from different firms have become equally well performing, thus, the basis of the competition has been shifted from the single product offered to a customized solution that should fulfill specific customer needs. In other words, in order to obtain an advantage on the main competitors, some additional services, that are needed during the use phase of the product, are added. These extra services take into account the real energy losses obtained during the operation of the EAF and the maintenance activities. To perform the economical analysis of the solution, it is thus necessary to calculate the EAF transformer's life cycle cost (LCC) or total cost of ownership (TCO), over the life span of transformer. At the present, no works have been conducted on the EAF transformer which are exposed to more critical conditions than power/distribution transformers, and no real conditions have been considered even for other forms of transformer. In addition, the only aspects that have been taken into account in the existing transformer's LCC were the purchasing price and a share of the total relevant costs of losses (no-load and load losses). Thus, the aim of the present work consists in the evaluation of a solution consisting of a tangible product (EAF transformer) and intangible services (e.g. maintenance activities, operational consultancy) that best satisfy the EAF operations' requirements, in order to simultaneously enhance competitiveness and support sustainability. Moreover, the other relevant contribution is the integration of maintenance aspects and failure risk, as design decisions affect also transformer's reliability and related maintenance activities.

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Keywords: EAF transformer; life-cycle cost; maintenance; product-service system.

1. Introduction

In recent years, energy efficiency has been a top priority for the European Commission, which set a reduction of 20% as a target for the energy consumption. Among the manufacturing sector, which is the greatest world energy consumer [1], energy efficiency represents a relevant opportunity especially in the steel industry, since it is characterized by a very energy-intensive production process consuming a huge amount of resources such as electrical and chemical energy (e.g. oxygen,

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natural gas, oil, carbon) [2]. In the past decades, in order to improve energy performance and quality of the steel-making process, huge improvements for the Electric Arc Furnace (EAF) have been introduced, which aims were: stability of the arc maximization, electric disturbances on the power supply network (flicker) reduction, productivity increase, electrode consumption reduction and cost of EAF's equipment and operation optimization [3]. Some examples of these improvements are: 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 in series. In spite of these several improvements, energy still represents a significant share of the total cost of steel production; thus, further developments in the process energy efficiency are needed in order to reach higher competitiveness and greater savings. However, additional progresses in the furnace are now difficult to be achieved, since the easier measures have already been performed. Consequently, the main opportunity to improve the global efficiency of the process consists in the improvement of relevant system components, especially focusing on the electric transformer, which is of a strategic relevance for EAF operations because greater part of the melting energy passes through it. A more energy-efficient transformer can make a valuable contribution to European energy savings and can lower process's energy losses, considerably reducing the running costs. For that reason, recently, EAF transformers of different firms have become equally well performing, reaching consistent reductions of the rated load and no-load losses. As a consequence, the basis of the competition has been shifted from the single product to a customized solution, consisting of 'tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs in an economical and sustainable manner', which in literature has been discuss under the topic of product-service system (PSS) [4]. Intangible value is currently the key to obtain competitive advantages and to overcome the competitors' performances. Moreover, this intangible added value makes the client willing to pay more than would be justified on the basis of rationality. Recent contributions ([4,5]) underline how PSS business models are emerging phenomenon, as they allow firms to create new sources of added value and competitiveness, satisfying client needs in an integrated and customized way and allowing clients to concentrate on core activities. Through PSS business model it is also possible to build unique relationships with clients, to enhance customer loyalty and to innovate faster since the firm knows better the needs of the market and the problems to face. The EAF transformer solution can be defined as a product-oriented service, according to the widely accepted classification in [4]: the provider (i.e. EAF transformer producer) sells a product, but also offers extra-services that are needed during the use phase, e.g. maintenance activities, and gives advice on the most efficient use of the transformer, taking into account the real energy losses obtained during the operation of the furnace and the auxiliary equipment (e.g. cooling system). The solution proposed aims to improve the economic and environmental efficiency of the process, reducing the life-cycle cost and increasing the sustainability of the EAF transformer: incremental efficiency improvements (e.g. through maintenance contract in a product-related service) can lead to a prolonged life and/or less use of energy and auxiliary materials. To perform the economic analysis of the solution, it is thus necessary to calculate the EAF transformer's life cycle cost (LCC) or total cost of ownership (TCO), over its lifespan, taking into account the purchasing price, the costs of energy losses (no-load, load, LV terminals and auxiliary losses) and the cost due to maintenance's activities. At the present, no works have been conducted on the specific context of the furnace process and thus on EAF transformers, which are exposed to more critical conditions than power/distribution transformers, and no real conditions have been yet considered even for other forms of transformer. In addition, the only aspects that are usually taken into account in the transformer's LCC are the purchasing price and a share of the total relevant costs of losses (no-load and load losses) [6,7].

The present work has been developed in collaboration with TES Transformer Electro Service Srl, an important Italian reality in high-power and special transformers market, whose commitment is precisely to offer tailor-made EAF transformers with extra services valuable for the users. The aim of the collaboration consists in the evaluation of the solution, involving of a tangible product (EAF transformer) and intangible services (e.g. maintenance activities, operational consultancy), that best satisfy the EAF operation requirements, in order to simultaneously enhance competitiveness and support sustainability. Moreover, another relevant contribution is the integration of maintenance aspects and failure risk into the definition of the solution, as design decisions affect also transformer's reliability and related maintenance activities.

2. EAF Transformer operation

The EAF transformers' operation is controlled by the melting process and thus by the furnace, consequently this special type of transformer is subject to more critical conditions compared with power and distribution transformers [8]: i.e. very high secondary currents, low secondary voltage, heavy current fluctuations, unbalanced conditions, switching transients, harmonics, short circuits, mechanical stress, frequent overloading conditions, vibrations, high ambient temperature, pollution and dust. These severe conditions worsen the performances and lower the lifetime of the EAF transformer. Thus, a higher focus on additional services, that control maintenance activities and guarantee the correct utilization of the transformer, leads to better performance of the product during its lifetime.

In order to achieve customer satisfaction, the challenge for suppliers is to design solutions that are reliable, cost competitive and that meet operation requirements: such a goal can be reached by optimizing acquisition, ownership and disposal costs. The ownership phase acquires great relevance especially in the EAF transformer lifetime cost and reliability: in fact, higher energy losses (in the form of heat) cause higher costs and higher degrade of the insulation over time. Moreover, a transformer with high efficiency reduces the amount of cooling power generation needed to accommodate the losses (both core and coil) and thus lower auxiliary energy losses. Further, reduced losses implies an improvement in the failure