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A Framework to Characterize Factors Affecting the Adoption of Energy Efficiency Measures Within Electric Motors Systems

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Abstract

Electric motor systems account for a remarkable share of total industrial power consumption (even more than 70% in some countries). Despite the wide set of effective opportunities to improve energy efficiency in this cross-cutting technology, the implementation rate is still quite low. Among the barriers affecting the adoption of such measures - identified by previous literature -, little knowledge of the factors that should be taken into account when deciding to undertake an action in this area emerges. Therefore, in the present study we present an innovative framework representing factors affecting the adoption of measures for improved efficiency in electric motor systems. Such factors have been classified according to several categories as follows: compatibility, economic, energy benefits, production-related and operations-related non-energy benefits and losses, synergies, complexity, personnel, and additional technical features, so to fully describe the relevant elements to be considered when considering the adoption of energy efficiency measures (EEMs) in electric motor systems (EMS). The framework may represent a valuable instrument to support industrial decision-makers in the adoption of EEMs for EMS.

Keywords: electric motor systems; energy efficiency measures; industrial energy efficiency; characterization framework.

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1. Introduction

According to recent estimates, the industrial sector is responsible for the major share of delivered energy consumption, covering about 55% of the world total delivered energy [1]. Among the broad set of equipment consuming energy in industry, electric motor systems (EMS) represent a cross-cutting technology to which, in some contexts, more than 70% of the power consumption can be attributed [2]. Therefore, it is apparent that, in order to improve industrial energy efficiency, greater attention should be paid to improve the adoption of energy efficiency measures (EEMs) in EMS. Despite the advantages brought by EEMs, there is a difference between the potential implementation rate and the effective one, confirming the existence of an *energy efficiency gap* [3,4]. Barriers to industrial energy efficiency have been widely investigated by literature (e.g., [5,6]), even with respect to electric motors (e.g., [7,8]). As authors note [7], economics represents an important barrier, but not necessarily the main one. Hence, what on a first look seems a *low hanging fruit* [9] is instead a much more complex situation; indeed, in many cases the lack of a thorough and clear understanding of the factors that should be taken into account in order to undertake conscious decisions prevents industrial decision-makers from adopting EEMs in EMS. Therefore, the present study aims at contributing to the discussion presenting an innovative framework characterizing the factors affecting the adoption of EEMs in EMS.

2. Literature background

When considering frameworks to characterize the factors to be considered when undertaking the decision of adopting an EEM, a basic distinction could be made by distinguishing studies that contributed to the discussion by describing single attributes of EEMs, from those that made an attempt to offer a structured knowledge, thus organizing attributes by categories. The contribution by Pye and McKane [10] falls under the first category: in their study, authors identified a broader range of productivity benefits, showing that energy efficiency projects' non-energy benefits often exceed the value of energy savings, so energy savings should be viewed more correctly as part of the total benefits, rather than the focus of the results. Similarly, Kats et al. [11] focused their attention on employees' productivity and health improvement in relation to an increased indoor environmental quality. Moreover, disadvantages should be highlighted.

First attempts to characterize the attributes can be rather found since mid '90s. Flanigan [12] provides a further contribution to literature introducing another classification based on direct economic benefits, indirect economic benefits, environmental benefits and societal benefits, whilst Mills and Rosenfeld [13] analyzes non-energy benefits from a consumer perspective, mainly represented by the industrial end user, providing a framework for understanding the many benefits of energy efficiency investments that extend beyond the energy bill savings alone, such as noise, improved process control and direct and indirect economic benefits from downsizing of equipment, as well as labor and time savings. Worrell et al. [14] stress the importance of non-energy benefits, whose omission generally results in an underestimation of the cost-effective savings potential. Six categories were identified as follows: reduced waste, lower emissions, improved maintenance and operating costs, increased production and product quality, an improved working environment and an "other" category. Similarly, Lung et al. [15] identified five categories to build the framework upon: operation and maintenance, production, work environment, environmental and "other". More recently, Fleiter et al. [16] characterize factors according to the following: relative advantage, technical context and information context. For the first time, attributes have been declined in discrete levels, which, in turn, have been assigned to every EEM analyzed and arranged according to their likely effect on the adoption rate of the measures themselves. Besides, the framework is comprehensive of attributes which goes beyond merely technical features to include basic considerations about the context in which the EEMs are implemented. Finally, Trianni et al. [17] identified six categories of attributes: economic, energy, environmental, production-related, implementation-related and indirect attributes. The categories were created by trying to follow the perspective of the industrial decision-maker, including not only energetic, environmental and economic issues, but also describing the impact an investment has on the existing production system.

Nevertheless, as this literature background shows, almost none of the previous studies has addressed specifically EEMs for EMS; indeed, previous frameworks seem to aim at describing EEM and impacts in general terms, thus being applicable to whatever EEM, without thoroughly analyzing the factors affecting the adoption of such EEMs in EMS. This, as highlighted by authors [18], leads to the understanding that some of the perceived characteristic of EEMs look as too ambiguous, since they are referring to a general situation without providing any insight regarding both the context and the type of intervention. In a nutshell, if a framework describing the characteristics is too general, all the information regarding the specific application and technology is lost, thus the insights provided are not precise enough to have a specific understanding. On the other hand, literature claims that focusing the attention on a single process specific or cross-cutting technology, the model would be too specific, losing the idea of a comprehensive tool and many of it would be necessary to handle all the problems related to the implementation of EEMs [18].

3. Factors affecting the adoption of EEMs in EMS

The proposed framework lies in between of the two aforementioned extreme situations, being specific enough in order to provide interesting information to a decision-maker regarding a precise cross-cutting technology, i.e. EMS, without losing specific insights that would be absent in a more general approach, but, at the same time, being capable of contextualizing the problem of low adoption rate in any industrial environment, avoiding the need of creating different tools addressing the same technology in different situations. Categories and attributes describing the intrinsic nature of EEMs and the consequence of their adoption are widely taken from previous studies and sometimes processed in order to fit the description of the specific cross-cutting technology with only few additions ex novo, since literature from this point of view is rather rich, even if lacking a specific target, as previously stated, and a synthesis tool.

Taking inspiration from previous literature, the following categories of factors have been identified: compatibility; economic; energy benefits; production-related and operations-related non-energy benefits and losses; synergies; complexity; personnel; and additional technical features. For a matter of brevity, in the present study we limit our presentation to the categories, without fully discussing each factor within each category (ref. Figure 1).

Compatibility category refers to a new technology to be installed in the existing EMS or to the new state of the system (because of the implementation of the EEM) that applies to already existent technologies. According to previous research [19], compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters. However, Fleiter et al. [16] pointed out that, despite being relevant for the adoption, compatibility and possible related factors are not considered properly because strongly dependent on the adopters' characteristics. The present work, given the focus on a specific cross-cutting technology, places its attention on the compatibility of the EEMs with the existing system, highlighting possible reasons of conflict which could compromise the adoption itself. This category is placed at the beginning of the framework, indeed it should work as a first filter, removing all the potential EEMs that are incompatible with the existing system, even if they are considered highly advantageous from any other viewpoint. Within this category we have four factors, namely load compatibility and adaptability to different conditions, as well as reduced layout flexibility and adaptability in every production environment.

Economic category, which considers both costs and economic benefits related to a certain EEM, represents a fundamental portion of knowledge every decision-maker should have in order to evaluate an investment on EEMs in EMS, as authors suggest [17]. Among this category, several factors fall, as follows: initial implementation costs, total adoption costs, monetary savings, pay-back time, financial flexibility, as well as adoption cost of secondary devices (in implementation and service phase) and cost adoption costs of other devices (in the implementation phase).

Energy benefits (EB) are placed immediately after the economic factors because of the tight relation they share. However, the EBs alone appear not to be the highest valued outcome to adopters. Coherently, authors recognize that quantifying the total benefits of energy efficiency projects helps companies understand thoroughly the financial opportunities of investments in EEMs [10]. They argue that EBs alone are not primary drivers in industrial decision-making and therefore EBs should be viewed more correctly as part of the total benefits of an energy- efficiency project, rather than the focus of the results.

Production-related non-energy benefits and losses. Certain technologies, identified as being energy-efficient because they reduce the use of energy, can bring a number of additional enhancements to the production process. These improvements are collectively referred to as non-energy benefits (NEBs) or losses (NELs) [21] because extend beyond the energy bill savings alone. From a consumer perspective, it is often the NEBs driving the decisions to adopt

EEMs. This category refers to NEB/NEL affecting the productivity of the plant, regarding both production and ancillary processes, taking inspiration from previous literature [14-15,17,21]. This category can be divided into two sub-groups, namely global and local. The *global* sub-group analyses how motor systems, considered as a whole inside the plant, influence production. Despite productivity and every other aspect related to it, such as production costs and quality, could be affected by both production and ancillary processes, it is wise to keep the contributions separated, providing the industrial decision-maker information about the source of improvement (or degradation) of production. Within this subgroup the following factors can be found: productivity, production quality, and production costs (both direct and indirect). The *local* sub-group rather focuses on the single EMS, describing how EEMs here can change its productivity. Several factors belong to this subgroup, as follows: set-up time, reliability, equipment lifetime, downtime (for implementation, as well as for maintenance and repairs), and improved process control.

Operations-related non-energy benefits and losses. Differently from the production related NEBs/NELs, this category provides information on what operative parameters the efficiency measures act, and how they affect their value, as previous studies suggest [14-15,17,20-21]. Different levels have been highlighted, in particular the attention moves from the condition of the physical motor system to a more global analysis of the entire working environment and goes on evaluating the impact of energy efficiency measure on the external environment. This category has three major sub-groups: motor conditions, working environment, and external environment. Indeed, before affecting people working in the company or the external environment, the consequences of the adoption of EEMs are visible observing the working conditions of the *motor conditions*: temperature, vibrations and power quality, as well as the quality of air, directly influence motor systems and in turn are influenced by them. An additional perspective regards the *working environment*, by looking at how operative conditions of the equipment can affect the working environment, in terms of air quality (for both motor conditions and personnel health), noise, temperature and vibrations in the environment, as well as safety. Finally, the third sub-group looks at factors in terms of impact to the *external environment*, in terms of waste and emissions reduction.

Synergies. After defining NEBs and NELs it is important to take into account all the possible and remaining relationships, with respect to the context and the operative conditions that characterize the organization during the implementation of an EEM. In fact, decision-maker can usually well identify synergies, either positive or negative, occurred with other interventions in that phase and may exploit the possibility of coordinating the action with other activities that are of the same type, or imply the same contextual conditions of the measure that is going to be installed.

Complexity. This category encompasses all factors related to the degree to which an innovation is perceived as difficult to understand and use [19,22]. Indeed, some innovations are readily understood while others are more complicated, maybe requiring new skills, and will be adopted more slowly. Thus, the complexity of an innovation is usually negatively related to its adoption rate. Several important factors fall under this category: training (in the implementation and service phases), dependency from other components/EEMs, physical placement inside the EMS, type of activity, technical maturity and diffusion of the technology in the market, as well as accessibility.

Personnel. This category is introduced to describe who among the people working in the plant is involved in the adoption of an EEM and the corresponding level of involvement. It is important to identify people affected by the establishment of an EEM, since it will help the company to design a better strategy. This category is especially important in describing whether the top management plays a relevant role in the decision-making process, i.e. if its authority is necessary for the correct adoption of EEMs. In the case of positive answer, this could represent an obstacle when top management is required but it is not willing to cooperate; viceversa, EEMs that do not need its presence are generally easier to be implemented. Here, many factors can be found, belong to two main subgroups, namely advantages and disadvantages. In particular, both *advantages* and *disadvantages* can be found for active personnel, passive personnel, as well as corporate involvement. Further, it is important to remark that, for personnel involved (either actively or passively), we can have implementation and service advantages and disadvantages.

Additional technical features. Taking inspiration from previous literature [17,23], additional insights in the technical description of EEMs are needed, such as implementation type, check-up frequency, eligibility for automation, needed to secondary devices or additional devices needed to change operating conditions.

Figure 1 synthesizes the categories of factors as well as their detail.

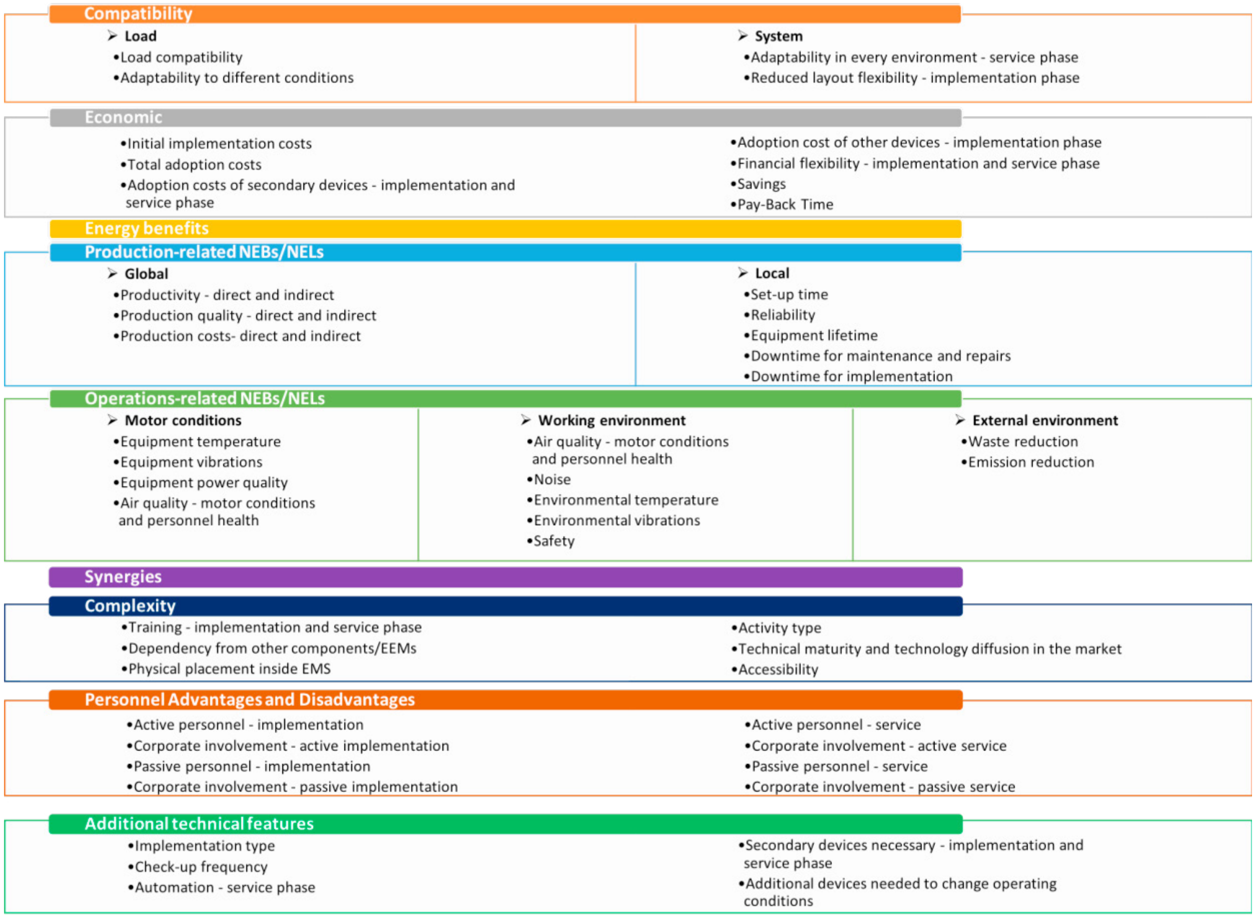

Fig. 1 Complete set of categories and detailed factors for the adoption of EEMs in EMS.

4. Conclusions and further research

The present study has introduced an innovative framework to characterize relevant factors affecting the adoption of EEMs within EMS. We believe this represents a useful instrument with relevant potential to support industrial decision-makers, as well a policy-makers, in adopting and fostering EEMs within EMS. As next steps, we plan to apply the framework for the assessment of energy efficiency opportunities within EMS for a single company, thus seeking for common behavior of the company (e.g., all EEMs not implemented present a specific value for a factor). Those findings would be extremely useful for decision-makers, e.g., energy managers or plant managers, to undertake corrective actions (e.g., at organizational level) and thus foster the adoption of EEMs within EMS. Useful insights could also come by performing a thorough empirical investigation within industrial companies to explore commonalities and differences in the adoption of EEMs within EMS, also trying to understand common patterns according to relevant contextual factors such as, e.g., industrial sector and firm size. Such indications would result particularly interesting for both policy-makers and major players operating in the supply chain of such EEMs.

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