Preliminary research about electric vehicle charging stations

Pesquisa preliminar sobre estações de carregamento de veículos elétricos

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Matheus Binotto Francescatto
Graduando em Engenharia Mecânica pela Universidade Federal de Santa Maria
Instituição: Universidade Federal de Santa Maria - UFSM
Endereço: Av. Roraima, nº 1000, Santa Maria - RS, Brasil
E-mail: matheusfrancescatto@hotmail.com

Ismael Cristofer Baierle
Doutor em Engenharia de Produção pela Universidade do Vale do Rio dos Sinos
Instituição: Universidade Federal de Santa Maria - UFSM
Endereço: Av. Roraima, nº 1000, Santa Maria - RS, Brasil
E-mail: ismaelb@viavale.com.br

Anderson Felipe Habekost
Mestre em Engenharia de Produção e Sistemas pela Universidade do Vale do Rio dos Sinos
Instituição: Universidade do Vale do Rio dos Sinos - Unisinos
Endereço: Av. Unisinos, nº 950, São Leopoldo - RS, Brasil
E-mail: andersonfhabekost@yahoo.com.br

Cristiano Roos
Doutor em Engenharia de Produção pela Universidade Federal de Santa Catarina
Instituição: Universidade Federal de Santa Maria - UFSM
Endereço: Av. Roraima, nº 1000, Santa Maria - RS, Brasil
E-mail: cristiano.roos@ufsm.br

ABSTRACT
With growing concern about environmental issues, there is a constant search for engineering solutions on a global scale. In this context, attention is focused on the automotive sector, which is responsible for a large part of environmentally harmful emissions. Thus, electric vehicles appear as one of the solutions to this problem. However, it is not possible to popularize these cars without a recharging structure that can meet this demand. In this context, the objective of this paper is to present studies and research carried out in the area of technical and economic feasibility focused on recharging infrastructure, in order to provide knowledge and assist future research projects in this area.

Palavras-chave: Recharging Stations, Electric Vehicles, Economic Engineering.

RESUMO
Com crescente preocupação com questões ambientais, há uma busca constante por soluções de engenharia em escala global. Nesse contexto, a atenção está voltada para o setor automotivo, responsável por grande parte das emissões prejudiciais ao meio ambiente. Assim, os veículos elétricos aparecem como uma das soluções para esse problema. No entanto, não é possível popularizar esses carros sem uma estrutura de recarga que possa atender a essa demanda. Nesse contexto, o objetivo
deste artigo é apresentar estudos e pesquisas realizadas na área de viabilidade técnica e econômica voltada para recarga de infraestrutura, a fim de fornecer conhecimento e auxiliar futuros projetos de pesquisa nessa área.

**Keywords:** Estações de recarga, Veículos elétricos, Engenharia econômica.

### 1 INTRODUCTION

By signing the Paris agreement in 2015, a total of 189 countries agreed to set individual carbon dioxide (CO2) reduction targets (Vital, 2018). One of the sectors most affected was the automotive sector, as it has a very high influence on the amount of pollutant emissions into the atmosphere. According to Deign (2016), countries such as Germany, Norway and India seek to ban internal combustion vehicles after 2030, thus triggering a search for acceptable substitutes. Among the substitutes is the electric vehicle, which becomes one of the best options for solving these problems, due to its benefits in terms of emissions and its damages. However, with the growing interest in electric vehicles, it is important to pay attention to the charging infrastructure needed for the effective introduction of these cars.

With this in mind, countries such as Brazil, where incentives and studies on this type of technology are not very present, becomes important to conduct a technical and economic feasibility research focused on the electric vehicle charging infrastructure. The present work is justified and seeks to contribute by providing one more research that deals with the implantation of charging stations in Brazil.

In this context, the main objective of this work is to identify in the literature research in the area of Economic Engineering that deals with the recharging infrastructure of electric vehicles, contributing with a bibliographic review on the subject. Along with this, this work has as secondary objectives: to present basic technical information about electric vehicles and charging stations, to present works in the technical area related to charging infrastructure and to determine the best options for the analysis of this type of investment.

### 2 RESEARCH METHODS

For this work, the bibliographic research method was used (GIL, 2007). Initially, it was based on the books of Hirschfeld (1979), Casarotto and Kopittke (2010) and Hess et al. (1992). Afterwards, the work was based on research in national and international journals, with international research focusing mostly on publications available through the Capes Journal Portal, on ScienceDirect and Emerald.

Following the definitions of Miguel (2012), this research has thematic focus due to the fact that it is focused on a specific focus, which is a theme of the engineering area. Also according to the
author, the research function is classified as updating, because it brings information from recently published studies. The chosen approach can be considered as an annotated bibliography, as it presents a set of sources without bringing a critical analysis, showing only a range of articles and research dealing with the analysis of the technical and economic feasibility of charging stations.

3 RESULTS: BIBLIOGRAPHIC SEARCH

This section presents the results of bibliographic research on electric vehicles and recharging stations, along with applied articles involving the technical and economic feasibility of recharging infrastructures.

3.1 Electric Vehicles

According to Footwear (2015), electric vehicles emerged with the goal of being an alternative to environmentally damaging impacts due to air contamination and noise emission caused by internal combustion engines. According to Xiong et al. (2019) One of the obligations of electric vehicles today is to achieve lower energy use, good economy and strong practicality, all at the same time. Electric vehicles are a proposal for optimization of conventional vehicles, however, they involve the essential means for the integration between electrical and mechanical engineering, as well as having a participation of electronic, materials and chemical engineering (CALÇADO, 2015).

In relation to its operation, basically the electric vehicle makes use of propulsion by means of electric motors to transport people, objects or a specific load, consisting of a primary power system, one or more electric machines and a drive and control system of speed (ORNELLAS, 2013). Along with these principles, there are other unique components of electric vehicles, such as single speed transmission, on-board charger and regenerative braking system (SOUSA, 2015).

There are four main types of electric vehicles that are among the most popular and most commonly used today: hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), plug-in electric vehicles (PEV) or battery electric vehicles (BEV) and fuel cell electric vehicles (FCEV).

The HEV uses an internal combustion engine in conjunction with electric batteries, making use of the brake energy to recharge these batteries, thus obtaining economic and environmental advantages over conventional cars (RAHMANI and LOUREIRO, 2019). According to Doppstad, Koberstein and Vigo (2016), with the problems that electric vehicles present in relation to the autonomy and energy capacity of batteries, HEV turns out to be a safer and more viable option. Rahmani and Loureiro (2019), point out that HEVs are cheaper than electric vehicles and PHEVs, because this type of car does not suffer from battery problems or lack of infrastructure, presenting benefits of public incentives in several countries, factor that makes them competitive in today's market.
The PHEV has two engines: one internal combustion and one purely electric. These two engines have the possibility of being easily alternated allowing the use of one or the other depending on the situation (PLÖTZ, FUNKE and JOCHEM, 2018). Due to this possibility of operation, according to Hiermann et al. (2018), PHEVs do not have the range of autonomy as BEVs, due to the option of being recharged, reducing the use of fossil fuels on the trip.

The BEV fully adopts the electric motor as the main motor, without the support of a traditional internal combustion engine, and can, like all electric vehicles, recharge the batteries through a process known as regenerative braking, which uses the electric motor to help slow down the vehicle by recovering part of the energy normally converted to heat by the brakes (CALÇADO, 2015).

FCEV has the ability to offer both autonomy and the short recharge time that consumers are used to with other types of cars, but it lacks infrastructure (LANE et al. 2017). Also according to the author, the FCEV uses a fuel cell as engine and hydrogen as fuel, resulting in a vehicle with zero emissions and a recharge time close to that of conventional gasoline vehicles. Compared to other types of electric vehicles such as BEV and HEV, FCEV also has more advantages such as: much higher energy conversion efficiency than traditional combustion engines and no emitted pollutants (SONG et al. 2017).

3.2 Recharging Stations

According to Gonzales, Siavichay and Espinoza (2019), the primary function of EVCS is to supply and control the energy that is transferred to the vehicle battery. With this in mind, charging stations play a critical role in the development of electric vehicles, whether in their daily use or in their interaction with the power grid (SBORDONE et al. 2014). According to Zhang et al. (2018), one of the main barriers to the widespread use of electric vehicles is the lack of public recharging infrastructure. According to Neiameh et al. (2017), an appropriate recharging infrastructure may be the necessary aspect for the mass adoption of electric vehicles.

For Sbordone et al. (2014), a charging station must have the ability to charge the battery of an electric vehicle quickly, detect the state of battery charge and adapt to different car and battery models. For the same authors, in any case, the charging time should be commensurate with the vehicle’s battery characteristics to ensure optimal recharging, extending battery life. According to Lokesh and Min (2017), the battery charging time depends on the type of charging station that is used and also on the initial charge present in the battery.

Gonzales, Siavichay and Espinoza (2019) classify charging stations based on energy levels along with the time required for charging, thus obtaining three categories:
a) Level 1: This level is used in homes with a voltage of up to 120 Volts and an energy capacity of 3.7 kW. In this type of station the charging of the electric vehicle takes a long time, which can be between 6 to 24 hours. The energy conversion must be done by the electric vehicle converter;

b) Level 2: has a voltage between 208 to 240 Volts, a capacity of 3.7 kW to 22 kW and a current that can reach 32 A. Charging time may be less than 6 hours depending on the current status of the vehicle. The electrical conversion must also be done by the electric vehicle converter;

c) Level 3: In this category are the so-called fast chargers, the maximum power range that this type of charging station can handle is 50 kW to 240 kW with an electric current reaching up to 400 A. At this level the charging stations They are responsible for the conversion between alternating current and direct current, the voltage reaches up to 600 V and is the result of direct current.

According to Zhang et al. (2018), a private recharge infrastructure is generally only accessible to one person or a small group, a public infrastructure is used publicly, with more vehicles available, and there is also semi-public infrastructure, which is reserved for local people, of jobs and clubs. The type of charging performed will also depend on the vehicle's input (receiver). Tier 1 or 2 loads are compatible with all vehicles with standard type 1 connector and receiver (SAE J1772 or Yazaki connector), used in the US and Japan, and type 2 (VDE-AR-E 2623-2-2 or connector). Mennekes), used in Europe and China (Tuite, 2012).

On the other hand, according to FGV Energia (2017), even though there is a standard for level 1 and 2 connectors, for fast charger type charging, a standard has not yet been developed, so that this type of recharge has up to three Different models: SAE Combo or CCS, CHAdemo and Tesla Supercharger. According to the author, despite the lack of uniformity, charging stations tend to have models that meet both CHAdemo and SAE Combo.

Regarding the specific recharging time, each electric vehicle will be different as they depend directly on the capacity of your battery. According to Pelletier, Jabali and Laporte (2014), it is also taken into account that the announced charging time is usually only considering 80% of the battery capacity, this is because recharging is not linear throughout the charging process. In Table 1, some technical data on the loading of some vehicles.
Table 1 - Technical data of recharge of some electric vehicles

| Vehicle          | Battery Type and Power | Autonomy | Connector     | Level 1 | Level 2 | Level 3 |
|------------------|------------------------|----------|---------------|---------|---------|---------|
|                  |                        |          |               | Recharge Time | Recharge Time | Recharge Time |
|                   |                        |          |               | Requirement | Requirement | Requirement |
| Toyota Prius PHEV (2012) | Li-Ion 4.4 kWh | 22.6 Km | SAEJ1722      | 1.4 kW       | 3 hours       | N/A |
| Chevrolet Volt PHEV | Li-Ion 16 kWh    | 65 Km    | SAEJ1722      | 0.96-1.4 kW  | 5-8 hours     | N/A |
| Mitsubishi i-MiEV | Li-Ion 16 kWh    | 155 Km   | SAEJ1722      | 1.5 kW       | 7 hours       | N/A |
| Nissan Leaf EV   | Li-Ion 24 kWh     | 161 Km   | SAEJ1722      | 1.8 kW       | 12-16 hours   | 50 kW |
| Tesla Roadster Ev | Li-Ion 53 kWh   | 395 Km   | SAEJ1722      | 1.8 kW       | 30+ hours     | 15-30 minutos |

Source: Adapted from Yilmaz e Krein (2013)

Higher power level means shorter charging time, but higher equipment cost, generally level 1 charging can be obtained from a standard charging station, for level 2 or 3 dedicated charging stations are required (YILMAZ and KREIN, 2013). A tier 2 charging station, according to Ference (2017), can cost anywhere from $ 1,200 to $ 2,000, while a tier 3 charging station, according to Ducharme and Kargas (2016), can cost anywhere from $ 15,000. and $ 60,000.00.

3.3 Applied Technical Studies Involving Charging Stations

Xue and Gwee (2017) conducted a study to give an overview of the technical considerations required for adopting a level 2 charging station, along with detailing the advantages that the level 2 charging station has over for those, the authors use the reference from other literature, case studies and global practices, inserting them in the Singapore scenario. The authors conclude that level 2 charging stations have advantages in aspects such as lower range anxiety, higher economic return and higher charging efficiency.

Gonzáles, Siavichay and Espinoza (2019) conducted a study to analyze the effect of the implementation of fast charger charging stations on the electricity distribution network of a Latin American city. In order to achieve this goal, the study covers social, geographic and technical aspects to determine the minimum recharge infrastructure required. The authors made use of computational methods with a 50 kW power station model. The results show that the impact of the inclusion of fast
charger charging stations in Ecuador is reduced in terms of harmonic distortion and energy capacity, generating an economic and environmental benefit for the city.

The size of the load required to charge plug-in electric vehicles can cause a low voltage problem in the distribution network. In order to mitigate this problem, it is necessary to limit the power consumption of the charging station (KIM et al. 2016). Thus, the station operator needs a method to properly distribute the energy to the vehicles, with that in mind, Kim et al. (2016) propose a method based on priority indices to properly distribute energy among electric vehicles. Electric vehicles are ranked by priority in real time using computer software, achieving an almost optimal solution in a short period of time. As a result, the simulations performed by the author prove the effectiveness of the method implementation.

Zhang (2015) conducted a study to propose a construction mode combining charging stations (level 1, level 2 and fast charger), generating an optimized location model. The purpose of this model is not only to determine the best location, but also to use queuing theory to determine the appropriate number of power equipment to achieve minimum costs. The result obtained by the author shows that the ideal place to install the charging station are located in urban areas.

3.4. Applied Economic Engineering in Research

Economic studies involving different charging stations are extremely important because they help define the best investment option and analyze and draw conclusions about the economic viability of the project. With this in mind, some bibliographies show different applications of economic engineering related to electric vehicle charging infrastructure.

In this context, Schroeder and Traber (2012) conducted an economic feasibility study on charging stations classified as fast chargers, using German economic conditions as a research scenario. In this study, Return on Investment (ROI) was used as the profitability indicator and thus the author can conclude that based on the German economic context it would be difficult to obtain a profitable fast charger recharge infrastructure as, the ROI for the initial amount of EUR 95,000 needed to implement the charging station would be far from economically viable. The authors used parameters such as CAPEX (installation and construction cost) and OPEX (operation and maintenance cost) to determine the cost related to the recharge infrastructure studied. Considering the revenue generated, factors such as the percentage of use, power of the charging station, the charging rate for the recharge, the number of electric vehicles in the region and their average recharge were taken into account.

Mazzeo (2018) approached the economic problem differently, conducting a comparative study between some scenarios. However, due to the greater relevance for the present work, it is decided to analyze only the first scenario generated, which is composed of a level 1 private wall box
recharging station, installed in a house obtaining power only from the electricity grid. To perform the economic analysis, the author made use of the Net Present Value (NPV). The result was a uniform increase in NPV as the distance traveled by the electric vehicle increased daily, presenting negative values at distances of less than 50 km per day. These NPV values ranged from -4.084,00 EUR to 20,754.00 EUR for this scenario.

A feasibility study by NYSERDA (2015) in New York City involving a level 2 recharging station made use of two methods: simple payback and NPV. The circumstances used took into account an assumption of annual growth of around 12% in charging station usage, a 20-year period, $ 0.45 / kWh recharge price and a minimum attractiveness rate of 7% per year. The NPV obtained by the author was US $ 7,482 along with an 8.71 year payback, confirming the viability of the investment.

Other authors, such as Vagropoulos, Kleidaras and Bakirtzis (2014), used NPV and internal rate of return (IRR) to analyze the profitability of level 2 charging stations in the Greek environment. In the study the authors considered two types of stations, one 3.3 kW and one 7.2 kW, within a 5-day period from Monday to Friday and a 6-day period from Monday to Saturday. The results obtained are shown in Table 2.

| Charger type | Monday-Friday | Monday-Saturday |
|--------------|---------------|-----------------|
|              | IRR | NPV   | IRR | NPV   |
| 3.3 kW       | 11.7% | 1055 € | 22.4% | 4473 € |
| 7.2 kW       | 13.3% | 1453 € | 24.9% | 5180 € |

Source: Adapted Vagropoulos, Kleidaras e Bakirtzis (2014)

Similarly Liu et al. (2016), carried out the economic feasibility study of the recharge structure in China using a scenario consisting of an electropost with 4 fast chargers and 16 level 2 recharge units. In this context, the authors make use of methods such as NPV, ROI, payback and IRR. Among the results obtained are: 15.84 years of payback, ROI of 7.55%, IRR of 3.78% per year and a profit margin of 5.66% for the investment.

Finally, with this bibliographic research it was possible to verify the methods most used and by other authors to perform the economic viability calculations applied to the charging stations.
4 FINAL CONSIDERATIONS

In this paper, definitions about electric vehicles and charging stations were identified and described. Also presented were applied papers addressing technical and economic feasibility studies of the recharge infrastructure. In order that the bibliographic research presented here will be used as a reference for future works, it was intended to add a reasonable number of bibliographic sources. In fact, this theoretical framework is part of a research project that is underway to be applied in the parking lot of the Technology Center of the Federal University of Santa Maria. The work is being developed in partnership with the Production Engineering Undergraduate Course and the Mechanical Engineering Undergraduate Course at the Federal University of Santa Maria.

With this work it can be verified that currently, to perform the whole process of installation of a charging station in Brazil, there is still the presence of a high cost. In addition, there are several models of charging stations available on the market that vary widely, both technically and economically. In this context, it can be stated that the main research question to be solved is to understand which are the best options for charging stations, both from a technical and economic point of view.

Thus, making a comparison between the different models of charging stations is an important research, mainly involving Economic Engineering methods. In this sense, from the bibliographical research presented in this paper, it can be stated that methods such as Net Present Value (NPV), Payback and Internal Rate of Return (IRR) are suitable for this purpose.

Lastly, it should be noted that this work fulfills its main objective by presenting a basic bibliographic review on the application of Economic Engineering in the implementation of an electric vehicle recharging infrastructure.

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