Overview of Electric Buses deployment and its challenges related to the charging - the case study of TRANSDEV

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Summary

An overview of the worldwide deployment of Electric Buses (EBs) is presented with a focus on TRANSDEV strategy. The results show an important increase in the EBs sells during the last decade. Nevertheless, because of the size of their batteries, EBs fleets could have significant impacts on the grid, which requires a smart charging management. The second part of this paper uses optimization algorithm to search for optimal plans that minimize an objective function (charging cost, load power variations, battery aging…) while taking into account several constraints like bus operating constraints and constraints related to the charging infrastructure.

Keywords: EV (electric vehicle); EVSE (Electric Vehicle Supply Equipment); optimization; public transport; smart charging

1. Introduction

Clean technologies in public transportation are more and more needed today to cope with air pollution in urban areas. The Energy and Environment policy in Europe and in France has strengthen recommendations and incentives to introduce a significant share of clean technologies for vehicles including Electric Buses (EBs) in the horizon of 2030 [1] [2]. Over the world, the last few years has shown an important increase of EBs use, mainly in China. The first part of this paper makes a short overview of the EBs fleet deployment in European countries, US and China for the period ranging from 2009 to 2008. A focus is then made on the TRANSDEV transportation company strategy dealing with EBs introduction in their public transportation fleet.

However, introducing significant number of EBs in a bus fleet will generate potential problems that have to be solved. The main difficulties with charging a large number of EBs is the potential impact on the grid and on the batteries [3]. Simultaneous charging of an EBs fleet could drive to a tremendous high power peak. Consequently, oversizing of infrastructures, equipment and grid supply subscription could generate extra costs. A solution is to distribute the charging period considering the technical, economical and operational constraints. In such smart charging management, the potential impacts, like the battery degradation, have to be considered. Indeed, the state of charge (SoC) profile imposed to a battery influences its aging [4]. The average SoC of a battery is a first order factor of the calendar aging that occurs during rest periods [5]. As the temperature acts also strongly on the aging, the management laws could be dependent on the season.

The second part of this paper deals with a smart algorithm development in order to optimize EBs fleet charging while respecting grid and operational constraints.

2. Worldwide electric buses overview

The number of EBs in the world significantly increased in the last few years. Figure 1 illustrates the size of EBs fleet in USA and European countries in 2018. Figure 2 gives the sales progression in Europe in the last years showing that the interest for EBs was recent and certainly urged by worldwide climate preoccupation [6]. In Europe EBs represented 9% of the buses sales [7]. The biggest electric buses fleet is definitively in China where 370000 EBs were reported in 2017 by IEA [8]. The chinese EBs fleet followed the same trend than the rest of the world but with a tremendous higher intensity (Fig.2). The most patent case is the city of Shenzhen which reached 100% of its fleet with more than 16000 EBS at the end of 2017 [9]. This was the result of a very incitative policy led by the chinese authorities. For instance,150000$ could be given as a government subsidy, which is more than half the price of the vehicle [9]. Despite these impressive number, EBs still account for only 17% of the chinese total buses fleet [10]. The charging strategies are divided in two main groups : overnight charging at bus terminals or depots – usually slow charging - and opportunity charging in the street – usually fast charging. Pantographs usually equip EBs for opportunity charging. In 2017 60% of the EBs sold in europe are equipped with pantograph [7]. In China 50% of the EBs are equipped for fast charging [11] but in some case slow charging is more widely adopted: 100% of the 16000 EBs at Shenzhen are charged with a plug for instance [9]. In the future, depot chargers are expected to be majority as even in the case of opportunity charging, need for charging at depot is still present [12].

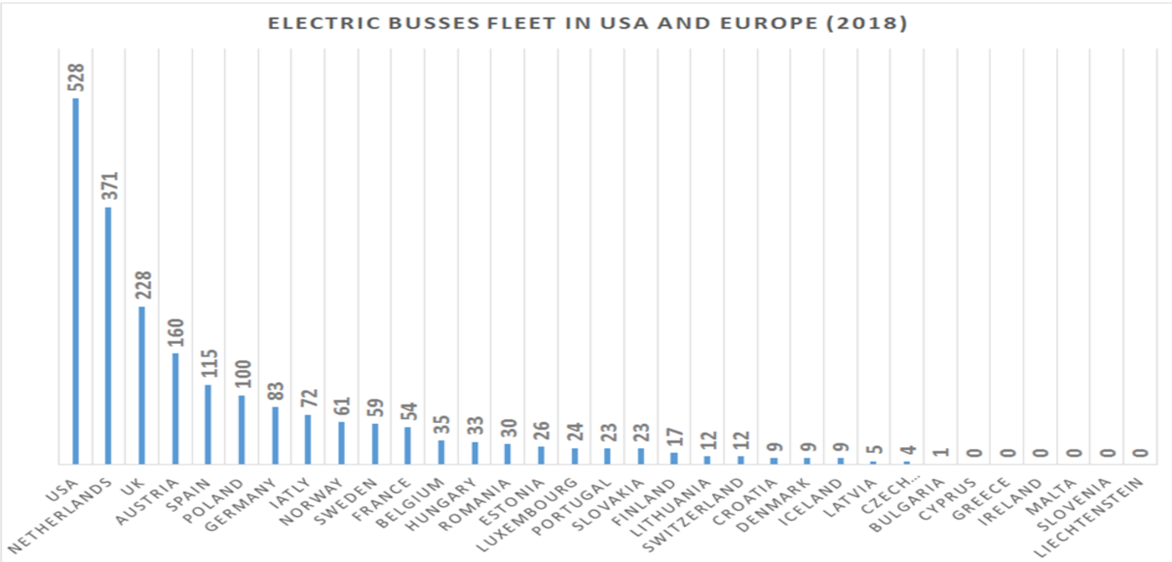


Figure 1: Electric buses fleet in USA and European countries (source: [13] & [14])

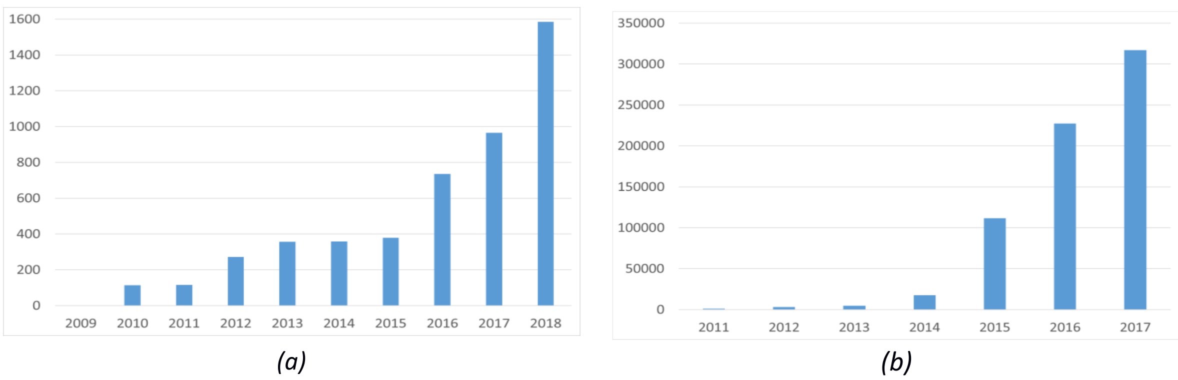


Figure 2: EBs fleet (a) in Europe (EU + Norway and Switzerland) [13] and (b) in China [15]

EBs sales predictions are expected to go further either in Europe or in the rest of the world. The International Energy Agency (IEA) built two scenarios for the progression of Electric Vehicles (EV) market: New policies Scenario (NPS) and EV30@30 scenario [8]. NPS is based on the policies and official targets the different countries has announced. EV30@30 is more ambitious and is consistent with the objectives of the Electric

Vehicles Initiative (EVI) set in the EV30@30 campaign [16] targeting globally 30% of EV in 2030. According to the last scenario in 2030, 60% of buses in China would be electric, 40% in Europe and only 15% in the USA as shown in Fig.3.

The ZeEUS project financially supported by the European Commission and coordinated by UITP focused on a review of the deployment of EBs in Europe by listing the fleets in cities and existing offers from bus makers. The final report [17] presents a possible evolution of EBs European market (Fig.4). In this scenario, EBs could represent more than 50% of the European bus fleet in 2030. Even if EBs would represent a minority of the total electric vehicles number [8], their large battery size makes them unmissable when studying the impacts of electromobility particularly on the grid.

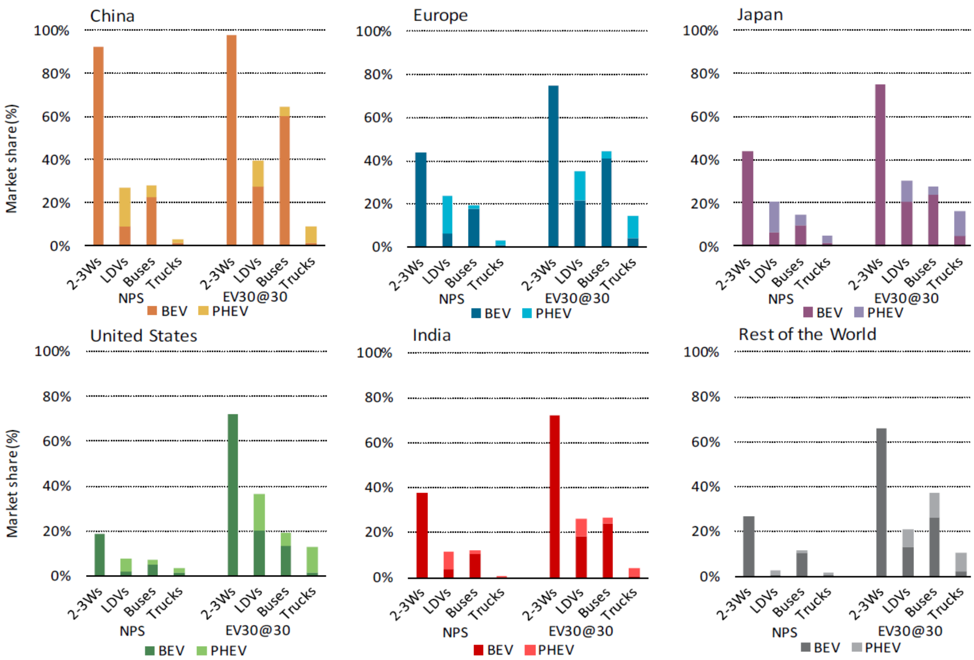


Figure 3: EBs market share evolution according 2 scenarios of IEA [8]

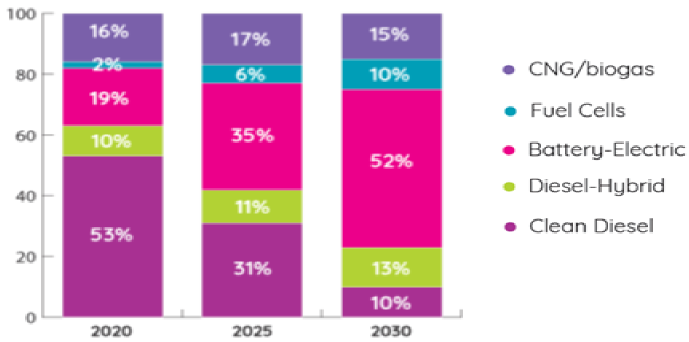


Figure 4: European bus market evolution [17]

European Commission supports several projects to promote and study the deployment of EBs in Europe. EBSF-2 [18] (European Bus System of the Future 2 - May 2015 to April 2018) studied contribution of innovative technologies to make bus systems more attractive and efficient, but not limiting to EBs. ELIPTIC [19] (Electrification of public transport in cities - June 2015 to May 2018) focused on the use of existing electric public transport infrastructure - e.g. metro, tram and trolleybus – as a charging infrastructure that could be considered as a smart grid itself. Experiments were carried out in several cities to integrate opportunity and overnight charging of EBs in this infrastructure. More recently, ASSURED [20] (fASt and

Smart charging solutions for full size URban hEavy Duty applications - October 2017 to September 2021) develops and tests high-power charging solutions designed to supply energy for a whole fleet of various types of heavy-duty vehicles (buses or trucks). The development of innovative charging management strategies is part of the project.

3. TRANSDEV Electric Buses deployment strategy

TRANSDEV is a major actor in the public transport and manages many EBs deployment operations in the world as illustrated in table 1. Electric buses operated by TRANSDEV at the end of 2018 reach about 600 units (including 157 midi or mini buses and 82 trolleybuses). The projections related to commitments with existing contracts give a fleet of 700 Zero Emission Buses in 2019 and more than 1000 in 2024.

Table 1: TRANSDEV EB fleets in the world (end of 2018)

EB Model	**Length**	**Country**	**Units**
Electric buses with overnight charging at TRANSDEV			
BYD	8-12 m	US	78
		Sweden	12
		The Netherlands	29
BYD	18 m	US	19
BYD	Double decker	US	4
PROTERRA	10-12 m	US	17
HYBRICON	12 m	Sweden	10
EBUSCO	12 m	France	4
BOLLORE	12 m	France	5
LINKER	12 m	Finland	1
LIONBUS	School bus	Canada	3
IRIZAR	12 m	France	3
MAGTEC	Double Decker	UK	4
HEULIEZ	12 m	France	8
CAETANO	12 m	Portugal	3
TRANSDEV electric buses with opportunity charging			
VDL	18 m	NL	43
VDL	18 m	NL	100
Volvo	12 m	UK	8

To this end, TRANSDEV is concerned about anticipation of the impacts caused by the spread of electric buses and the ways to limit the eventual drawbacks. A cooperative research work with IFSTTAR has been initiated in 2017 and is dealing with smart charging strategies management of EBs fleets. Figure 5 illustrates a typical charging power curve of a single EB. Such a profile, with no management of the charging of a fleet could cause a very large power peak. For this reason, a smart charging must be applied.

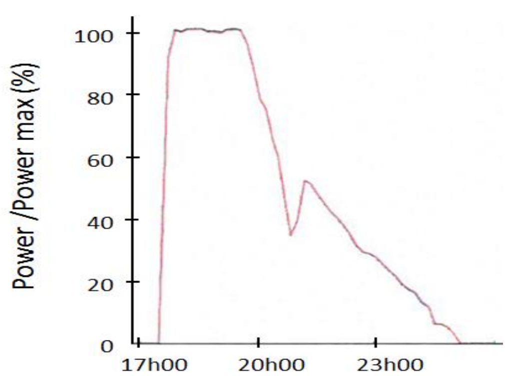


Figure 5: example of charging power curve of EB (doc TRANSDEV)

4. A smart charging methodology to manage the large-scale deployment of Electric Buses

4.1 Methodology and system modeling

To cope with issues of EBs deployment, a smart charging methodology has been proposed in the frame of the cooperative research work between TRANSDEV and IFSTTAR.

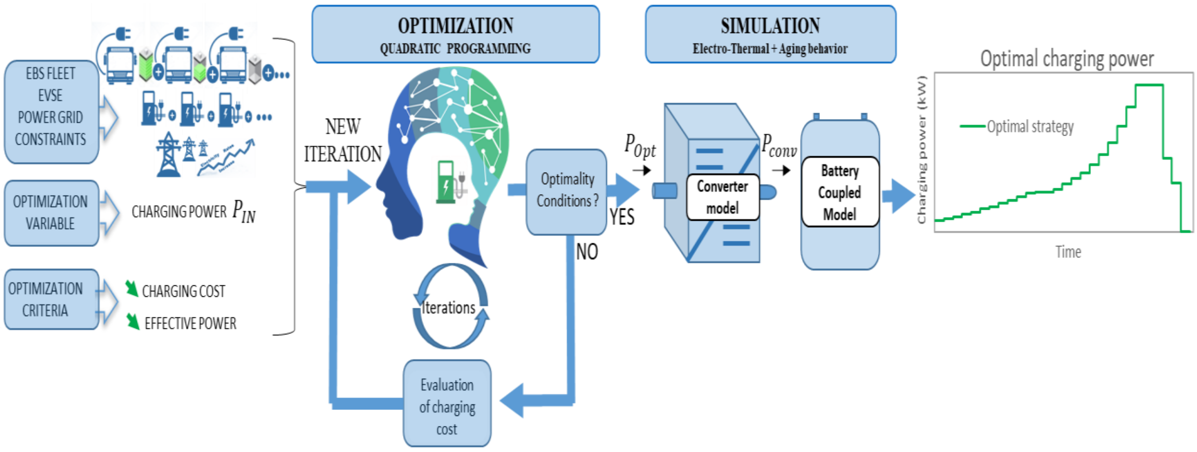


Figure 6: Smart charging methodology for a fleet of electric buses in urban transport

This part introduces a methodological approach (Fig.6) to develop an optimal charging strategy for a fleet of EBs in urban transport in the case of overnight charging at depot. The approach uses quadratic programming to search for optimal plans according to the objective function (by minimizing the charging cost as well as the effective charging power) while taking into account several constraints. The main constraints are directly related to the bus operation (number of buses, initial SoC, arrival and departure time, trip distance, maintenance period …) among other constraints that could be added. For instance, limiting the charging power to alleviate the demand on the power grid during peak consumption periods or avoiding exceeding the subscribed power of the charging station.

The optimization methodology has been implemented in the Matlab/Simulink environment. During the smart charging process, information on the operating bus constraints and other constraints related to the charging infrastructure and power grid has to be provided. The optimization algorithm attributes an optimal charging power profile for each bus to minimize the charging cost and the effective charging power while respecting the constraints. Once the optimization is finished, the optimal charging power profile P_{Opt} is applied to a converter model that represents the charger and a battery coupled model. The aim is to check if the battery receives enough energy and if its temperature is not too high. The converter model represents the charger efficiency. In a first approach, until we develop a specific converter model, we used a linear interpolation of charger efficiency values based on the experimental results used in [21].

To make the entire battery model more accurate, three sub-models are interconnected. The electrical model simulates the dynamic behavior of the battery within a specified period and provides different data values such as the SoC variation, the equivalent resistance, battery current and voltage.

The thermal model simulates the dynamic behavior of the battery temperature within the specified period. This model uses information about the equivalent resistance and the battery current to provide the battery temperature variation.

The aging model simulates the battery capacity fade within the specified period. This model uses information about the SoC variation and the battery temperature variation.

4.2 Optimization results of an electric bus fleet in urban transport

A case study was performed to illustrate the smart overnight charging methodology of the EBs fleet. The considered charging station is capable of supporting the simultaneous recharge of 10 EBs. The EBs will operate during the day an existing conventional bus line. A total of 10 chargers will be used to charge the EBs fleet during a charging time period of 14 hours.

We chose a time step Δt of 30 min that gives a total of m=27 time slots, which results in a reasonable search space. Each bus arrives to the depot at different time with different initial SoC. We fixed the battery initial temperature and the outside temperature to 25 °C. The initial capacity fade was fixed to zero.

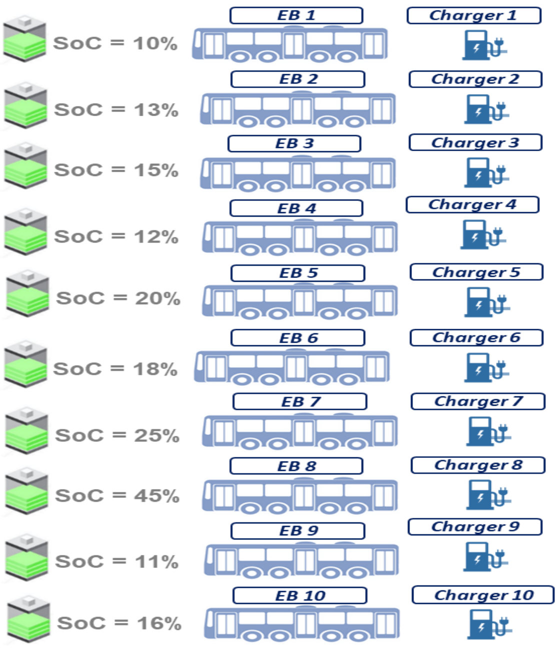
These data are summarized in Table 2.

Table 2 : Optimization parameters

Parameters	Value
Number of buses	10
Number of chargers	10
Number of simulated days	1 day
Charging time period	14 h
Charging slot	30 min
Maximum charging power per charger	Pmax
Subscribed power	600 kW
Number of charging time slots	27
Initial battery temperature	25°C
Initial battery capacity fade	0%
Fixed outside temperature	25°C

We are going to optimize a fleet of 10 EBs with specific operating constraints quite similar to an existing conventional bus line. First, information on the operating bus constraints (number of buses, initial SoC, arrival and departure time, trip distance, maintenance period) and EVSE constraints has to be provided. The smart charging algorithm will attribute the optimal charging power for the EB fleet to minimize the charging cost and the effective charging power while respecting the constraints.

The operating constraints are presented in Fig.7.



Arrival time	Departure time	Length of the trip	Target SoC
23:00	5:00	179 km	100%
23:00	15:30	83,33 km	50 %
23:00	8:00	179 km	100 %
18:00	5:00	155 km	80 %
20:00	5:00	178 km	100%
20:30	5:00	175 km	90 %
21:00	6:00	178 km	100 %
23:00	7:00	175 km	90 %
19:00	7:30	66 km	40 %
19:30	05:30	143 km	70%

Figure 7: Operating constraints

4.3 Results and analysis

In scenario no. 1, we are going to optimize 10 EBs with operating constraints mentioned above while imposing a subscribed power of 600 kW.

To illustrate the potential economic gain, we will compare a "**baseline**" solution to the optimized charge strategy. The "**baseline**" represents one typical behavior by charging the EB with a maximum power of Pmax during off-peak hours as soon as possible until it is fully charged.

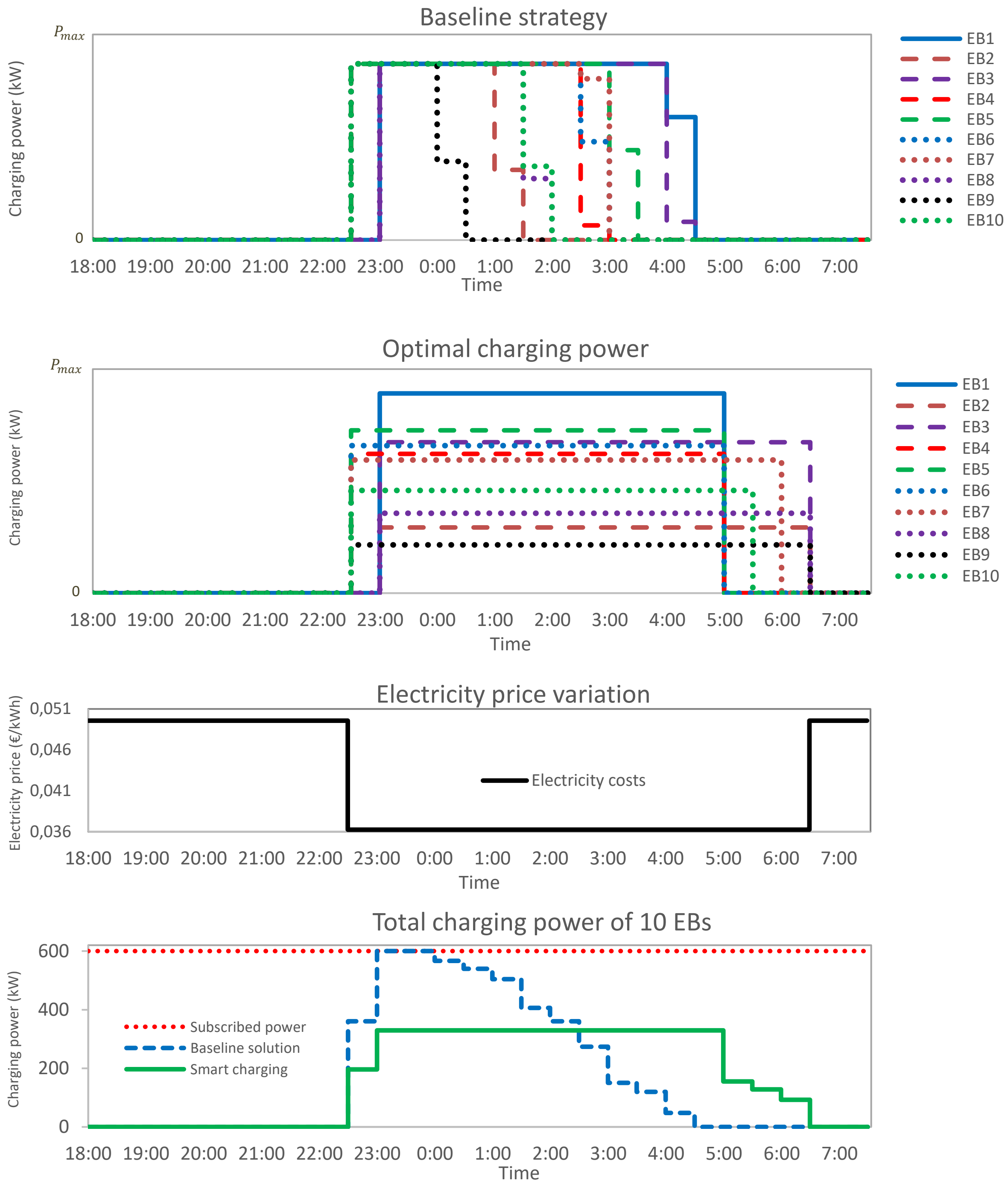


Figure 8: Baseline strategy and optimal charging power scenario 1

The results of the quadratic optimization in Fig.8 show that the optimal charging power charges all the electric buses during low-cost period (providing that the bus arrived at the depot) with an average power in a way to expand the charging period as long as possible while respecting operating constraints. The total charging power fluctuations of 10 EBs are smoothed by the **smart strategy** comparing to the **baseline strategy**. In addition, the total maximum charging power has been halved allowing a 50% possible reduction of the subscribed power.

In scenario no. 2, we are going to optimize 10 EBs with the same operating constraints mentioned above while reducing the subscribed power to 200 kW.

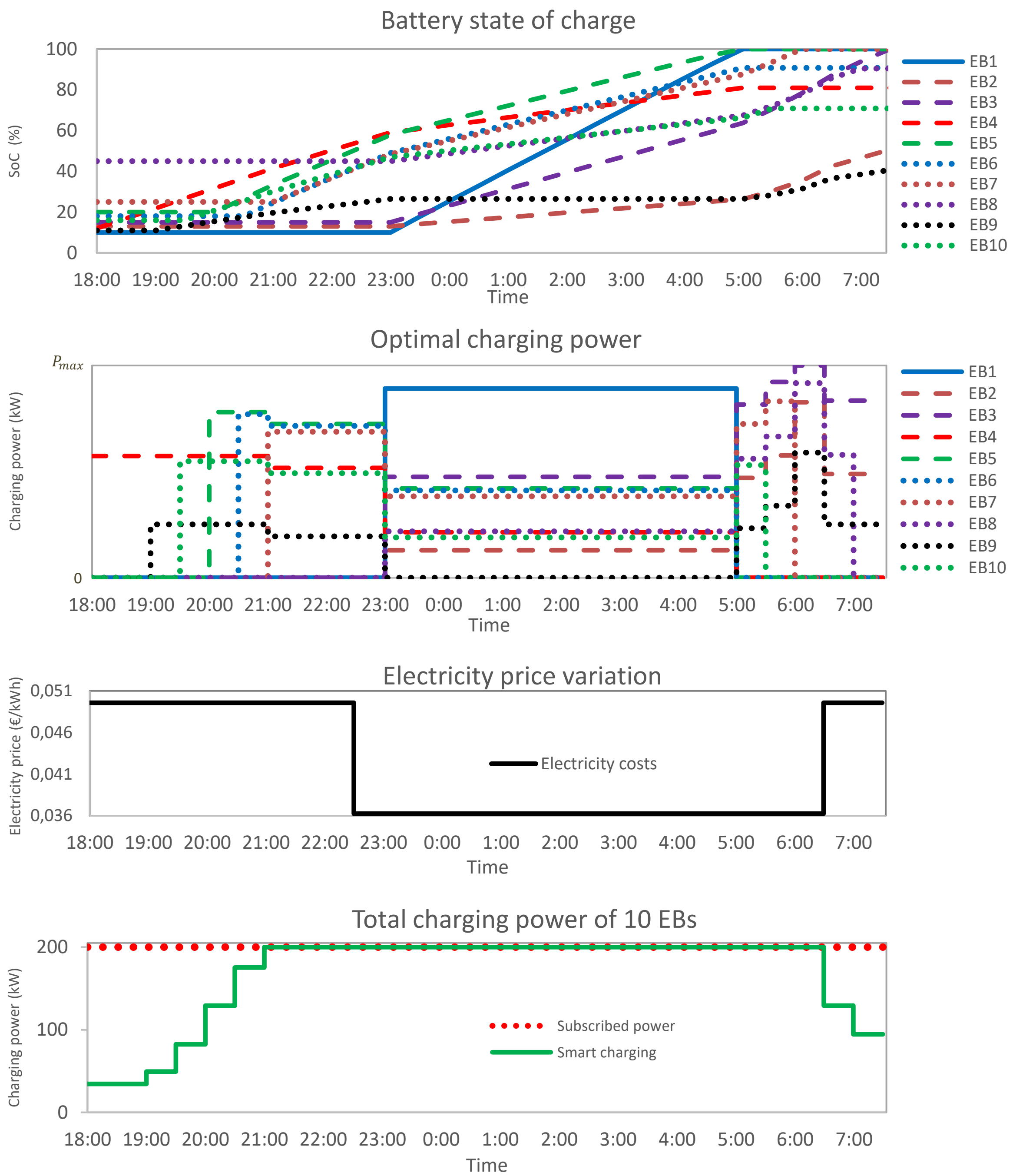


Figure 9: Optimal charging power scenario 2

The results of quadratic optimization in Fig.9 show that the optimal charging power fills the EBs charging profile during the low-cost period in a way to avoid exceeding the subscribed power. Subject to several constraints, once the algorithm filled all the low-cost period, it is forced to charge during the high cost period otherwise the power would exceed the subscribed power. Buses are charged when they arrive to the depot (successively EB9, EB10, EB5, etc …) during the first high cost period and the last buses that will leave the depot during the second high cost period. In other words, this algorithm gives priority to low cost periods. When the maximum energy in this period is not enough to charge every bus to its corresponding target SoC, the algorithm can predict it and will act by assigning some power gradually with each bus arrival to the depot. Also, for buses that are leaving later, the charge is delayed to leave some available power to buses leaving first.

5. Conclusion and future works

This paper introduces an overview of electric buses deployment and its challenges related to the charging. A present collaborative work between TRANSDEV and IFSTTAR that uses optimization algorithm to search for optimal plans to face up these challenges has been presented. A case study has been implemented to illustrate the smart charging of a fleet of 10 EBs during the overnight charging at the bus depot. The first results showed a coherent behavior of the algorithm and a short computational time (1s) that makes possible to deal with large fleet of several hundreds of buses.

In future work, it would be interesting to perform a conjoint optimization of the charging cost and the effective power together with the battery aging. Particular attentions must be paid to the aging mechanisms at high and low temperature.

Finally, we would like to extend the methodology so that the optimization tool will be able to size the charging infrastructure by minimizing the subscribed power.

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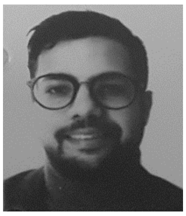
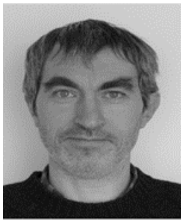


Adnane Houbbadi was born in Casablanca, Morocco, in 1991. He received in 2015 the Master's Degree in Mechatronics and Energy Research and Development from the University of Strasbourg. He received in 2016 the advanced Master in Renewable Energy Projects and Production from Arts et Métiers ParisTech. In 2017, he joined IFSTTAR as a PhD student. His work is in collaboration with TRANSDEV and focuses on the optimization of an electric bus fleet charging.



Serge Pelissier was born in 1963. With a PhD in Electrical Engineering from the Institut National Polytechnique Grenoble, he first became Associate Professor and then Professor at the University of St. Etienne. In 2007, he joined INRETS (IFSTTAR since 2011). His work focuses on modeling, characterization and ageing of batteries in automotive applications.

Rochdi Trigui was born in Sfax, Tunisia, in 1969. He received the PhD degree in Electrical Engineering in 1997 from the Polytechnic National Institute of Lorraine. He then worked for one year as an associate researcher at PSA Peugeot Citroën. Since 1998, he is full researcher (senior since 2012) in IFSTTAR (former INRETS) in the field of modeling and energy management of electric and hybrid vehicles. He is now deputy head of AME department of IFSTTAR and was co-chair of IEEE VPPC 2010.

Eduardo Redondo-Iglesias was born in Vigo, Spain, in 1981. He is in charge of the battery test equipments in IFSTTAR. In 2017 he received the Ph.D. degree in Electrical Engineering from the University of Lyon (France). His research activities are electrical modeling and characterization of batteries and their ageing for transportation applications.

Tanguy Bouton was born in 1986. He graduated two Master 2. First one at La Sorbonne University in International Business Consulting, second one at Paris Est University, specialized in urbanism and urban transportation. He worked in the manufacturing industry for PVI on the first demonstrator for a 12m electric bus in France (System Watt at Nice Airport) and then joined the operator business as planner for the network of Riyadh (Saudi Arabia), to become later Energy Transformation Business Manager at TRANSDEV Group Headquarters.