Madrid / Spain

SOLUTIONSPLUS I SCALE-UP CONCEPT NOTE

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PROJECT PARTNERS

ABOUT

This paper has been prepared for the project SOLUTIONSplus to describe the plan to scale up the installation of charging infrastructure to achieve full electrification of Carabanchel bus depot by the end of 2024.

TITLE

Solutionsplus Scale-Up Concept Note: Madrid, Spain

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LAYOUT

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PICTURES

All the pictures are provided by the SOL+ partners

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Scale-Up Concept Note

Electrifying EMT Madrid Carabanchel bus depot with smart charging solutions

Madrid/Spain

1. Background

Currently (as of February 2023), with 28 100% electric EMT lines, Madrid is the city with the most electrified routes in Spain and the second in Europe, after Berlin.

Electrification is a key aspect of EMT's new Strategic Plan. This roadmap, which will set the direction of the organisation until 2025, ensures a historic investment by Madrid City Council: more than 1 billion euros to undertake a real technological transformation.

Despite the long trajectory of the company in electrification (the first fully electric buses were added back in 2007, and between 2018 and 2022 EMT operated the first Spanish induction charging bus line with 5 retrofitted buses working on a commercial basis to demonstrate the feasibility of these solutions), the corporate objectives of the new Strategic Plan reinforces the route map towards a green and decarbonised organisation with an energy sustainable model, customer-oriented from excellence, financially sustainable and deeply innovative in technology.

To achieve these objectives, and in line with the "Madrid 360 Environmental Sustainability Strategy" of Madrid City Council, EMT Madrid is firmly committed to the gradual electrification of its bus fleet with the aim of reaching a 25% electric fleet by 2025. As an example, last May 2022, EMT awarded the largest purchase of electric buses to date: 150 vehicles, for a total of 81 million euros, partly financed by Next Generation funds (41.2 million euros for the purchase of 206 electric buses until 2023).

In addition to that, EMT phased out its last diesel bus last December 2022, making Madrid the first major city in Europe in having a 100% clean bus fleet according to the EU Clean Vehicles Directive.

EMT is currently running a pioneering project for the automation of intelligent charging by using inverted pantographs involving in its first phase an investment of more than four million euros and is backed by up to 90% financing from the EU Next Generation funds. One of the objectives pursued with this initiative is having a charging solution to be adapted to all manufacturers, regardless of the manufacturer of the bus or charger. Through this standardization, the solution can be replicated in other operations centres of EMT.

The new Strategic Plan also includes ambitious infrastructure projects to advance electrification, such as the transformation of the current facilities of the La Elipa Operations Centre into a reference centre to house a 100% electric fleet. This facility will have a capacity for up to 318 electric buses and will have a large photovoltaic installation that will be a national benchmark for energy efficiency. EMT's plans also include the remodelling and adaptation of the Carabanchel, Entrevías and Sanchinarro operations centres to the new operational needs of the municipal company, rigorously following sustainability and efficiency criteria.

Last but not least, aligned with the decarbonization strategy, EMT is also involved in a project to build a hydrogen plant and the photovoltaic installation that will supply it at the Entrevías Operations Centre, providing green hydrogen for a fleet of ten buses that EMT plans to acquire in the first phase. The project involves the commissioning of the necessary facilities for the production (by using photovoltaic panels), storage and distribution of green hydrogen.

2. About the Project

2.1. Goal

Many times, decarbonization is focused on the e-fleet side, considering charging infrastructure as the necessary but obvious element linked to the e-bus. Also, most of the times, PTOs rely on the bus manufacturers to count with the charging infrastructure to be installed at bus depots, adapting to the existing buildings and facilities.

Thanks to SOLUTIONSPlus, EMT has been testing, in its Carabanchel bus depot, an innovative and modular charging solution by using inverted pantographs. This solution, provided by ABB (also project partner), has allowed EMT, as the main goal of the project, to gain experience on fast charging and the use of smart software to be able to charge many buses at the same time while keeping at a minimum the assets to reduce the fixed costs of operation.
The goal is to fully electrify Carabanchel bus depot, to become the flagship facility of the company regarding electrification.

2.2. Scale-up Approach

In order to ensure the scaling up of electrification within the company, a deep review of the state of the electromobility in urban public transport by bus has been conducted from all different charging strategies, types of chargers, and e-buses with a general overview and a SWOT analysis. A review of five case studies worldwide (Bergen, Eindhoven, Bogotá, Groningen and Shenzen) was also conducted (together with the experience from the site visits under SOLUTIONSPlus project to the cities of Hamburg, Gotheborg, Copenhaguen, Birmingham, Coventry and London) and a real case study with real data was shown in depth: EMT Madrid, where all chargers and charging systems were developed in a single operation center. Total Cost of Ownership (TCO) from the literature and from the case study for e-buses were shown as compared with different bus technologies.

The scale-up approach is a real case study where in a single operation center (depot +300 buses) all typologies of charging exist, so real investment costs (infrastructure + e-bus) and operation costs can be shared and compared with the state of knowledge to contribute for improving best practices in this great energy transition in bus public transport.

2.3. About the scale up project

Following traditional gas and fuel refueling strategies, the first approach introduced to charging electric fleets was to introduce depot charging. However, the limited range of the batteries brought the need to introduce additional charging along some routes. This is known as opportunity charging.

Charging at the bus depot: Under this scheme, fleet charging operations are carried out only at the depot. Charging is usually conducted overnight due to the cheaper power prices and to avoid interfering with operating hours.

With a single time possibility of charging, the operation of the transport units must be planned to ensure that the autonomy of the buses is sufficient to cope with the daily scheduled operating conditions. Warehouse cargo may also include the following subdivision:

- Charge only overnight. Buses are charged only at night.
- Night + intermediate charge. Buses are charged mainly at night. However, some lines may experience a daytime charge between shifts to address limited range issues.

Opportunity charge: Under this scheme, the fleet's charging operations are carried out at the depot itself and/or at additional points in the bus network. Typically, these additional charges are matched to bus stops or line headers/ends. The operational needs of the service are somewhat unrelated to the autonomy of the vehicles due to greater access to charging on the network. For this reason, smaller-capacity (and therefore cheaper) batteries can be used. However, as the number of battery charge cycles per year increases, the lifespan of the battery decreases.

Like vehicles, charging equipment manufacturers have consolidated their portfolios with a variety of products, primarily focusing on increasing power output and diversifying the technologies offered. Basically, there are two main types of chargers: column chargers, which are the ones that integrate all the components inside a container (mainly with cable connectors) and modular chargers that are made up of several units, a power module, and a connector (conductive or inductive) as central elements.

The first approach to charging electric buses was to use column chargers that were normally supplied by the bus manufacturers themselves; however, in the interest of optimization, modular chargers are taking over and charging equipment manufacturers have taken a major role. This shift from individual charging columns to high-power modular chargers with multiple outlets has been seen in cities such as Amsterdam and Hamburg, which are currently at the forefront of electric public transport systems. High-power modules (above 150 kW) allow these modular systems that optimize space consumption as they allow several outputs to be connected to a single power module, space limitations being a common issue in depots throughout Europe.

Lately, power modules greater than 1MW have been introduced on the market. Nevertheless, although high-power modules bring many benefits, they also have their own drawbacks. In fact, even though charging powers are increasing, charging speeds are still limited as the maximum battery voltage and C-rate determine the minimum charge time required. In addition, a great step has also been taken with the standardization of communication technologies and protocols, specifically ISO15118, IEC 61851, Oppcharge, or OCPP.

In fact, standardization has proven to be essential in the expansion of electric fleets and the implementation of large-scale charging infrastructure systems. Early pilots had a limited number of buses and chargers, so charging operations could be conducted mostly manually. However, with the introduction of opportunity charging and the improvement of electric fleets, automated charging becomes essential. For this, intelligent charging systems are paramount.

These systems make it possible to monitor and control the power that is transferred to the vehicles in a way that optimizes operation and maintenance. For the transition to automated charging procedures, the selected charging technology or connector type plays a key role. Regardless of the charging strategy, any available charging technology can be used.

However, some charging technologies are better suited to certain strategies. For example, automatic quick-change technologies are more advantageous for opportunity charging than wire (cable) charging. Multiple technologies have been developed for both electric cars and electric buses. However, the following are the most common for battery electric buses: (i) wire charging; (ii) induction charging, and (iii) contact charging, including traditional pantograph and inverted pantograph.

After a deep analysis of options and testing, EMT Madrid has chosen the charging at the bus depot by using inverted pantographs for the scaling-up policy.

Conductive charging (pantographs) by panto-down:

The inverted pantograph or “Panto-Down” consists of a pantograph located on a pylon or structure. When the bus reaches its charging position, the pantograph is downlifted by means of internal hydraulic pumps until it connects with a receiver located on the roof of the bus. The table on the next page shows a SWOT analysis of traditional inverted pantograph or panto-down.

As mentioned, pantographs have significant advantages and some disadvantages over cable charging. In addition to that, inverted pantographs aim to solve some of the shortcomings of “Panto-Up” ones.

The list of strengths of this technology is remarkably long; however, one of the biggest advantages of inverted pantographs is that they are universal, requiring only a couple of connecting rods to be installed on top of buses. Thus, it enables a full decoupling of charging infrastructure and buses, allowing the implementation of new operating models.

The transfer of the pantograph from the vehicle to the tank represents a significant saving in weight in buses, which translates into better energy consumption. Since the weight of the pantograph is no longer a penalty, they can be designed to be stronger and larger if required.

Although few in number, they still have certain disadvantages. With a limited number of chargers, in the event of a breakdown, this can affect all vehicles on a given line. However, this is not a problem in the case of Carabanchel since there will be one pantograph per bus.

Therefore, in case of failure, other pantographs can be used under fast charging to charge more than one bus. Overall, this system is robust and even the risk of getting stuck in the “down” position can be overcome by ropes.

EMT Madrid Carabanchel bus depot has served as a test bed of all different charging infrastructures (wire charging, induction charging and conductive charging). All different in concept and technology coexisting during certain time.

The experience obtained from these different charging infrastructures together with the SOLUTIONSPlus pilot, has allowed EMT Madrid to set the most optimal and flexible model for the electrification of 100% of the fleet in the following years, which is based on the use of inverted pantographs.

In the following table the different advantages and disadvantages are shown.

Table 1: SWOT analysis of Traditional inverted pantograph or panto-down

STRENGTHS	WEAKNESSES
○ Allows automatic charging maneuvers. ○ High power allowed (up to 600 kW). ○ The connection can be universal, so buses can park and charge at any parking spot equipped with a pantograph. ○ No weight is added to the vehicle. ○ The pantograph is not exposed to the weather: less maintenance. ○ It allows lighter and more aerodynamic buses—lower consumption. ○ Allows decoupling of vehicles and charging infrastructure. ○ The pantograph is more robust since weight is not a penalty. ○ The pantograph can be longer to fit smaller buses. ○ Due to the universal connection, it allows to have less pantographs.	○ More expensive charging infrastructure. ○ Requires wireless data transfer in the vehicle.
OPPORTUNITIES	**THREATS**
○ Enables an intelligent charging management system. ○ Allows fast and secure opportunity charging. ○ "Universal": can work for any make and size of bus. ○ It facilitates the optimization of the charging system in terms of the number of chargers. ○ It allows a modular and scalable design of the electrical system. ○ It would be compatible with automated buses. ○ Depending on operational constraints and charging strategy, you could have fewer pantos (serving multiple buses with the same pantograph). Depending on operational constraints and charging strategy, you could have fewer pantos (serving multiple buses with the same pantograph).	○ If the panto gets stuck in the down position, it can pose a hazard when pulling out the bus and pose a hazard to other buses. ○ With limited chargers, if one pantograph fails it can affect an entire line. ○ The technology is in a development/adoption phase, so there are still few manufacturers

Scaling up

To define the electrical infrastructure for charging by inverted pantograph, EMT Madrid has planned two phases, i.e., a first (called second phase) for the implementation of 52 charging points for 50 buses that arrived in 2022, and a second one (third phase) that is intended to be replicated in the very short term consisting of 118 charging points for another 150 electric buses of 12 m length planned for early 2024. This will mean having a total of 233 compatible charging points (63 per socket and 170 per pantograph) for a total of 250 buses of 12 m length, reaching a total number of 293 charging points by the end of 2024 (with the final phase, the fourth one, with 60 additional pantographs). As general characteristics, these are electrical infrastructures where the energy supply is carried out at 400 V through underground transformation transformers, 15 kV/400 V and 2500 KVA of power (six in total, one for every 25 buses approximately).

The distribution in low voltage is carried out by means of hanging prefabricated trunking (busbar) capable of distributing up to 4000 A. As it is necessary to support the inverted pantographs, the execution of a canopy in two heights is planned, the first one for support and anchoring of the pantographs and the armored bar, which also serves to protect the buses against climatological agents, extending their useful life, and a second one to house the charging equipment that will feed the pantographs.

The entire surface of the canopy is used for the installation of photovoltaic panels that will allow the residual charge that is carried out during the day to be through self-consumption. The power of the photovoltaic installation will be approximately 300 kW for every 50 places electrified by pantograph (more than 1000 kW in total). At a particular level, the infrastructures of each of the phases differ in the maximum power to be supplied to each of the pantographs by the charging equipment, as well as their layout. In phase 1, designed for 52 buses, there is a charger or pantograph charging equipment with a maximum power available in the installation of up to 275 KW (400 A) per bus individually, and a charging power of between 80 and 100 kW per bus for all 52 points charging at the same time.

Figure 1: Phase II of the inverted pantographs in Carabanchel bus depot

For phase II, it is planned to have charging equipment for several pantographs so that the maximum power of the charging equipment can be given to just one of the pantographs or buses or distributed among all the units it feeds. The minimum power to be able to supply a single pantograph will be 300 kW and the minimum to be supplied with all the vehicles associated with that charging equipment, charging simultaneously, will be 75 kW.

The maximum power of the equipment will not exceed 720 kW. Both solutions allow the possibility of having multipurpose points in the Operations Center that allow slow or uniform charging for 2–3 hours at night, where the electricity rate is cheaper, and also allow fast charging at any of the points so that emergency situations, unforeseen events, or service needs can be dealt with.

Conclusion:

The charging strategy for scaling up described in this concept note allows EMT Madrid to design fully optimized charging infrastructures, with simultaneity coefficients that are not very high, avoiding the creation of oversized and consequently more expensive infrastructures.

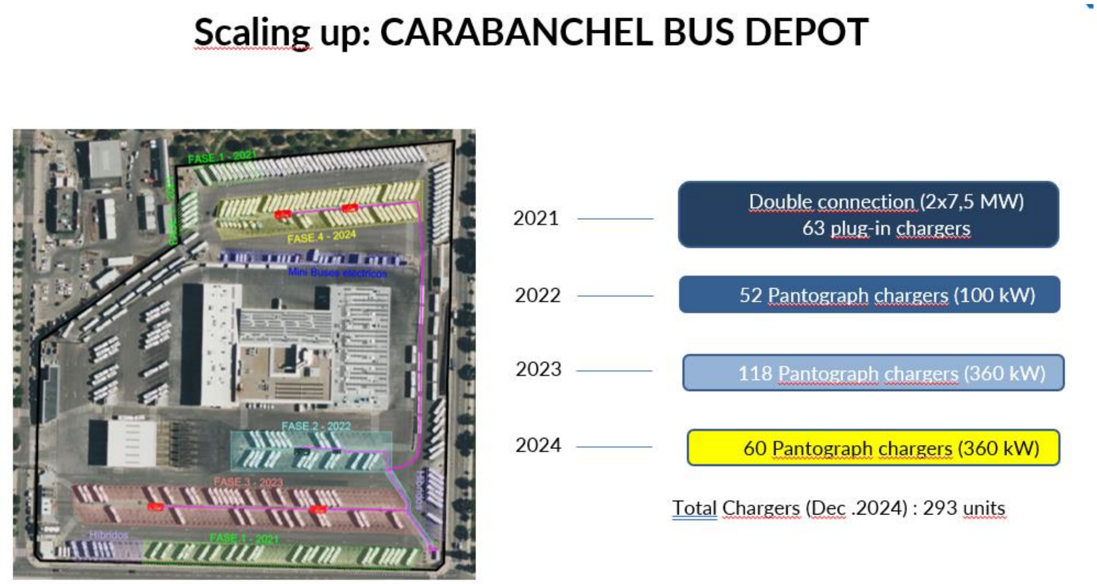
In order to charge with these characteristics, an intelligent charging system "Smart Charging" is essential to manage the charging process based on the different objectives that are to be achieved during said process, which are detailed below and which EMT Madrid explored in its studies:

- Minimum power per bus (increased battery life). Based on the available charging time per bus, the buses are charged with the minimum energy input. In this way, the maximum power peak in the electrical network is reduced since all the available charging time is used. However, a smart charging strategy can introduce changes in power input based on other variables, such as the cost of contingencies. Changes in power input do not affect battery health, as long as the power is medium to low.
- Maximum fleet availability. Configure the charging process so that at a certain time all the buses are loaded regardless of their departure time. This increases the power needed and the charging power of each battery but reduces the risk of a bus not being available at the required time.
- Cost reduction. Optimize the charging schedule based on energy costs. This strategy allows buses to be charged at low-energy-cost schedules, seeking the optimal point between schedules, electricity rates, and necessary power.
- Balance. This strategy combines charging power, availability, and least-cost strategies. The buses are charged in hours of low energy cost with an available power higher than the strictly necessary and which allows the buses to be safely charged well in advance of their departure time.

Each of these strategies is considered feasible in EMT Madrid, since there is one charging point per bus; any other option would lead to a maximum power charging strategy available in each charger with more than one vehicle during the entire bus availability period in the bus depot.

2.4. Timeframe

For the Carabanchel bus depot, this is the schedule of the scaling up of charging infrastructure:



2.5. Stakeholder Engagement

To develop this project it is fundamental to set the proper public-private cooperation framework, beyond the traditional procurement processes. Public-private cooperation is essential to drive bus electrification projects and their large-scale scalability. This collaboration combines the strategic vision and regulatory framework of the public sector with the innovation, efficiency and capital of the private sector. Together, they can overcome technical and financial obstacles, accelerating the transition to cleaner and more sustainable public transport.

The scalability of these projects not only reduces greenhouse gas emissions, but also fosters job creation, improves air quality and promotes equity in access to transport. Ultimately, public-private cooperation in bus electrification can be a powerful catalyst for the green transformation of our cities.

3. Budget

The planned investment in this mode of charging in execution will be €540,960 for purchase and €93,629.57 for charging infrastructure for each e-bus.

More in detail, the costs for phase II and phase III (phase IV is still under evaluation) are:

Phase II: 52 pantogrphs: 2.969.126,44 €
Phase III: 118 pantographs: 6.697.692,07 €

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