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Feasibility study of reconfigurability between different power transmission concepts for electric bus charging

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Abstract

Within the framework of ASSURED project, towards fast and smart charging solutions for electric urban heavy-duty vehicles e.g. buses and trucks, a feasibility study on reconfiguration of two pantograph concepts into each other is performed. The concepts are categorized as inverted and roof-mounted pantographs. State of the art of both concepts in mechanical, electrical, and communications points of view are considered. Both systems are used and well-integrated in the fast charging infrastructure, which can allow the electric buses to charge on route at terminal stops. Since both concepts are incompatible, a bus with a roof-mounted pantograph cannot be charged at a charging station built for an inverted pantograph system due to different interfaces, and vice versa. Thus, this feasibility study focuses on required modifications at both charging infrastructure, and vehicle sides. Technical possibilities of switching between two pantograph solutions are also investigated.

Keywords: pantograph concepts; fast charging solution; inverted pantograph; roof mounted pantograph; charging infrastructure

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1. Introduction

One of the major challenges within Assured project is to study the reconfigurability of two power transmission concepts i.e. pantographs into each other. Inverted and roof-mounted pantographs shown on Fig. 1 are widely used in electric public transport market these days, while it is very likely for a vehicle to be used under another operational circumstance. Thus, there will be a need to reassemble pantograph systems on the vehicle. The same goes for charging infrastructure, as the situation within an urban environment might change due to public transport operator (PTO) policy changes, etc. This study is performed to investigate all mechanical, electrical, and communications modifications required on both vehicle and infrastructure to move from one pantograph concept into another one.



Fig. 1. The two investigated pantograph concepts in this study (a) inverted pantograph also referred to as top-down or infrastructure mounted; (b) roof mounted pantograph also referred to as bottom-up

As a prerequisite for this study, a comprehensive knowledge on both pantograph concepts, in three levels of infrastructure, pantograph, and vehicle is essential. Therefore, state of the art of pantograph solutions and charging infrastructures are reviewed. SCHUNK Group, as one of the leading companies in pantograph manufacturing, has provided in-depth details on both inverted pantographs SLS201 (referred to as concept A) and roof-mounted pantographs SLS102 (referred to as concept B). On the other hand, HELIOX as a charging infrastructure supplier (TIER1), has provided diverse information on mast and pillars, pantograph installation, and charger communication units. VTT relates every corresponding standard on each part of the study whether is it electrical, mechanical, or on communications. By observing the two concepts and their functionalities, manufacturers have stated that there is no mechanical interoperability between two concepts. Thus, this study is focusing on the infrastructure side and vehicle side modifications. Consequently, it should be pointed out that in order to reconfigure concepts, each pantograph system is completely removed, and the other one is installed. The progressive workflow of the study is summarized in Fig. 2. The inverted pantograph is referred to as “Concept A” and roof-mounted pantograph is referred to as “concept B”.

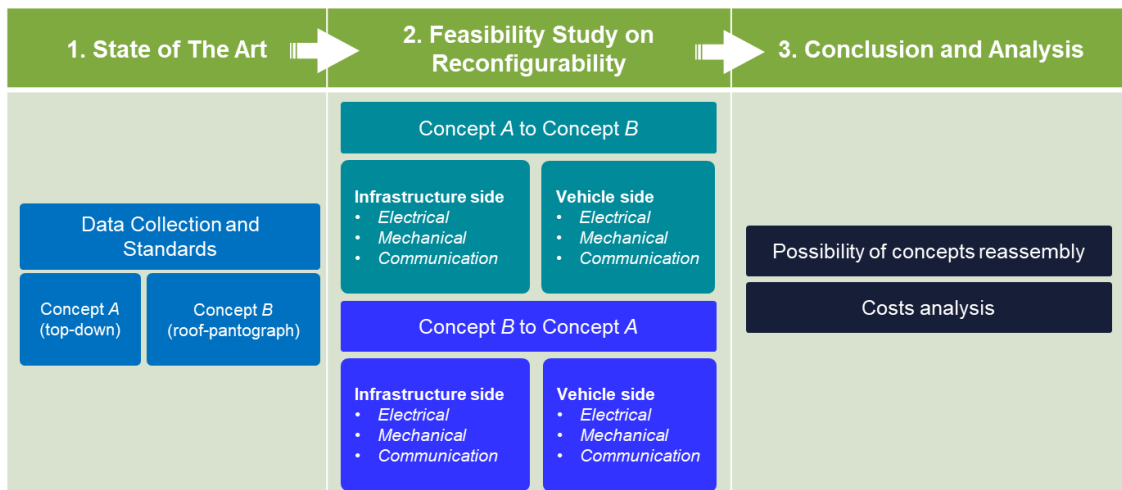


Fig. 2. workflow of the study

2. State of the art of pantograph solutions

Standardization of charging solutions is the most important challenge to make them interoperable. The main standards related to the vehicles' charging are ISO 15118 (communication), IEC 61851-23-1 (electrical safety)

and ISO 17409 (vehicle electrical safety). Due to progressive charging power levels, existing standards are required to be modified and updated according to the market’s new demands. This process is still ongoing. Standardization of mechanical parts of the charging connection has been recently started in IEC TC23h WG5.

Fig. 3(a) demonstrates an inverted pantograph which can have different connection interfaces. Since the rail interface is one of the common interfaces in the market, the study has been conducted on rails installed on the bus roof. Though the interface by itself does not make any significance difference in fundamental charging parameters. Also, a roof-mounted pantograph is demonstrated on Fig. 3(b) including the pantograph and the resting frame to be installed on bus roof, and the contact dome to be installed on infrastructure. The main parameters of both concepts are summarized in Table 1.

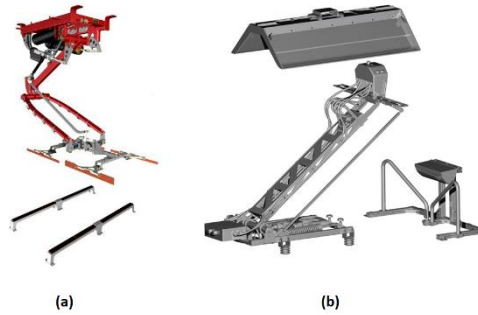


Fig. 3. The two studied pantograph perspectives (a) inverted (b) roof-mounted.

Table 1. Technical parameters of two studied pantograph concepts

Parameter	Concept A value	Concept B value	Unit
Maximum rated voltage	1500	1000	VDC
Nominal voltage	750	750	VDC
Charging current	500	500	A
Maximum current (<10min)	600	800	A
Electric lowering unit voltage	24 ± 30%	24 ± 30%	VDC
Contact force	500	250 +10%	N
Weight	175~180	85	Kg
Operational temperature	-30 to +65	-30 to +65	°C

A&B concepts have a working range of 700mm to 2.3m, and 1.5m to 1.8m respectively depending on the project. Within the working range the contact pressure remains the same amount. Inverted pantograph descends from the overhead pole to meet four lightweight (approx. 15-20kg in total) current collector rails with two in series and two in parallel on the roof of the bus. The series rails are separated in the center by an insulator, to make a total of 4 contacts, Positive, Negative, Earth and Pilot. Concept B charging system guides the electricity from the roadside charging station via the contact dome through the pantograph to the energy storage unit of the vehicle. It enables high power transmission for pulse charging (1000A/30s/750kW). Other supported charging strategies are opportunity charging (700A/10 ~15min/450kW) and depot charging (150A/100~150kW) [1]. Same values apply for inverted concept except for opportunity charging duration which is 3~6min. All charging strategies can be performed with the same pantograph. So, it is possible to charge a vehicle during the service with fast charging and to use the pantograph at the depot for overnight charging. Both concepts use 4-pole design according to CCS mode 4 communication. Compensation of parking tolerance mechanism for both, offsets vehicle movement during charging process as well as parking tolerances. Parking tolerances of the electric bus, including kneeling, are +/- 500mm in the driving direction, +/- 350mm parallel to the driving direction, 4° (5° for concept A) kneeling. Contacting of both systems takes place within few seconds and permits a constant contact pressure during charging. Fig. 4 shows actual demonstration of two buses being charged based on concepts A and B.

3. Reconfiguration of pantograph solutions

As discussed in previous sections, this study is focusing on the infrastructure side and vehicle side modifications since there is no mechanical interoperability between two pantographs. Consequently, it is agreed that in order to

reconfigure concepts, each pantograph system is completely removed, and the other one is installed. The study is performed in mechanical, electrical, and communications points of view.

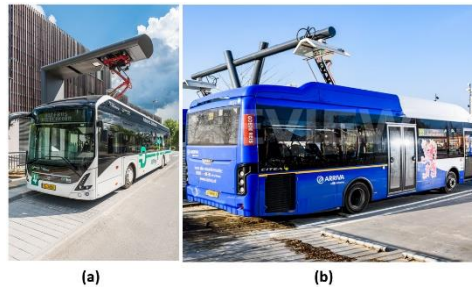


Fig. 4. Real life demonstration of e-buses being charged at stations based on (a) concept A and (b) concept B systems.

There are several ideas proposed to investigate the impact of a reconfiguration. It is chosen to consider the two most impactful reconfigurations:

- **Concept A to Concept B:** This idea considers a charging station with an inverted pantograph installed on the pillar, and a bus with current bars. The study investigates modifications made on the vehicle and infrastructure, to remove the inverted pantograph, and install a roof mounted one.
- **Concept B to Concept A:** This idea considers a charging station with a dome counterpart installed on the pillar, and a bus with a roof-mounted pantograph. The study investigates modifications made on the vehicle and infrastructure, to remove the roof mounted pantograph, and install an inverted one.

3.1. Mechanical perspective

Required modifications of both infrastructure and vehicle sides will cover following aspects:

Height: each concept has different working ranges either on upper side or lower side as on Fig. 5(a).

Weight: Since pantographs and their counterparts and rails weigh different, vehicle and pillar must be capable of handling new values after reconfiguration.

Mast arm length: Length requirements for both concepts must overlap on a mutual criterion to perform the reconfiguration process as shown in Fig. 5(b).

Space clearance: pantographs and their counterparts occupy different spaces. Sufficient clearance is met before reassembly process as on Fig. 5(c)&(d).

Fastening points: new fastening points are made on both sides to install new equipment as on Fig. 5(c)&(d).

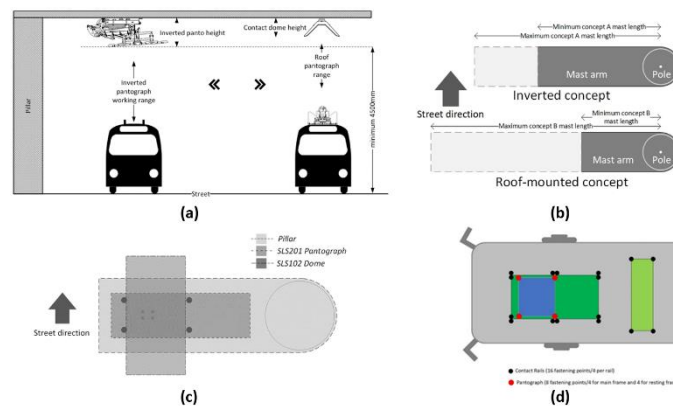


Fig. 5. Mechanical considerations for reconfiguring pantograph concepts in terms of (a) height (b) mast arm length (c) space clearance and fastening points on infrastructure (d) space clearance and fastening points on bus roof.

3.2. Electrical perspective

For this aspect of reconfiguration on the pillar, cable length, type, connector, and quantity of cables have to be considered. Insulators are the other electrical aspect which has to be taken into account. Basically, four cables of DC+, DC-, PE, and CP are directed from charger/vehicle to the pantographs. Fig. 6 demonstrates all differences on power connections of pantograph systems either on vehicle side or infrastructure side.

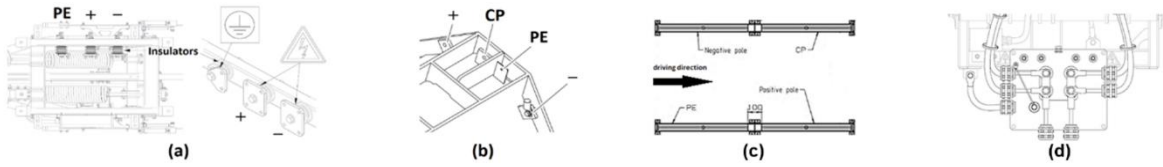


Fig. 6. Electrical connections of pantograph concepts (a) concept A on infrastructure side (b) concept B on infrastructure side (c) concept A on vehicle side (d) concept B on vehicle side.

3.3. Communications perspective

Communications point of view is directly dealt with starting and terminating the charging process. Below are two sequences for both concepts. Reconfigurability is done by making the new concept compatible with sequences shown in Fig. 7.

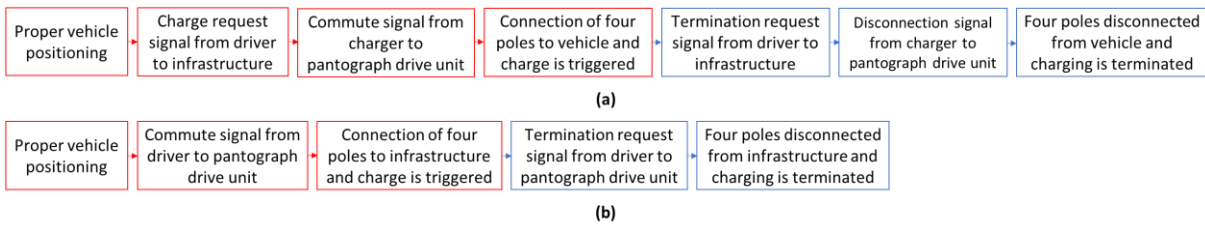


Fig. 7. Connection/disconnection sequences for (a) inverted concept (b) roof-mounted concept

3.4. Costs analysis

Costs of reconfiguring both pantograph concepts into one another are summarized in four charts as in Fig. 8. On Fig. 8 (a), installation of the roof-mounted has dominated the costs share as other modifications are removing the rails, and additional cabling within the vehicle. For Fig. 8 (b), same process is duplicated but only by removing the inverted pantograph on the infrastructure and installing a contact dome. However, by moving from concept B to A as shown on Fig. 8 (c)-(d) communications costs are more highlighted as wireless communications is used in inverted pantographs and it requires specific hardware e.g. routers.

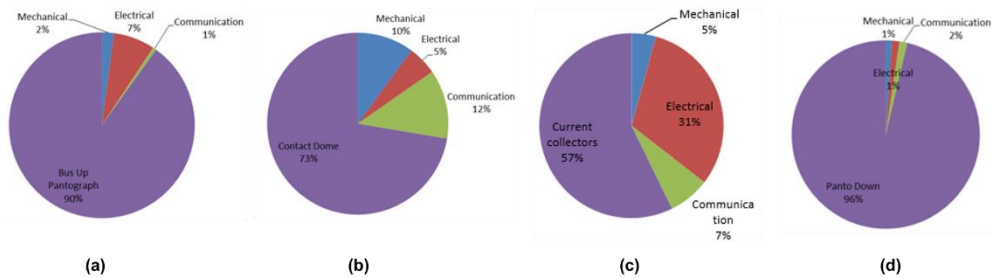


Fig. 8. Reconfiguration cost breakdown for concept A to B on (a) vehicle side (b) infrastructure side and for concept B to A on (c) vehicle side (d) infrastructure side

Conclusion

This feasibility study demonstrates that pantographs are not permanent extensions to a vehicle and infrastructure. Depending on the urge to modify an automated connection device concept, a trade-off between costs of reconfiguration and staying on the current concept must be made with reference to costs analysis study within this research. Reconfiguration process is customer specific and is dependent on operational requirements. Therefore, this part of ASSURED project has provided key points to be considered to perform the reassembly task and has concluded that reconfiguration from one concept to another is feasible.

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