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Prospects for Implementing of the 25 kV 50 Hz Voltage System in Poland

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Summary
In this article, the possibility of introducing a 25 kV 50 Hz voltage system into PLK's network is discussed. It compares two voltage types – 3 kV DC and 25 kV 50 Hz – by describing on the experiences of neighboring countries like the Czech Republic, Slovakia, and Ukraine, which use AC and DC in their railway networks. In Poland, potential implementation the 25 kV 50 Hz system includes the CMK, LHS, and the planned Y line. Both the Czech Republic and Slovakia had plans for the gradual re-electrification of selected lines, transitioning from 3 kV DC into 25 kV 50 Hz. However, due to the significant costs involved, this process was staggered. The advantages of the 25 kV 50 Hz system over the 3 kV DC system, such as lower construction and operating costs for the line, have prompted considerations for its implementation, particularly on heavily trafficked lines.

Keywords: supply voltage, 3 kV DC, 25 kV 50 Hz, Poland, PKP

1. Introduction

The debate over whether to introduce 25 kV 50 Hz on the Polish State Railways network emerged in the 1950s. [1]. It is now necessary to discuss and adapt the modernization plan to contemporary times [2]. In 1961, a comparison was made regarding the electrification costs of two lines: Cracow – Przemyśl – Medyka (LK 91) and Poznań – Szczecin (LK 351) with both power supply systems. Ultimately, due to economic reasons, the 25 kV 50 Hz system was abandoned. Both lines were electrified with 3 kV DC in 1964 and 1978, respectively. However, concerns not only revolved around higher costs with the 25 kV 5 Hz system but also the potential problems for rolling stock manufacturers, who might have struggled to building vehicles suitable for operation under two different power supply systems. The construction of dual-system vehicles before the silicon revolution of the 1970s was significantly more technically complex. During that time, producing rolling stock for 25 kV 50 Hz was considerably more expensive than for 3 kV DC, but nowadays, for the electrification of railway lines, it is more cost-effective for 25 kV 50 Hz. Nowadays, with modular vehicle construction, the cost difference between building AC and DC rolling stock is less. Nevertheless, the production of multi-voltage vehicles (family of *Traxx*, *Vectron*, *Prima* locomotives) has now become commonplace. With the liberalization of transport in EU countries, the production of single-voltage vehicles is limited to low number of vehicles and is practiced only one or two countries. These include, for example, selected *Traxx* series or the *Smartron* type (single-voltage version of the *Vectron*), *Griffin* and *Dragon* (Newag), and *Gama* (Pesa).

2. Rationale for introducing 25 kV 50 Hz in Poland

Currently, with the prospect of constructing high-speed lines in Poland, the need has emerged (stemming from the EU directive regarding TSI for lines with speeds $V > 250$ km/h) to implement 25 kV 50 Hz voltage on the PLK network [3, 4]. It appears that the entire process will proceed in several projected directions:

1. Transitioning the voltage across the entire PLK network (from 3 kV to 25 kV) does not seem expedient. Apart from the substantial conversion costs involved, there is also a shortage of rolling stock in Poland adapted for operation at 25 kV 50 Hz.
2. Conclusions from EU countries (i.e., Belgium and Italy), which, like Poland, use a voltage of 3 kV DC, serve as an example that high-speed lines (completely new constructed lines) have been electrified

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with a voltage of 25 kV 50 Hz, while the 3 kV DC voltage is still in use on the majority of their railway networks. Currently, there are no plans to convert them to 25 kV 50 Hz. A similar situation occurs on the railway network in the Netherlands, where a voltage of 1.5 kV DC is used on the NS network, and for instance, the HSL-Zuid[2] [1] is electrified with a voltage of 25 kV 50 Hz. A similar scenario exists on the railway network in France (SNCF Réseau), where 1.5 kV DC and 25 kV 50 Hz are used respectively in the southern and northern parts of the country (both voltages are used in the Paris hub), with all new high-speed lines (LN, LGV) have been electrified with a voltage of 25 kV 50 Hz.

3. In Poland, the concept for the Y line or potential modifications to access lines to CPK (ultimately for high-speed lines – the intended route is very similar) assumes a comparable approach to the countries mentioned above. The new line would be electrified using a voltage of 25 kV 50 Hz, while the access lines would remain on a voltage of 3 kV DC.
4. The change of voltage on CMK (LK 4) is currently not planned due to substantial investments made in recent years, primarily in power lines and traction substations (Fig. 1). This is not excluded in the future, but factors such as future passenger flows or the use of the line for fast freight traffic (e.g. container trains operating at night) may have an impact. However, predicting the situation on the line in, for example, 30 years is challenging – there are too many variables influencing the assessment of final demand and the volume of transportation.

Fig. 1. Włoszczowa Płn. station on the CMK (LK 4) after modernization (16.08.2018) [photo: M. Graff]

5. The 25 kV 50 Hz voltage is used in all of Poland's[3] neighbors, except Germany. The mentioned voltage is already in use at the border stations of Polish State Railways with BC or UZ (1520 mm) (Brest and Izov stations, respectively) and will be implemented by LG Infra for the Rail Baltica line, which is currently under construction (1435 mm)[4], (Fig. 2, 3, 4).

Fig. 2. Przemyśl Gł. station is the border station with UZ network: on the left is the 3 kV DC electrified line LK 91 (1435 mm), on the right – the line LK 92 (1520 mm) (16.09.2016) [photo: M. Graff]

Fig. 3. Kuźnica Białostocka station (LK 6) is the border station with the BC network (16.04.2016) [photo: M. Graff]

[2] Amsterdam – Hague – Rotterdam – Breda (– state border with Belgium – Antwerp – Brussels) high-speed line (przypis dolny / footnote).
[3] The RZD use 3 kV DC and 25 kV 50 Hz; in the Kaliningrad Region bordering Poland, 3 kV DC is used. In the case of BC, the sections electrified at 3 kV DC are the short lines from Poland – Terespol – Brest and Kuźnica Białostocka – Grodno (1435 mm).
[4] On the German side at the PL-D border, there are also two sections between the 3 kV DC (PLK) and 15 kV 16.7 Hz (DB Netz) supply systems – in the middle of the Frankfurt (Oder) Oderbrücke station and 1.576 km from the state border on the line Węgliniec – Horka – Roßlau (Elbe) (PLK 295 + DB 6207). A third similar section will be built as the part of the electrification of the Szczecin Gumieńce – Angermünde line currently underway (PLK 409 + DB 6328).

Fig. 4. Brest Central station is located at the Polish-Belarusian border and the so-called Warsaw part of the station is present: two tracks from the left with a rail gauge of 1435 mm and electrified with 3 kV DC, and two next (from the right) – wide gauge tracks (1520 mm) electrified with 25 kV 50 Hz (25.02.2018) [photo: M. Graff]

6. Infrastructure managers in the Czech Republic or Slovakia, namely SŽ and ŽSR, and in Ukraine – UZ, which employ both types of voltage within their railway networks, have deemed the 25 kV 50 Hz voltage more economical than 3 kV DC. Meanwhile, new sections predominantly electrify using the 25 kV 50 Hz voltage (3 kV DC is used only in specific cases, such as completing the electrification of a particular line). It demonstrates the superiority of the 25 kV 50 Hz system over 3 kV DC in practice.
7. The potential implementation of the 25 kV 50 Hz voltage system in Poland may occur on the LHS (Broad Gauge Metallurgy Line) [5], or on the section Hrubieszów LHS – State Border (– Izov – Kovel): UZ has electrified the Kovel – Volodymyr-Volynskyi – Izov line with a voltage of 25 kV 50 Hz [6, 7] (approximately 80 km, completed the process in June 2022 [8] – despite wartime conditions in the country!). Although UZ urged Polish State Railways to undertake electrification of the border section, the plea remained unanswered.
8. The planned electrification of the LHS (LK 65; 396.4 km) will not be implemented shortly – the line is not included in the TEN-T network, which makes it significantly more difficult to obtain EU funding for potential electrification. It is estimated that, at an expenditure of a minimum of 4.7 million PLN per 1 km (a comparable cost to that of the PKM [9]), the expenditure would be about 2 billion PLN, so without state aid or EU support, electrification seems unfeasible. Admittedly, for a voltage of 25 kV 50 Hz, its cost would be lower (smaller diameter of contact wires, a smaller number of supply substations – every 50 km instead of 10–12 km), but circa 1 billion PLN is the absolute minimum. The estimated electrification of the border section (Izov –) State Border – Hrubieszów LHS, i.e., about 5–8 km, would cost 24-35 million PLN. It should be added that the importance of the LHS line, especially in freight traffic, has been recognized in recent years (e.g., the transport of containers from China to EU) and in February 2022 after Russia's aggression against Ukraine in particular (e.g., the transport of Ukrainian export cereal). The 25 kV 50 Hz voltage is even ideal for freight traffic, as the ease of obtaining high power at the pantograph makes it unproblematic to run heavy trains. It is defined by formula (1):

$$P = I \cdot U \tag{1}$$

where: P – power, I – current, U – voltage.

Approximately eight times more current is required to deliver a comparable power output at 3 kV compared to 25 kV. It necessitates overhead line conductors with a larger cross-section to diminish resistance or heat loss. Similarly, the pantograph must feature arms with a larger cross-section according to (2):

$$W = P \cdot t = U \cdot I \cdot t = I^2 \cdot R \cdot t = \Delta Q \tag{2}$$

where: W – work, t – time, Q – heat, R – resistance.

Additionally, the presence of electrified sections at 25 kV 50 Hz, (admittedly on the 1520 mm rail network) would be a chance for excellent testing for Polish operators or infrastructure managers to gain experience with 25 kV 50 Hz.

The conversion of electrified lines with 3 kV DC to 25 kV 50 Hz in the Czech Republic and Slovakia and the electrification of new lines with 25 kV 50 Hz in Ukraine are characterized below. Two types of voltage are used in the Czech Republic and Slovakia: 3 kV DC and 25 kV 50 Hz for the electrification of the railway network. The former has been in use since the inter-war period and the latter since the 1950s. The Czech Republic is also home to a manufacturer, Škoda, which produces rolling stock not only for the domestic market but also for export. Škoda plants have supplied more than 5,000 locomotives, multiple units, and others, and in some countries, besides the Czech Republic and Slovakia, locomotives made in Plzeň have been a mainstay of passenger traffic up to the present (UZ, BC, RZD, BDZ, etc.). In recent years, railway infrastructure managers in both countries have begun to seriously consider changing from 3 kV DC to 25 kV 50 Hz to achieve more favorable operating results and reduce costs (Fig. 5, 6, and 7).

Fig. 5. Międzylesie station (LK 276) is the border station with SŽ / ČD network (8.03.2017) [photo: M. Graff]


Fig. 6. Dual-voltage Bratislava Petržalka station (25 kV 50 Hz, 15 kV 16.7 Hz) (22.06.2019) [photo: M. Graff]

Fig. 7. Český Těšín station on the Košice – Ostrava line (3 kV DC), Czech Republic (27.08.2017) [photo: M. Graff]

The Czech Republic

At the meeting on December 20, 2016, The Central Commission of the Ministry of Transport approved the study entitled „Concept for the Transition to a Unified Electricity System about the priorities of the 2014-2020 programming period and meeting the requirements of the ENE TSI" [10]. A long-term goal was also adopted to unify the traction power supply systems of the railway network in the Czech Republic, which is currently supplied by 2 voltage systems – 3 kV DC in the northern part of the country and 25 kV 50 Hz in the southern part. A study carried out jointly by SUDOP Praha and SUDOP Brno confirmed that the DC system is already inadequate for current operational needs and that strengthening it would bring only limited benefits with disproportionately high investment. Thus, the solution is a gradual transition to a more favorable AC system. In addition, the conversion from the 3 kV DC system to the 25 kV 50 Hz system will enable the following objectives to be achieved:

- Increasing the efficiency of rail transport through a more efficient power supply.
- Improving energy efficiency by reducing energy losses (lower transmitted current).
- Decreasing the expense of electrifying new lines, including a smaller contact wire cross-section, potentially utilizing a single contact wire instead of two, thus reducing the weight of the overhead contact line.
- Although it is more costly to construct vehicles for 25 kV 50 Hz than for 3 kV DC, the transformer enables a more optimal selection of voltage and current from the taps of the transformer's secondary winding for powering the traction motors on the vehicle. Consequently, it generates more favorable technical and operational characteristics for locomotives or EMUs (electric multiple units); moreover, the transformer more effectively mitigates fluctuations in the voltage supplied to the traction converters or, previously, directly to the traction motors of the vehicle compared to filters and choppers in vehicles operating on a 3 kV DC voltage.
- Recuperative braking for 25 kV is possible over a much wider range of voltage values than for 3 kV DC, due to the requirement not to exceed 3.9 kV DC for a 3 kV DC electrified network, which results from the adopted voltage limits for traction units in service (2.0–3.9 kV DC).
- Eliminating the need for current processing in substations, supplied at 110 kV (for 25 kV 50 Hz) instead of 22 kV (for 3 kV DC).
- Compatibility of the power supply of future high-speed lines with the conventional rail network.
- Improving train traffic by making more optimal use of the technical parameters of modern traction vehicles.

The estimated investment and renewal costs of the power supply equipment in the conversion of the DC system to alternating current are projected at CZK 79.3 billion (€3.35 billion) over 30 years. Conversely, maintaining the DC system (and thus the two different power supply systems) would necessitate an outlay of CZK 70.8 billion (€2.99 billion) required for the necessary strengthening of the system to meet current and future operational requirements and the regular replacement of equipment at the end of its life. A cost-benefit analysis was utilized to verify the socio-economic benefits of the transition option. The primary economic benefit of the AC system is the reduction in operating costs (diminished energy losses and increased use of energy recovery during braking) along with the elimination of damage from stray currents and the cost of rectifying them. The internal rate of return was calculated at 6.88%, surpassing the required limit for investment projects in the current programming period (5.00%). Additional economic benefits may be anticipated in the future; however, these have not been incorporated into the profit and loss analysis due to methodological accuracy. According to the authors of the report, electrification on an AC system is 30–50% cheaper compared to a DC system. In the future, the new high-speed lines will be able to be integrated into the existing conventional railway network more simply. The results of the study will be an important document for the preparation of assumptions for the modernization of the railway network in the Czech Republic to secure co-financing from EU funds in the next Community budgets, aiming to minimize the necessary costs of the future transition to the AC system. Simultaneously, regulatory changes are suggested regarding the materials and technologies currently used and the development and operation of modern traction units. The proposed roadmap for the transition to the 25 kV 50 Hz system in 2019-2037 has been accepted as recommended. Following the planned modernization measures for the railway infrastructure, the associated structures will then be implemented. The conversion of the DC to the AC system itself should also consider the operational capabilities of the operators.

At the beginning of January 2020, the Czech Republic's railway infrastructure manager (SŽ) announced a tender for the preparation of a feasibility study to determine the timing and method for converting from direct current (DC) to alternating current (AC) in selected lines to give railway managers a more precise date for the start of the conversion in the Nymburk, Hradec Králové and Pardubice regions. The study should include a detailed and comprehensive schedule for the transition, considering the procedure of conversion and the scope of sections to be divided at each stage [11]. It should also address the requirements of operators in terms of rolling stock modernization and renewal processes. The study will cover heavily trafficked lines such as the Kolín – Chocna line (part of the Prague – Ostrava mainline) and a section of the Prague – Děčín (– Dresden – Berlin) line, known as the right-bank line, currently electrified with 3 kV DC. According to SŽ, besides the completed in 2021 reconstruction between Nedakonice and Říkovice stations (current interconnection of the 25 kV 50 Hz and 3 kV DC systems) on the Ostrava – Břeclav (– Vienna) line, the date of the voltage switching between Střelna station at the Slovak border and Vsetín will occur in 2025, with other sections are currently under implementation. Specific investment projects will be developed based on the prepared study.

At the end of September 2020, the modernization of the Dětmarovice – Petrovice u Karviné (– Zebrzydowice) line in the Czech Republic commenced as part of a project co-financed under the CEF Blending scheme, comprising funds from the Connecting Europe Facility (CEF) financed by the EU (20%) and the European Investment Bank (EIB, 30%), plus state budget funds (50%) [12]. A consortium of Strabag Rail and OHL ŽS was selected as the contractor, and the scope of work includes the modernization of a 10.8 km double-track section and a single-track section from Závada to Koukolná, enabling bypassing of the Petrovice u Karviné station on the Zebrzydowice – Karviná line. Two-level crossings and the Dětmarovice, Závada, and Petrovice u Karviné stations will be modernized, and new railway infrastructure to allow increased travel speeds. The modernization will also include the overhead line system and power substations, which will be adapted for the future voltage transition from 3 kV DC to 25 kV 50 Hz.

In response to the infrastructure manager's plans, the operator – ČD decided that part of its rolling stock – primarily the newest – will be converted from a single-voltage (3 kV DC) to a dual-voltage system. Given the voltage conversion process is estimated to take about 20 years, it does not seem necessary for similar modifications to be applied to older vehicles due to their natural life cycle, estimated at 30–40 years.

Slovakia

At the beginning of August 2015, on the ŽSR network, the interconnection points of the 3/25 kV power supply systems were changed from their previous location at km 155.521 on the Púchov – Ladce (– Bratislava) section, creating two new systems [13]:

- the first at 158.6 km on the Púchov – Považská Bystrica section, from the Púchov station towards Žilina;
- the second at 0.894 km on the Púchov – Lúky pod Makytou section, which is a temporary solution, as with the progressive unification of the supply system of the ŽSR network in Slovakia, the interconnection points will be shifted towards Žilina and Lúky pod Makytou stations.

All power supply change works were carried out during the station modernization and, once completed, power was switched from the 22/3 kV substation to the existing 110/25 kV transformer station of the local traction power station (TNS). The current 22/3 kV substation will remain in operation until the power system is switched to 25 kV on the line via Lúky pod Makytou along the state border with the Czech Republic, which was planned in 2017. To date, the Púchov – Považská Bystrica section has been powered from a mobile 22/3 kV substation located at the head of the station in Žilina, but later it will be supplied from a new 110/25 kV transformer station. During the voltage switching operation, carried out over a weekend, diesel locomotives of the 754 and 742 series, sometimes in double traction, were used for long-distance trains, while local train service was suspended and bus services were provided. The maximum delays recorded did not exceed 20 minutes.

In parallel with the modernization of the Bratislava – Žilina – Košice line, which is Slovakia's main transport artery, a decision was made to adjust the course of the line in the Púchov – Milochov section. The original route, located along the meandering Váh River and Nosice Reservoir, prevented increasing speeds to 140–160 km/h due to curves with small radii and significant terrain slopes. Therefore, the length of the Púchov – Milochov section was reduced by 2.814 km (from 18.742 km to 15.928 km). Additionally, 6 new road and railway bridges, 4 two-level road and pedestrian crossings, 11 culverts were built, and 4 level crossings (single-level) were eliminated. The design was created by REMING CONSULT, Bratislava, and the works were carried out by the companies: Doprastav Bratislava (main contractor), TSS GRADE Bratislava, Subterra, Prague, and Elektrizace železnic Prague. The value of the works amounted to €365 million net, making it the largest and most demanding investment in the history of ŽSR [14]. The completion of the works was scheduled for December 2021, i.e., 64 months after the construction started in September 2016 (initially planned for January 2016), due to the necessity of relocating a high-voltage power line, which was not included in the technical documentation. Additional challenges included difficult geological conditions on the Stavná Hill and the need for complex works in the 1861 m-long Milochov tunnel (changes to the original tunnel lining were necessary). Other issues were archaeological sites, necessitating the temporary suspension of construction works, and an old, hidden rubbish dump that had to be removed. Ultimately, the Púchov – Považská Bystrica section will be equipped with the ETCS 1 system.

Ukraine

In Ukraine (despite the war following Russia's aggression in February 2022, where the railway operate under extreme conditions), electrification with the 25 kV 50 Hz voltage has been realized for two lines – Kovel – Izov at the border with Poland and Cherkasy – named after T. Shevchenko (planned to be completed in 2022, UZ data). UZ operates a railway network electrified with both types of voltage, 3 kV DC and 25 kV 50 Hz (Table 1), with about half of the railway lines is electrified, slightly favoring the 25 kV 50 Hz voltage (5500 km versus 4500 km), (Figure 8). Although most of the rolling stock currently operated by UZ was produced for the Soviet Railways (SZD) before 1991, Ukrainian manufacturers have supplied small numbers of vehicles (mostly, non-modern)

Table 1

Characteristics of electrified railway networks with 3 kV DC and 25 kV 50 Hz voltage in the Czech Republic, Slovakia, Poland, and Ukraine

Parameter	Czech Republic	Slovakia	Poland	Ukraine
(Dominant) rail gauge [mm]	1435	1435	1435	1520
Voltage system used on railway network	3 kV DC, 25 kV 50 Hz	3 kV DC, 25 kV 50 Hz	3 kV DC	3 kV DC, 25 kV 50 Hz
Availability of 3 kV DC / 25 kV 50 Hz rolling stock	high	high	high / low	high
Availability of multi-system rolling stock	high	high	low	low
Experience in operating lines at 3 kV DC / 25 kV 50 Hz	extensive	extensive	extensive / none	extensive
Experience in manufacturing 3 kV DC / 25 kV 50 Hz rolling stock	extensive	limited	extensive / limited	moderate
Voltage choice for electrification of new lines, considering experience in line operation and rolling stock manufacture	25 kV 50 Hz	25 kV 50 Hz	3 kV DC	25 kV 50 Hz

[Authors' own elaboration].

optionally for both types of voltage. UZ has experience in operating the 25 kV 50 Hz voltage, and the economic advantage of this power supply system was a deciding factor in choosing alternating current for the Kovel – Izov section[5]. The power of locomotives used by UZ is also significant: electric series VL80 (6400 kW), and diesel series 2TE116 (4500 kW), and 2M62 (2940 kW) [15]. Thus, it is possible to assemble heavier trains and achieve tangible savings in rolling stock operations.

Fig. 8. Lviv Main Station is a voltage switching station – individual sections have the option of being powered by either alternating or direct current: VL40-1457-1 (1520 mm, 25 kV 50 Hz) with a long-distance train to Kyiv (UZ carriages) and VL10-1478 (1520 mm, 3 kV DC) with a long-distance train as the one Chop – Kyiv – Moscow (RZD carriages) (28.04.2013) [photo: M. Graff].

For the Polish side, the potential choice of 25 kV 50 Hz, even for the LHS – UZ border section, including the Hrubieszów LHS station, would involve not only understanding the specificity of the new voltage but also acquiring AC[6] rolling stock that is only just beginning to be produced in Poland, such as the ET43-series *Dragon* two-voltage locomotives (Newag) for PKP Cargo, or the 654-series *Elf II* units for the Czech operator *RegioJet* (Pesa)[7]. Therefore, for UZ, the electrification of the Kovel – Izov section and the choice of type of voltage were simpler than for LHS and PKP. However, the decision to retain the 3 kV DC voltage for the future electrification of LHS would involve the necessity of creating a transitional section, possibly a voltage switching station, or electrifying the eastern part of the Hrubieszów LHS station with 25 kV 50 Hz, and the western part with 3 kV DC (analogous to the DB Netz Frankfurt (Oder) Oderbrücke station on the Berlin – Warsaw line). The second solution would likely be chosen, as it would not require acquiring dual-system rolling stock, and increasing the already high costs of electrification for LHS. For UZ, it would be feasible but troublesome due to the small number of similar locomotives (VL82 class). The possible sectoral electrification, as described for the Hrubieszów LHS station, could be implemented for the Izov station, or rather the adaptation of part of the aforementioned station to also be powered by 3 kV DC, in addition to 25 kV 50 Hz (see Fig. 9a, b).

a) b)

Fig. 9. Contact wires of the traction network and differences between the 3 kV and 25 kV systems: a) the LG Vilnius station (1520 mm, 25 kV 50 Hz, 20.03.2016), b) the RZD Svetlogorsk-2 station (German: Rauschen-Düne, Polish: Ruszowice), Kaliningrad Region (1520 mm, 3 kV DC, 02.05.2016) [photo: M. Graff]

[5] The line running to Kovel from the east is electrified at 25 kV 50 Hz.

[6] Locomotives for the LHS use a rail gauge of 1520 mm; although it does not seem to be a problem with the current modular building of rolling stock.

[7] Currently, Alstom is realizing a contract for the delivery of multi-system EMUs for NS and SNCB (the vehicles are being produced in the company's plant in Chorzów); however, it is used technology developed earlier outside of Poland.

The 25 kV 50 Hz voltage has a significantly broader range of tolerance compared to 3 kV DC (Table 2), which is possible because voltage fluctuations are dampened by the transformer to a much greater extent than filters and choppers for the 3 kV DC power supply system [16–18]. The criteria for assessing the interaction between the pantograph and the overhead contact wires in terms of ensuring interoperability are defined by standard EN 50367, and the coordination between the power supply system and rolling stock in terms of interoperability – by standard EN 50388 [19, 20].

Table 2

Voltage fluctuations for 25 kV 50 Hz and 3 kV DC power supply systems, according to BS EN 50163:2004

Power supply system	25 kV 50 Hz	3 kV DC
Nominal voltage [kV]	25	3.0
Minimum operational voltage [kV]	19	2.0
Minimum permissible voltage [kV]	17.5	2.0
Maximum operational voltage [kV]	27.5	3.6
Maximum permissible voltage [kV]	29	3.9
Range of permissible voltages [kV]	19–27.5	2.0–3.6

[Authors' own elaboration].

4. Prospects for Implementing 25 kV 50 Hz Voltage in Poland

Now, the implementation of 25 kV 50 Hz voltage in Poland seems feasible in the future, following the construction of the Y-line [21] or possibly on the CMK [22]. It is due to high traffic intensity and high speeds (> 200–250 km/h), which necessitates a high power demand from the supply substations (Table 3). Drawing from examples in the Czech Republic and Slovakia, the re-electrification of lines is justified but needs to be spread over time to avoid high costs (as in the case of the CMK).

For LHS, which is a freight line (it running away from larger or even medium urban centers), the prospect of introducing passenger traffic is unrealistic [23], and the current intensity of freight traffic is too low to justify electrification (Fig. 10). It also seems that the necessity of allocating > 1.0–1.5 billion PLN from the state budget. LHS is unlikely to obtain a similar amount from bank loans without state guarantees and it will lead to the abandonment of LHS electrification.

The process of rebuilding Ukraine, or the current transit of Ukrainian export cereal, will require efficient transport from the Polish side, including railway. Therefore, LHS – thanks to its transshipment

Table 3

Railway lines in Poland with the prospect of implementing 25 kV 50 Hz voltage

Line	CMK	LHS	Line Y
Line status	in operation	in operation	planned
Line type	high-speed with mixed traffic	classic	high-speed
Main purpose of the line	passenger traffic, to a lesser extent freight	freight traffic	passenger traffic
Line length [km]	223.8	394.6	~450
Operational speed [km/h]	200–250	80–100	300–350
Rail gauge [mm]	1435	1520	1435
Electrification	3 kV DC	none	25 kV 50 Hz
Operated rolling stock (dominant)	locomotives + couches / cars and EMUs	locomotives + cars	high-speed EMUs
Number of trains per day	30–40 (currently)	10 (currently)	30–40 (estimated)
Benefits of implementing the 25 kV 50 Hz voltage	lower operational costs	currently moderate	the use of 3 kV DC on high-speed lines is not permissible (due to EU regulations on railway interoperability [24–26])
Advisability of implementing 25 kV 50 Hz voltage	advisable in the future	significant in the future	justified by high traffic intensity

[Authors' own elaboration].

stations (1435 + 1520 mm) – could potentially relieve the main border and transshipment stations with Ukraine, such as Medyka, Żurawica, and Dorohusk. The electrification of lines – as exemplified by the LK 71 (Rzeszów – Ocice section) completed in 2021 and LK 68 (Stalowa Wola Rozwadów – Lublin Zemborzyce section) in 2020 – leads to increased capacity, higher speeds, and reduced operational costs. Thus, the electrification of LHS is realistic in the medium-term perspective.

Fig. 10. The Sławków station on the LHS / LK 65 (1520 mm), western turnout point (25.06.2016) [photo: by M. Graff]

5. Conclusions

The unification of power supply system towards re-electrification (3 kV DC → 25 kV 50 Hz) in the Czech Republic and Slovakia appears logical, especially it leads to lowering the maintenance costs of the railway network. Spreading the process over the years and linking it with the gradual modernization of individual lines means that the necessary expenditures may be reduced. In Poland, the 25 kV 50 Hz voltage will likely appear within 10–15 years with the construction of the Y line and the Rail Baltica line on the section between Poland and Lithuania. The prospect of changing the voltage across the entire or a significant part of the PLK network is considered rather unlikely because of substantial costs. The electrification of the LHS would be realized using 25 kV 50 Hz voltage, is not feasible now due to economic reasons.

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