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HOW TO CONVERGE ELECTRIFIED RAIL TRANSPORT IN THE EU TOWARDS A UNIFIED SOLUTION – SAFETY AND TECHNICAL COMPATIBILITY CHALLENGES

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Abstract
Railway transport is the only transport mode, which cannot ensure fluent transport over internal EU borders. In that respect the traction powering systems' differentiation is an important obstacle. Article points out associated challenges, possible solutions as well as risks especially those related to transitional periods together with proposed mitigation possibilities.

Introduction

Different power supply systems were introduced in Europe, due to several reasons. Firstly, because national railways were using national solutions provided by national or quasi national industry. Secondly, because when the railways were electrified it was not seen to be wise to facilitate passing borders by trains – namely by military trains. Thirdly, because when electrification started it was a must to keep the same system for all lines countrywide to preserve unity of the national networks.

Since then perception of the railway as a transport mode changed significantly. Due to globalization processes industry is no longer subdivided between different countries. Armies no longer consider using trains for quick moving of military vehicles on medium distances (circa 300-1000 km e.g. between different countries in Europe) mainly due to evolution of military vehicles and due to revolution in other transport modes, which are offering at present competitive transport services. It is however still imaginable to use railway for transport of military vehicles on long and extra-long distances (circa 2000 km and more), especially having peace inside and possible conflicts outside outer EU borders. Adding EU economic freedoms: namely free movement of persons, and free movement of goods it is necessary to point that countrywide technical compatibility has to be replaced by European-wide rail transport coherency, and that is a real challenge.

Main converging challenges

Fortunately in the past, but unfortunately looking from the present perspective, within European Union we do have four different traction power supply systems, which significantly differ one from another. The map showing distribution of the four different traction power supply systems in Europe is well known to experts and can be easily find in the internet. The four systems are 1.5 kV DC, 3 kV DC, 15 kV 16.7 Hz AC, 25 kV 50 Hz AC. The most up-to-date solution ensuring high reliability and reasonable cost, not only for conventional rail services but also for extra heavy trains and even for high speed trains, is 25 kV 50 Hz AC.

Differences in traction power supply systems constitute of course not the only obstacle on railway lines at the internal EU borders. It seems, that liquidation of some obstacles are even more difficult, e.g. different track gauges. However over seventy years ago gauge of the railway tracks from Warsaw to Berlin was changed from 1435 mm to 1520 mm by soviet army during the war and then after the war from 1520 mm to 1435 mm. The line was on wooden sleepers and therefor it was possible. Now on many lines we have concrete sleepers, which are more sustainable, but we do have gauge changing wheel sets and stands enabling passing from one track gauge to another without stopping. We also have step by step changing form 1668 mm track gauge to 1435 mm track gauge tracks in Spain, thanks to extensive construction of new 1435 mm gauge lines which keep coherency with the rest of the network thanks to automatic gauge changing systems. 1435 mm tracks are generally dedicated for passenger transport while 1668 mm tracks are more and more dedicated to freight.

Another important obstacle is related to signaling. The signal aspects shown on the color lights signals differ from country to country. The operational rules, which are applicable, differ not only in normal situations but also significantly in downgraded cases. Also that problem can be pointed as already solved by the European cab signaling system based on track-train digital transmission of movement authorities and predefined values of national variables reflecting operational rules applicable in degraded situations. Implementation is ongoing not only in so-called EU15 countries but also in the others especially thanks to European co-financing of such projects. The same applies to unification of mobile communication, which takes place all over Europe thanks to implementing European system which is also pending. Coming back to power supply. The four traction power supply systems differ not only in voltage and frequencies, but also in a number of other important parameters. The most known is the difference in pantographs' geometries and zigzag of the traction system overhead contact lines. The typical, pantograph head length in Europe is 1600 mm. However in some countries traction system is constructed for longer pantographs, usually 1950 mm. The 1600 mm head is too short to ensure protection against encroachment of the pantograph head above the contact plane or even break off of the overhead contact line, when lateral deviation due to zigzag is prepared for 1950 mm heads. To ensure safe current collection in relation to heads' lengths and zigzag one have to take into account geometry of the tracks, dynamic behaviour of the car body and of the pantograph, and even expected maximum wind strength. It could be a solution to use only longer pantographs, but that will affect pantograph gauge causing potentially collision e.g. with road viaduct over the railway line. The difficulty with pantograph length and zigzag is unfortunately only part of the challenge related to current collection via pantographs. We need technical compatibility between pantograph working heights and overhead contact lines heights including tolerances, gradients and overhead line uplift by passing pantograph. We need also to ensure minimum coherency between materials used for pantograph heads' contact strips and overhead contact lines both electrically and mechanically e.g. regarding strip widths, arching, and contact forces. The interface between traction power supply system, and traction rolling stock (between pantograph head and the overhead contact line) is a key one, but co-working of the traction power supply system and traction vehicle power consumption has to take into account on the side of trackside: substations with transformers and rectifiers, connecting cables, supporting structures, overhead contact lines, etc. and on the side of on-board: dis-connectors, inverters, engines, gears, etc.

Simple solution

It was already stated, that the most up-to-date solution ensuring high reliability and reasonable cost, not only for conventional rail services but also for extra heavy trains and even for high speed trains, is 25 kV 50 Hz AC. Therefore the simplest solution would be to replace the other three with 25 kV 50 Hz AC to have the only one. This is not possible over one night but may be step by step. Let's assume following steps:

1. equipping chosen 3 kV DC traction units used for long distance passenger trains with 25 kV 50 Hz AC, and purchasing double system traction units;
2. building 25 kV 50 Hz AC substations on railway lines dedicated to long distance services (longer distances between substations, different requirements for external powering, different transformers, different electro-energetic equipment);
3. deep reconstruction of the catenary (changing part of supporting structures to achieve zigzag appropriate for pantograph heads 1600 mm, changing contact lines and insulators which differ significantly due to different currents, due to different equipment preventing electrical shock, overvoltage, electrocution, short-circuit etc.;
4. switching off the 3 kV DC substations on lines already equipped with 25 kV 50 Hz AC;
5. starting service under 25 kV 50 Hz AC on long distance lines using traction units equipped for two traction power supply systems (single system traction vehicles will not be capable to leave or to enters 25 kV 50 Hz AC lines);
6. introducing operation of new multisystem traction units;
7. equipping additional 3 kV DC traction units with 25 kV 50 Hz AC and purchasing new double or multi-system locomotives and train-sets;
8. repeating steps 1-7 for other passenger lines and mixed traffic lines and respective traction units;
9. repeating steps 1-7 for freight lines and traction units.

Threats and weaknesses of the simple solution

Quick quasi SWOT (strengths, weaknesses, opportunities and threats) analyses show, that the final situation is perfect, however within transitional period a number of significant risks will occur. Within a pool of existing traction units some cannot be equipped with 25 kV 50 Hz AC at all, some can be equipped only if 3 kV DC is dismantled, some can be equipped without automatic switch between different traction power supply systems and only very few can be fully equipped with two systems together with switching equipment. Many experts say that multisystem traction units can only be specially constructed from the very beginning. The use of 3 kV DC traction units will be significantly limited – more and more. The same will be applicable in transition period to 25 kV 50 Hz AC only traction units – however less and less. As a result turn-rounds of traction units and therefore turn-rounds of trains will be permanently changing. To keep the route knowledge, which is required from train drivers, permanent training will be necessary. Otherwise route knowledge cannot be guaranteed and speed limitations will have to be imposed on many individual trains.

The transition period on twenty thousand line kilometers managed by Polish railway infrastructure manager will last minimum ten years assuming unlimited financing. Such long transitional period means that the train drivers will be wearied and route knowledge competences will degrease. It has to be assumed that the risk that lack of route knowledge related accidents will take place will increase significantly.

Moreover we have to assume that 25 kV 50 Hz AC traction units will be incidentally entering, due to human mistakes (train drivers), the 3 kV DC lines or sections causing not only technical damages of the lineside equipment (e.g. signaling due to electromagnetic disturbances) but also temporary degraded train operation. Such degraded operations mean high risk due to use of permissive signals and phone announcement as a basis for rail transport management. As a result human mistakes (traffic controllers) will incidentally occur and cause accidents up to train derailments on switches, or even crashes. From the safety point of view long and intensive transition which will take place in case of migration in the scale of the whole network is not acceptable unless speed is significantly reduced. On the other side significant speed reduction is not acceptable because as a result railway will totally loose the market for competing transport modes. It is not only a challenge for railway but also for a whole transport system on the State or even European scale as increasing road transport especially in relation to shifting huge freight transport volumes to roads including dangerous goods will create unacceptable risk.

Also the 3 kV DC traction units entering, due to human mistakes (train drivers), the 25 kV 50 Hz AC lines or sections will cause not only technical damages to traction units but also temporary degraded train operation as main tracks will be blocked. Such trains from the point of view of the signalman are obstacles. Passengers moving from trains to other trains, shunting movements on main tracks, rerouting of trains, changing paths, in extreme cases passengers getting out on the tracks and walking along them, all that will cause degraded train operation. Again this means extensive use of permissive signals and phone announcement for rail transport management. As a result human mistakes (traffic controllers) will occur and cause accidents up to train derailments on switches, or even crashes. From the safety point of view once more we conclude that long and intensive transition which will take place in case of migration in the scale of the whole network is not acceptable.

Additionally the multisystem traction units will have lower reliability. More traction units will be needed for the same scale of transport services. At least in transition period, also the reliability of the signaling equipment will degrease due to disturbances caused by electromagnetic influences and due to influence on non-traction power supply lines.

As a result: safety and reliability decreases significantly, technical and human costs are increasing significantly, and as a result railway as a transport mode will lose its, already low, market share. Additionally overall transport safety will decrease.

Additional difficult barrier will be created due to lack of cross-acceptance. Each new type of vehicle can only run on tracks in commercial service if it is legally accepted. Without such acceptance vehicle can only be hauled for transport or run under special conditions e.g. for testing purpose. Such rules are applicable in each member state independently, whether it is already accepted in another member state or not. As a result traction vehicle, which has to be running in ten countries must be accepted legally by ten different national safety authorities. Each of them have national requirements complementing the European ones. Due to differences between railway infrastructure in different countries national requirements differ and sometimes they are even contradicting. It has to be expected that not only time and money will have to be spent, but also new technical solutions will be required for instance to fulfill e.g. different national requirements regarding electromagnetic disturbances (the maximum level of generated disturbances and the minimum resistance to disturbances both as a function of frequency).

Reasonable solution

During dedicated works [1, 4] within European Union experts, representing different member states, agreed that a workable solution is to keep the four power supply systems and to introduce multisystem traction vehicles as already existing solution which can remove obstacle by introducing relatively limited percent of multisystem traction vehicles comparing to the overall number of traction vehicles.

In passenger transport in case of big countries only singe percent of trains (e.g. 2%) are passing borders between countries, creating a challenge to pass from one traction power system to another, while countrywide coherency of the power supply systems is already ensured. In case of neighboring small countries usually the same power supply system is used due to historical and practical reasons.

In freight transport long distance heavy trains are passing borders much more frequently, however borders between systems are stable and drivers keep their route knowledge without problems. Freight trains are running with lower speeds, and therefor working hours of the drivers cover shorter routes. For extra-long distance trains this means changes of the drivers on the route, and minimizing challenges related to lack of the route knowledge.

This means in practice that changing of the power supply system from one to another will be negligible in comparison to the already described simple solution.

Opportunities and strengths of the reasonable solution

Quick quasi SWOT (strengths, weaknesses, opportunities and threats) analyses show, that the final situation is far from assumed perfect one. Firstly because it does not allow all traction vehicles to pass borders. Secondly, as such solution does not create big enough fully open common market [1, 2, 4] for the power supply system's related products. However such solution is good enough to minimize border obstacles. It gives a possibility to replace step by step practice of changing locomotives at the borders by introducing seamless rail transport based on multisystem train-sets for passenger traffic and multisystem locomotives for freight transport services. It is very important, that such multisystem vehicles already exist and are being used successfully. Comparing this idea one can say, that chosen reasonable solution is equal to stop at the beginning of the simple solution accepting transition time lasting forever.

The necessity to purchase double or multisystem traction units will stay, however will be related only to traction vehicles dedicated for passing borders between traction supply systems. It is assumed that it will affect maximum 5% of traction units for passenger trains (including train-sets) and maximum 20% of freight locomotives in a long time perspective. The growth of the amount of multisystem traction vehicles will be strictly related to needs and will not entail putting existing single power supply system traction vehicles, namely the 3kV DC ones in case of Poland, on junctions.

The key is to migrate from present to further solution only in relation to passing already existing power supply borders. This means step by step resignation from changing traction units at the borders from single traction unit of one type to single traction unit of another power supply type and introduction of the multisystem traction units passing borders without stopping [1].

Taking into account, that two and a half percent of vehicles are changed yearly to new ones (railway vehicles are assumed to be used forty years) there is no need even to consider rebuilding of existing 3kV DC traction units to double system ones. The challenges related to acceptance in different countries separately are also minimized as such vehicles will be constructed having in mind their future use in more than one country [2, 4]. National requirements complementing European ones are known thanks to European legal obligatory information which is put on one database driven by the European Railway Agency [1, 3]. All the requirements which are not notified to the European Commission and consequently not put into this database cannot be imposed by national safety authorities.

European certification of the multisystem traction vehicles

The national safety authorities as governmental legal bodies are not prepared for technical examinations of vehicles and have to rely on technically competent organizations [1, 2]. Such organizations have to understand not only technical requirements [4] but also procedures [3], which are used to verify whither all requirements are fulfilled. That requires on one side detailed technical requirements together with detailed procedural regulations, but on the other side too detail requirements do cause stop of the technical development, which is necessary for railway as a transport mode.

Such contradiction is a typical dilemma applicable to all common European markets for products. They are produced in one country and have to be accepted in all European countries. Pointed technical requirements [4] and specially the verification procedural regulations [2] used in different countries must lead to the same or almost equal products. That was a challenge for many products in the past, and now it is also for multisystem traction vehicles. This challenge have been solved by introducing so called essential requirements. The essential requirements [1] are defined generally and can be fulfilled using different technical solutions. For many products European legislation as essential requirements point: safety, reliability, health and influence on environment. Safety must be high but reasonable. Full – one hundred percent safety does not exist in reality, therefore it is key to achieve acceptable level of risk. Reliability also have to be high. Also in that case one hundred percent reliability does not exist. Low reliability means high cost of transport services. To demonstrate the consequences in case of high reliability vehicles twenty vehicles can be used to ensure all day transport service using eighteen of them. In case of low reliability of vehicles using eighteen vehicles for service will require twenty two vehicles which will make transport costs minimum ten percent higher. Vehicles must not affect health and environment even in degraded situations. For instance it is not allowed to use toxic materials. Such essential requirements are not enough for railways. As already mentioned opening railway market requires technical compatibility between rolling stock and infrastructure. The reasonable solution requires double- and/or multisystem on-board but only for limited number of traction vehicles and keeps multisystem trackside in the European scale but single system on parts of the European network, namely the national ones which are already equipped adequately.

The last but not least is the essential requirement to ensure accessibility of the railway passenger transport for people with reduced mobility. This is not applicable to traction units disregarding whether they are single- or multisystem ones from the traction power supply point of view.

Conclusions

Converging electrified rail transport towards European railway system capable to compete with other transport modes is a must. This is a challenge especially from the safety and technical compatibility point of view. Out of two possible solutions – the simple one and the reasonable one only the second is workable without unacceptable risks and very long transition periods lowering already very low railway competitiveness. Implementation of the second solution based on long time usage of multisystem traction units has already started and can be judged to be promising.

References

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