Analysing the business case for introducing a 3 kV traction power supply in Dutch railways

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Abstract

The Dutch railway system is equipped with a 1500 V DC system. In order to facilitate further growth, the 1500 V system has needed and will need significant investments in substations. In 2001 the railway sector analysed the system and decided to continue with the system until at least 2017 and to re-evaluate the system performance again a decade later. 25 kV AC was considered the best option but difficult to realised in a "brownfield situation" on existing tracks.

ProRail started a quick-scan study in 2011 and 2012 in which the actual existing options for power supply as described in European standards (TSI Energy) were put to the test. It led to new insights, which were not available back in 2001, and related to updated traffic development insights and a new possibility and importance of sustainable power consumption. A migration path to an alternative traction system was subsequently elaborated in 2013, the so-called 3 kV DC alternative, which was developed jointly with a societal business case. It was found that the current 1500 V DC system can still be improved in terms of efficiency but that a 3 kV alternative can achieve a step change in energy savings as well as travel time savings. The draft business case and migration plan will be the start for discussions with the operators and development of a joint business case and recommendation of the railway sector. The process has not been finished but key results from the analysis and lessons learned from this process will be discussed in this paper.
Keywords: railway traction, energy savings, travel time savings, sustainability.

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1 Introduction

Every day 1.2 million passengers and 100,000 tons of freight are transported on nearly 7,000 km of railway track in the Netherlands. ProRail is infrastructure manager, responsible for constructing, managing and operating the infrastructure. Infrastructure use is charged on a variable cost basis, which includes the energy consumed (including energy transport losses). Netherlands Railways (NS) is by far the largest operator, realising more than 80% of passenger train kilometres through the main network transport concession. A number of regional and freight train operating companies is active as well on the network including (mostly non-electrified) regional lines.

The Dutch railway system is equipped with a 1500V DC system, one of the few remaining areas in Europe with this system. ProRail is the distributor of electrified power to the trains through this catenary system. The railway undertakings are united in a purchasing consortium called 'Vivens' to acquire the energy from public producers. Figure 1 shows how the Dutch rail system is connected to the public grid. The power comes from 10 kV AC connections and is then transformed and directed to 1800 V DC. The rails works as the minus side of the system.

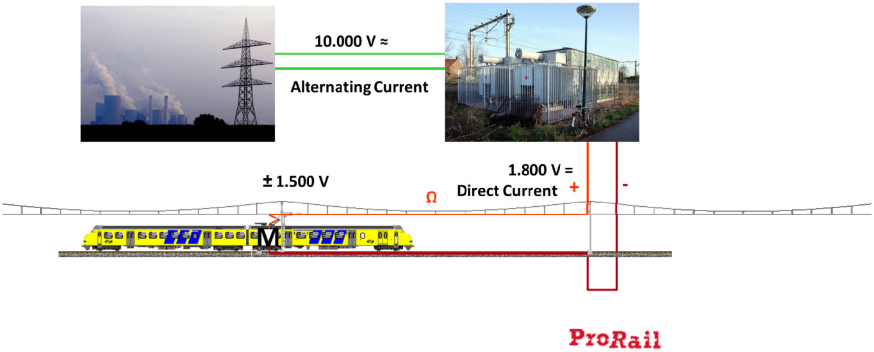

Figure 1: Scheme of energy distribution to trains for a 1500 V DC system.

Around 75% of the network, i.e. 2100 km of railway line (including double track) has been electrified. Some regional lines still remain unelectrified to this date. To facilitate the traffic on the core network, 243 substations with a capacity of 2.5 to 12 MVA and 130 track sectioning stations have been built. The average distance between substations is 6 km.

An important limitation, coming from the traction system design, is that trains can, at maximum, take a 4 kA current from the system. This means that with an average of 1500 V, the available power for acceleration to high speeds is limited to 6 MW per train. Also significant investments in new substations have been needed to keep pace with significant changes in the timetable in the last years and a further 210 million Euros has been estimated for investment in new substations to facilitate even higher traffic frequencies up to 2028.

The catenary system has been mechanically designed for speeds of 140 kph to 160 kph (depending on location) and, as an exception, for 200 kph on the newly built Hanzeline. Apart from this ‘conventional network’, two lines were built for dedicated traffic, and they have been realized with 25 kV AC systems. [1] The Betuweroute is a dedicated freight line to Germany. The High Speed Line Zuid is part of the European high-speed axis from Amsterdam to Brussels, Paris and London. These lines, as well as the non-electrified regional lines, have not been included in the analysis so far and will not be discussed in this paper.

Section 2 will briefly recall history of railway electrification in the Netherlands, where this is important to understand the current situation. Section 3 will introduce a ‘quick-scan analysis’ performed in 2012 which revealed 3 kV DC as a promising alternative. Section 4 will discuss key benefits for trains and the technical migration options developed by the Dutch rail sector. Based on this, a preliminary business case has been built for a system migration to 3 kV DC. Section 5 will draw conclusions.

2 History of investments in traction power supply

In 1908 the electrification of Dutch railway lines made its start, between Rotterdam and The Hague (not on the current main line, but the so-called Hofpleinlijn, currently part of the Randstadrail system). The railway company employed a 10 kV AC system using its own electrification plant. Costs per train kilometer dropped by a third, compared to steam. Soon other lines followed, using different systems. The history is well covered in Wikipedia [2].

An important milestone in history for this paper is 1922, when a government commission decided to electrify Dutch railway lines with a 1500 V DC system. Other systems such as 15 kV AC and 3 kV DC were already known at the time. A key argument mentioned in favour of 1500 V were the simple, light engines that could be used on trains. 15 kV required heavy engines with high wear rates. The fact that heavier, more expensive catenary was needed, was considered not a critical issue given the relative short distances in the Netherlands. In World War II, catenaries were torn down and railway lines had to be rebuilt due to war damage. It was decided to continue with 1500 V DC in order to be relatively quickly in service again, since the trains were relatively undamaged [2]. During the 1950s, many lines were electrified using 1500 V DC. Since then, the annual electric power consumption for rail transport increased to 1400 GWh (Figure 2).

The use of the 1500 V DC traction standard has been reconsidered a few times as far as known; the last major evaluation by joint parties in the railway sector was performed in 2001. An advice was developed for the Ministry of Transport which stated to maintain the 1500 V Dc system at least until the year 2017 where a next review should be organized in 2012. 25 kV AC was (and is)

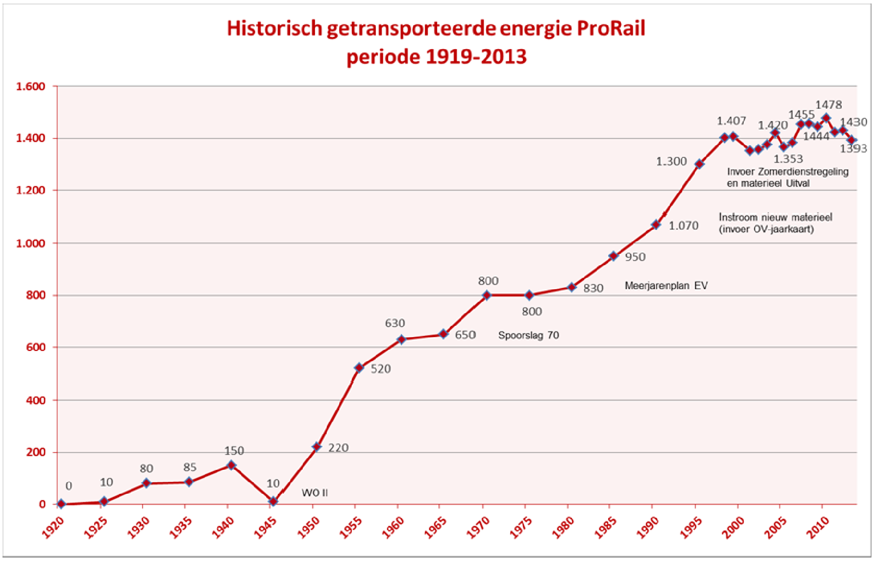

Figure 2: Traction power distribution over the years [2].

considered the state of art system, but problematic to introduce in the given, ‘brownfield’ situation. Transport demands e.g. required speeds and logistic model of the future were unclear; a net present value analysis demonstrated that 1500 V would be a sound choice for the time being. Some measures with minimal costs in case of upgrading and new built tracks and trains were agreed at the time between the infrastructure management and NS to prepare for 25 kV DC such as the use of more insulation in the catenary poles.

It is important to understand the performance in terms of efficiency of the current system. Figure 3 shows the current ‘energy balance’ and efficiency of the system [3]. It reveals that around 10% of the energy taken from the public grid is directly lost through losses in the system. Some of the energy is used for the assets in the railway infrastructure, such as signalling. Of the energy supplied to the train, a relative big part of energy is used for auxiliary systems in the train itself such as heating, cooling, and IT systems. Currently about 50% of the trains has the possibility for recuperation and under 1500 V system this can basically only be used for the auxiliary systems on the train, or eventually trains that are really on nearby tracks [4].

3 Analysis of system change options

In 2011 a quick-scan process at ProRail was initiated to analyse the current state and options for traction power supply on the currently electrified conventional network. During this quick scan all factors previously considered were assessed on their current outlook, e.g. which changes in transport use could weaken or strengthen the previously made decisions. Also a rough assessment of costs and benefits of four traction systems for the Netherlands was undertaken, using the new TSI Energy for Conventional Rail [5] as a starting point for acceptable alternatives and continuation of 1500V as the reference option. The result has been summarized in Table 1. The key finding of the quick-scan was that a 25 kV AC system would not become a reality despite minimal investments made in the rail infrastructure on some lines. A full migration would need an investment over 10 billion euros and there were no scenarios to limit the logistic challenges and operational hindrances during a long period of time. It led also to the insight that an alternative path, towards a 3 kV DC traction system, could become feasible.

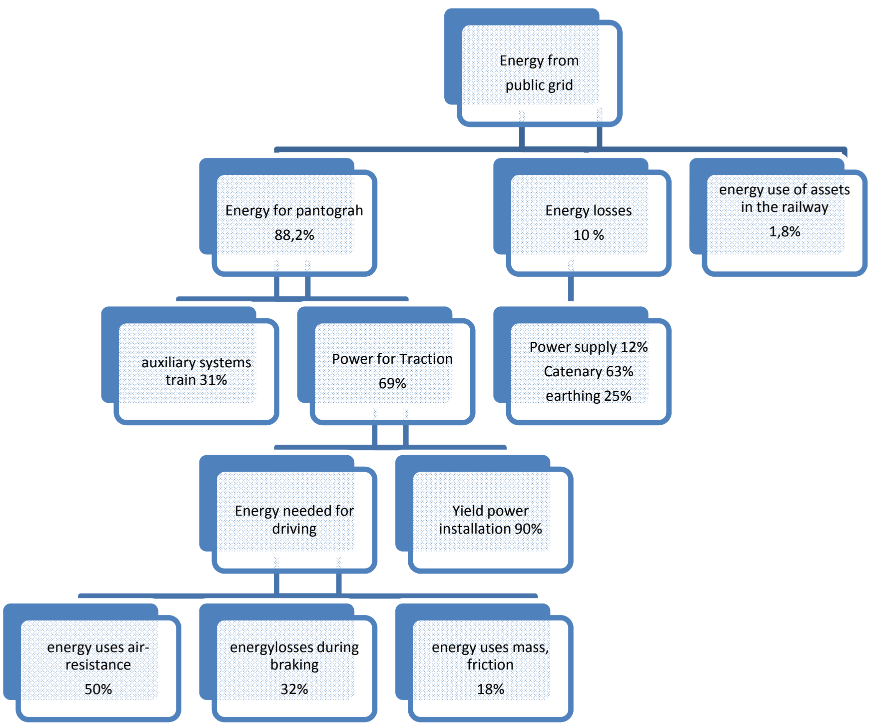

Figure 3: Balance of energy on the network.

Table 1: Key findings from quick-scan study.

Important assessment aspects.	**Upgraded 1500 V**	**3 kV**	**15 kV en 25 kV**
Energy efficiency and sustainability.	8–9% estimated energy system losses.	4–5% estimated energy system losses (at same level of energy demand). Additional 13.5% / 240 GWh less energy consumption due to regenerative breaking.	4% estimated energy system losses.
Investment costs including impact on other systems.	200 million euro for upgrading substations for PHS corridors.	620 million for national network including PHS and adaption of trains. Including 100 m euro before PHS and 130 m euro for additional transformers at substations.	> 3–12 billion euro, depending on what exactly is taking in account and very extensive nuisance of operation during the migration (new catenary). Replacement of actual train detection by axle counters.
Asset management.	100%. Keeping know-how of 1500 V system up to date in Netherlands will be an issue.	Same number of components. But less substations to maintain.	Less asset to maintain.
Robustness, fit for future demands.	Endured customization by adding new substations on demand.	Lots of room for further growth. Possibly margins for use in smart grids. More sustainable energy savings can be achieved.	Very robust, fit for heavy rail, advantages mentioned at 3 kV are more significant.
Speed and power.	Customization, so depending on installed capacity. Speed remains 140–160 km/h.	Powerful, faster acceleration possible. Speed is 140–160 km/h.	Very powerful and high speeds achievable (i.e. acceleration and line speed > 160 km/h).
Interoperability.	Not with neighbouring countries.	Interoperable with Belgium.	25 kV is “target” of TSI, but our neighbors do not use it and it is not compulsory.
Interface with train protection.	Actual systems are compatible.	Additional research needed, but probably compatible.	Actual train detection system has to be replaced by another compatible system.

4 Analysis of impact and migration options for 3 kV

A societal business case for 3 kV was considered possible, because energy saving and CO2 reduction are becoming serious issues as well as travel time savings are still as important as ever.

During 2013, ProRail started an analysis of the technical possibility and costs and benefits of a migration to 3 kV, firstly focused on the infrastructural aspects. In April 2013 also NS joined the analysis. The following steps (Figure 4) were designed and resulted in a draft business case by the end of 2013, still excluding freight operators and regional operators.

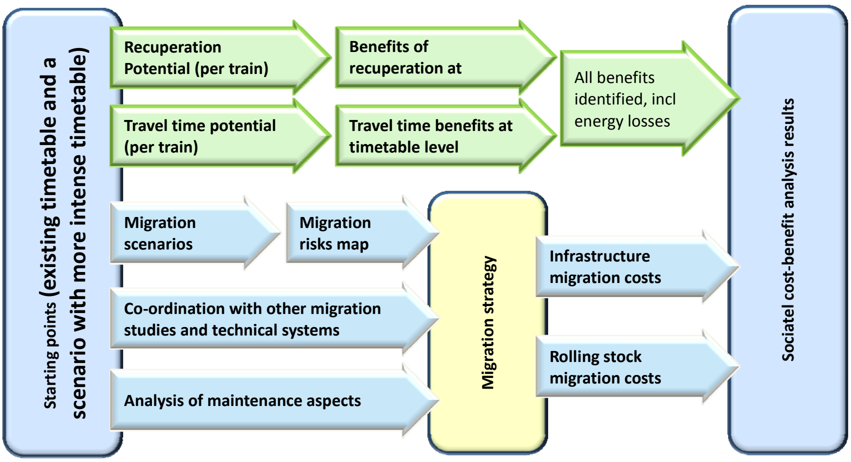

Figure 4: Process scheme of the analysis steps.

The analysis would be performed following the guidelines for a Social Cost Benefit Analysis (SCBA) according to the guidelines of the Ministry of Economic Affairs [6]. The costs and benefits were intended to be estimated with an accuracy of 20%. Apart from 3 kV, also a more energy efficient 1.5 kV system was chosen as a reference (so-called 1500 V Ecosave). The costs and benefits were determined in the context of two scenarios.

- Scenario *Current Timetable*, based on the continuation of the current transport concept;
- Scenario *Intensive Timetable*, in the context of the significant increase of the traffic [7].

The following results of the stepwise analysis were pursued:

- Migration risks and costs in the conversion of trains to the new system;
- Migration risks and costs of the conversion of the infrastructure system;
- Estimated the travel time profits and benefits, first for individual trains, subsequently for the timetable and passengers;
- Estimated energy savings and benefits, first for individual trains and subsequently within the given timetable.

A technical outline plan for 3 kV introduction was developed, by migration of the traction units and the rolling stock. A first step would be the conversion of substations (traction groups) and creating the multi-current rolling stock. This means the preparation of substations for 3 kV while having them be able to deliver 1500 V. Different technical variants have been analysed, but the costs have been based on a most secure option to renew the traction units completely. A next step would be the switching phase, where over a weekend (or in an even shorter period of time) a range of substations in one geographic area will be switched to 3 kV. 12 such areas are foreseen, based on the required amount of personnel and the limitation of voltage changes during the switching period. Key risks were investigated, but are not yet including the rolling stock side. For the conversion phase 7 to 10 years is considered necessary; the switching phase could be realised in one year.

In conjunction with NS project members, the effects to be appreciated in the SCBA have been decided (Figure 5). It was decided to elaborate a business case based on 'conservative assumptions'. Also the increased impacts of 3 kV in case of increased train speed scenarios (160 kph and more) have not been included. Impacts on attracting more ridership, through providing more competitive travel times for passengers, have not been included so far. With respect to travel time savings, it was decided to monitorise those only through the travel time values from the approved CBA method of the Dutch government [6] and not to included eventual savings in avoided infrastructure investments due to capacity effects. Savings were included in terms of savings on rolling stock and personnel use through accelerated lead times in the system. Also CO2 reduction has a value in the SCBA. Some other effects, such as increased robustness, were not included.

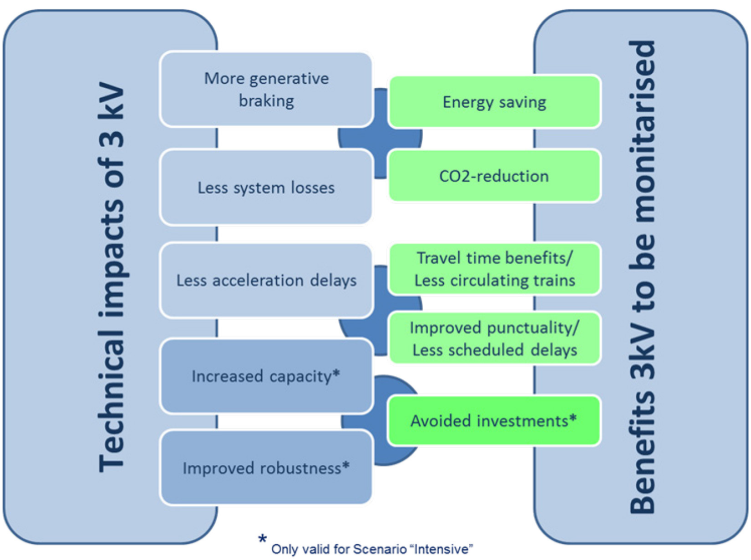

Figure 5: Scheme of benefits to be assessed in the SCBA.

4.1 Energy benefits

Simulation studies were performed after having the individual acceleration characteristics investigated [7, 8]. A simulation was not performed for the intensive traffic scenario, but consequences were extrapolated. For alternative 3 kV and 1.5 kV (with enhanced ecosave measures) energy balances were determined at the level of in feeding substations. Significant more efficiency can be realised through recuperation (from 6–10% of energy reuse to 18–25%) and through halving the transport losses (from about 10% to 5%). The result is illustrated in Figure 6. The conclusion is that conversion to 3 kV can result in more than 20% efficiency increase, compared with the present situation. Apart from out-of-pocket money savings, 150 k ton of CO2 can be saved per annum.

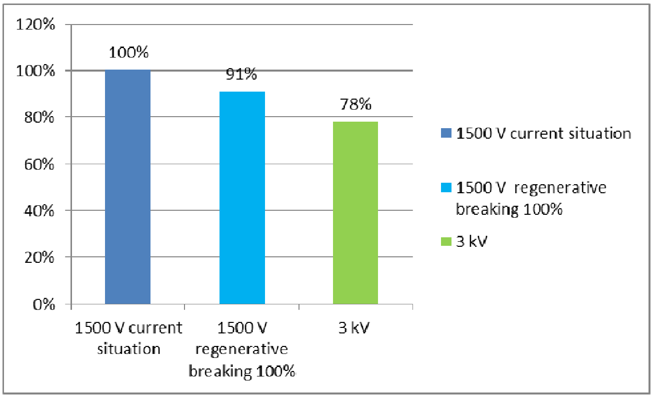

Figure 6: Indication of energy savings possible through system optimization of existing 1500 V system (blue bar) and through migration to 3 kV (green bar).

4.2 Driving benefits

In a parallel research step, all individual impacts of 3 kV to different train types were analysed and they would be the basis for estimating the usefulness of 3 kV in terms of extra time savings within the setting of the current timetable, using representative network nodes and lines.

Time savings per station stop of 7 s, 9 s and 13 s, for 130 kph, 140 kph, 160 kph respectively were considered possible under 3 kV. This is the minimum time savings for converted sprinter trains (so-called SLT trains). Using additional modifications or newly acquired trains, 70 to 100% extra time savings are possible under 3 kV. The total time savings in schedule were valued in the SCBA including the time saved on circulation of trains in the network. In the SCBA time values of 8 euros per passenger per year were used accordingly [6]. The acceleration benefits of the sprinter trains (SLT) also cause advantages in terms of benefits for intercity (long-distance) trains passing by. This means that their timetable can likely be accelerated by a minute on five corridors.

4.3 Indicative SCBA for timetable with NS trains on the core rail network

An indicative SCBA is available in January 2014. The costs associated with preliminary preferred variant (new traction groups) including costs for a pilot is estimated at roughly 400 million euros in the current timetable scenario and at least 100 million Euros more in the intensive traffic scenario. However, also in both scenarios 1500 V needs investments (more than 200 million euros in the case of the intensive scenario). Estimates for conversion of the trains were available but needed more validation. The figure below gives an indication of how the Net Present Value results look like.

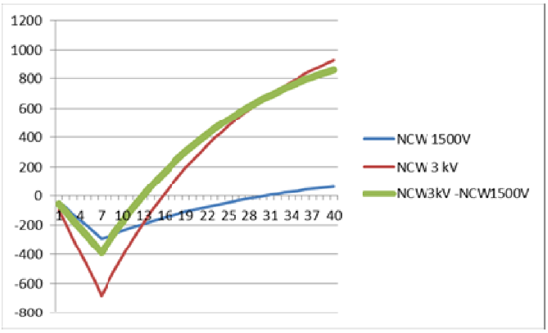

Figure 7: Indication of Net Present Value ("NCW" in the figure).

The figure shows that the payback period for the alternative 1.5 kV 'energy save' is considerably longer. This effect is even much stronger for the intensive scenario. The payback period of 3 kV compared to 1.5 kV 'energy save' is only 5 years after completion of the conversion in the intensive scenario. For the current timetable scenario, the payback is less than 10 years after completion of the conversion. Moreover, the benefits after 40 years are much lower for 1.5 kV.

5 Conclusions and next steps

It was found in the societal business case that 3 kV can achieve significant energy savings of around 20% as well as benefits through travel time reductions (7 seconds at least per station stop). The migration can be facilitated through preparatory works in substations and a stepwise approach in terms of migration logistics.

A risk-based approach proved to be a good method to identify costs and building a strategy for a migration in the infrastructure. Also it proved to be a necessary method to first identify the benefits for individual train types, and subsequently to analyse their impacts in the context of an entire timetable.

The business case potential has been a reason to involve the railway undertakings in an early phase of development. The process is, however, far from finished and there is still uncertainty in the business case, particularly on the rolling stock side of the analysis. Important next steps are planned for 2014:

- In an SCBA a consultation with all stakeholders should take place. Kin 2013, the stakeholders ProRail, NS and engineering firms were involved. Completing the business case is an issue for the entire Dutch railway sector, including freight and regional traffic.
- Optimising cash flows and available projects and programmes to realize cost-effective investments will be part of an eventual investment proposal.
- Development and final specification of the needed technology for migration to a 3 kV system is part of the next step. A real-scale testing case is considered necessary to prove feasibility of the working method and demonstrate expected benefits in practice.

Some lessons can already be learned from the process undertaken.

- Relevant factors for management/business case valuation: travel time savings, and energy savings becoming more important… a new setting with increased energy and sustainability awareness among stakeholders, can change the picture and create new opportunities for the system.
- Working in brownfield rather than Greenfield. Not only go for perfect solution (25 kV) but look at consequences and opportunity – second best solution may be more than good enough.
- Traction power has an important role in the development of the timetable and can help with solving timetable problems. Architectural/systems approach of solving problems in the timetable is relevant.

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