O.R.R. Consultation Document on Sustainable Development and Environmental Duties

- Response concerning efficient use of electrical traction power

The O.R.R. Consultation Document on Sustainable Development and Environmental Duties requests Responses on “on-train metering” (4.31), “regenerative braking” (4.32), and “other issues” (4.34).

The main theme of this area of consultation is to identify efficient use of electric traction power and devise financial incentives to achieve this.

The following contribution is based on the author’s experience. Though primarily a Signalling engineer the author has considerable experience of electric traction from his work on Electrification / Signalling compatibility and signalling equipment for use on electrified railways.

The conclusion is that the D.C. system has quite a few complications incumbent on achieving on-train metering and may not permit the full benefits of regeneration to be obtained at all times.

However, it is possible to reduce the significant “system losses” on the D.C. system by timetabling which intrinsically may have a very low cost.

Future train control technologies offer greater benefits in efficient use of electric traction energy.

<u>On-Train Metering</u>:

The idea of on-train metering has the benefits of exact allocation of energy usage, and permitting direct procurement of traction electricity by train operators. There is the added cost of metering and administration, and the question of whether this outweighs the benefits.

In technical terms it must be appreciated that the actual energy imported / exported must be metered. This will require measurement of:

- line voltage (variable with location and loading)
- current drawn / regenerated
- power factor on the A.C. system

Thus the metering equipment will have to process 2 or more parameters and deduce the actual energy used. Connections to line voltage have to be made with care because of the high voltage involved.

On the A.C. system power is taken / returned by one pantograph per traction unit – locomotive or multiple unit. This makes it very simple to meter at just one location.

On the D.C. system the situation is much more complicated because of the use of “+ve” bus-bars along units to prevent “gapping”.

In fact even a dormant D.C. train will carry electric traction to other trains along its “+ve” bus-bar because the collector shoes connect the bus-bar as a parallel path to the conductor rail along its length. Thus to discover what the train itself uses would require metering on each collector shoe. Alternatively the connections of powered equipment to the bus-bar could be metered – but again this may be 4 traction packages on a 4-car e.m.u. plus any auxiliaries.

Either of these alternatives would require several meters on the unit, and perhaps a dozen or more on a multi-unit 12-car train.
It might be expedient to reduce the number of meters to a sample one, and accept the resultant inaccuracy – but this would mitigate against the purpose of the system.
If direct procurement of electricity was undertaken, this would be likely to be time related. This would then require the meters to have a time-relating capability – which may not be difficult or expensive – but would need to be appreciated.

There would also be the operational problem of calibrating and availability of the meters. It would be expected that reading of the meters, and calibration could be carried out without too much difficulty – but it would have to be done. On the other hand the metering should be available before the train enters service. This raises the possibility of trains being kept out of service until the metering is proved to be correct and operative – a more serious situation, especially with multiple meters on a consist.

The conclusion is that there are several issues of availability, calibration and reading that would need to be addressed. They would not be expected to be insuperable as comparable metering of domestic electrical supplies is a mature technology with modern techniques, but would mitigate against its cost effectiveness. Implementation on the A.C. system would be considerably easier than on the D.C. system in terms of the number of meters required.

Regenerative Braking:

The technical aspects of implementing Regenerative Braking have been known for some time, as it is currently in use on both A.C. and D.C. electrified areas. The regenerating train is effectively a moving Sub-Station of somewhat higher voltage which cannot be switched off by the ECR. Some of the requirements for permitting regeneration are:

- ensuring adequate System Protection under fault conditions
- working procedures to ensure that a line is not regarded as isolated until all regenerating trains have stopped regeneration
- component insulation being able to withstand the higher line voltage produced by regeneration
- potential signalling interference from the regenerated current
- different current flows on the A.C. system causing different scenarios for induction into lineside cables

Once these questions have been addressed for a new rolling stock or route, then regenerative braking should be viable.
Of course the solving of these issues requires the co-operation of several parties, some of which will gain, and others of which will have to undertake expenditure. Although it appears certain that there is an overall gain to the railway system it may be difficult to apportion the gains / expenditures of individual parties accurately. However, it is believed that this is being addressed by another body at present.

Thus in technical terms there appears to be no insuperable technical impediments to further development of regenerative braking.

Undoubtedly regenerative braking will assist sustainable development as it will permit rail transport using less energy. It is to be hoped that the body which will gain in overall terms (the body subsidising the railway) will be able to devise a mechanism for funding the expenditure and gaining the rewards from further regenerative braking.

In practical terms there are significant differences between the use of regenerative braking on the A.C. and D.C. electrified systems.

On the A.C. electrified systems the rolling stock which can regenerate will do so not only to other trains, but also back into the electricity grid. Thus the system is always “receptive”, and a known level of gain will accrue.

On the D.C. system the regeneration cannot propagate into the electricity grid, and the line is only “receptive” when there are other train loads in the vicinity. Furthermore the relatively high resistance of the D.C. supply system requires the regenerating and receiving trains to be close, otherwise the voltage required to regenerate becomes too high and the braking has to become rheostatic. Unless the regenerating and receiving trains are close to conductor rail cross-connections at Sub-Stations or T.P.Huts it will be difficult to regenerate from one track to another, which will reduce the probability of regeneration occurring. This could be improved by putting in additional cross-connections, or higher insulation voltage equipment, but both of these would be very costly. All this mitigates against regeneration on the D.C. system being as effective as on the A.C. system – but there is little that can be done about it. At peak hours on multi-track areas the regeneration will be most effective, but in the off-peak on outlying routes it will not be so. However, by being at its most effective under peak demand it will achieve the most benefit in terms of reducing peak power requirements.

The conclusion is that although regeneration should be very efficient on the A.C. system, it will not be so efficient on the D.C. system but will be at its most efficient when it will achieve the most benefit.

Other Issue – System Losses:

The Consultation Document considers the calculation and apportionment of system losses (4.28(b)).

System losses can represent a serious inefficiency in the use of electric traction.

The document considers “excessive / inefficient losses for which Network Rail should carry the costs in order to encourage them to minimise these additional losses”.

The A.C. system does not suffer significantly from system losses because of the higher voltages and lower currents used. In general line regulation occurs because of reactive impedance rather than resistive impedance, with its associated losses.

The D.C. system is quite the reverse. The supply system losses were so severe that the Boat Train Route upgrade required all the T.P.Huts to be converted into Sub-Stations – in what many would regard demanding more power from the low voltage D.C. system than it could realistically be asked to provide.

However, deciding what are “excessive / inefficient” losses would be quite difficult.
At present the parameters controlling the losses of the D.C. supply system (conductivity of the conductor rail / cross-connection of the return rails / spacing of Sub-Stations / T.P.Huts) have been determined on the basis of maintaining the line voltage which the traffic requires. Altering any of these requires significant expenditure which hitherto has been regarded as sub-optimal. Thus it could be regarded as unfair to suddenly decide that the customary arrangements are lead to “excessive / inefficient” losses.
It is true that the situation of a Sub-Station going “off-line” would lead to increased system losses. But this happens already and is tolerated. Perhaps it might be correct to use the present level of Sub-Station being “off-line” as a tolerable baseline, and require no worsening, or agreed improvement of their reliability.
In fact there seems little scope to regard the existing supply arrangements as leading to “excessive / inefficient” losses when they have hitherto been regarded as optimal.

There is however scope for reducing system losses by traffic control.
The system losses are related to the current being drawn, and they increase with the square of the current.
The greatest current is taken during mid-range acceleration, and for perhaps 30 - 60 sec. When running/coasting, the current would be perhaps 30 % of the maximum. When stopped the current would be 10 – 15 % of the maximum even with heavy auxiliary load. Because the losses depend on the square of the current being drawn they are only significant during acceleration.
Assume that one train accelerating at a location creates one unit of system losses during its acceleration. If two trains accelerate at that location at the same time, the current would be doubled, and the system losses quadrupled. If however the two trains accelerated sequentially there would be just two units of system losses sustained. Thus the act of having the accelerations sequential rather than simultaneous causes the system losses to be halved.

System losses can be significant. A sample calculation would be as follows. With a 5 km spacing between Sub-Stations, the supply resistance between the intervening T.P. Hut and the Sub-Station along one track would be about 0.1 ohm. A current of 1000 A along this track would reduce the line voltage from its nominal 750 V to 650 V, down to 87 % of its nominal. This would result in 13 % system losses. A single train could take 4000 A at that location (2 tracks in both directions), and at 650 V would obtain 2.6 MW of power. If two trains accelerated at that location the line voltage would be reduced to 550 V, which would lead to 27 % system losses.

However, the power delivered to each train would now only be (4000 x 550) = 2.2 MW. So to accelerate to the same speed the train would take about 17 % longer. Thus the cumulative losses are about (14 x 1.17) = 16 % greater, and now represent about 30 % of the total power. Thus the simultaneous acceleration of the trains causes the system losses to be multiplied by about 2.5 times.

To achieve the same reduction in system losses as by having trains accelerate sequentially would require massive infrastructure upgrading – by halving the Sub-Station spacing, or halving the resistance of the conductor / running rail systems.

Of course the infrastructure owner can do nothing about this variation in system losses. From one moment to the next he is not able to control if multiple trains accelerate at the same time at the same place.

Thus the simplest way to achieve significant reduction of system losses is by timetabling – ensuring that multiple trains do not accelerate at the same time at locations remote from the Sub-Stations. This could reduce overall power usage by 15 % at the most adverse locations. Even taking into account that many locations are closer to the Sub-Stations and sustain lower system losses, and that train accelerations do not represent a significant proportion of train operating time, there could be overall energy savings of perhaps 5 %, which would be quite worthwhile.

Intrinsically this should cost very little, because we are talking of timetable variation of 60 sec. or less.

Of course there is the question of adhering to this timetabling with the customary service perturbations that occur.

One technical solution would be to require the train to test the line voltage to see if it was already low because of the load of an accelerating train in the vicinity. The train would only be allowed to start acceleration if the line voltage was high enough to constrain system losses. The snag with this is that Sub-Station voltage varies from 650 – 750 V across the D.C. system which would make setting the “start acceleration” level problematic.

The other method of reducing system losses, and power in general, is to reduce the acceleration rate and/or the maximum speed. Coupled with train regulation to avoid multiple accelerations it would have a double benefit. Also it would be beneficial to try and match accelerations with regenerative braking in the same area – delaying one train’s start until another train was braking.

What this leads to is the real-time control of train movement to minimise power usage and losses. Such a system could also be used to avoid route conflicts – another cause of wasted power. This would not be too difficult to achieve on a simple route, but for the Network Rail system it would require considerable communication and processing. This facility is quoted as a benefit of ERTMS, and would be worthwhile to consider for the next generation of train communication and control.

Conclusion:

On-train metering and regenerative braking are the simplest to achieve on the A.C. electrified system where they have the least complexities and best results.
On the D.C. system the metering is complicated and regenerative braking is less efficient, although at its best when it is most needed.
The D.C. system suffers significant “system losses” but the infrastructure is probably already at its optimum design. It is difficult to see what Network Rail can do apart from ensuring that all its Sub-Stations are “on-line” as much as reasonably possible by keeping them in good repair.

In fact the easiest and least costly improvement is achieved by timetabling to avoid multiple accelerations at locations remote from Sub-Stations. Such a benefit may only be a few per cent of overall energy use – but it does come with minimal expenditure.
Beyond this there are benefits to be obtained by train regulation to minimise overall power consumption by avoiding route conflicts and matching regenerative braking with acceleration. This is quite a complicated business but is one of the capabilities expected from ERTMS equipment. It would be worthwhile doing a business case to examine the savings accruing from such a system, and the cost of train control equipment required to achieve it.

Beyond this, other energy reduction measures would appear to have disadvantages:

- reduced acceleration / maximum speed would increase journey times (perhaps they should be used unless needing to recover time)
- switching off air conditioning / heating would reduce passenger comfort
- converting to LED lamps for illumination would be costly
- running fewer / shorter trains would lead to over-crowding

In terms of improving the efficiency of the overall railway system the way forward would be to specify a timetable that optimised journey time, comfort, reliability and energy usage. A sophisticated train control system such as ERTMS type equipment would achieve this, but would need a business case to be constructed to ascertain its viability.

Constructing a commercial framework which encourages Network Rail or train operating companies to implement on-train metering and further regenerative braking may be difficult as the schemes span more than one party.
It may be possible to offer train operating companies an additional financial incentive to eliminate timetabled multiple accelerations at adverse locations.

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