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Guidance Note

Impedances of 25 kV a.c. overhead lines for Classic system

Endorsement & Authorisation

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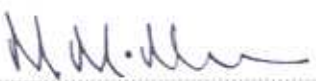
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1 Purpose

This Guidance Note contains information on the impedances of the 25 kV a.c. overhead lines and related items, for use by electrical design engineers who calculate line voltage drops or the settings of the feeder protection relays.

2 Scope

The numbers provided in this document are based on a simplified representation of the impedances, which is suitable for manual calculations, for calculations undertaken by means of spreadsheets, and for use in the computer program 'OSLO'. This representation is not suitable for the Autotransformer system.

All of the provided numbers apply at the fundamental frequency, 50 Hz.

It is assumed that the users of this document understand the basic theory of electric circuits, including Ohm's Law, Kirchoff's First and Second Laws, and the use of complex numbers to represent the voltages, currents and impedances in an a.c. circuit.

3 Reference documentation

NR/GN/ELP/27043	Code of Practice for Protection Settings and Methods of Calculation for 25 kV a.c. Electrified Lines
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4 Definitions

Not used

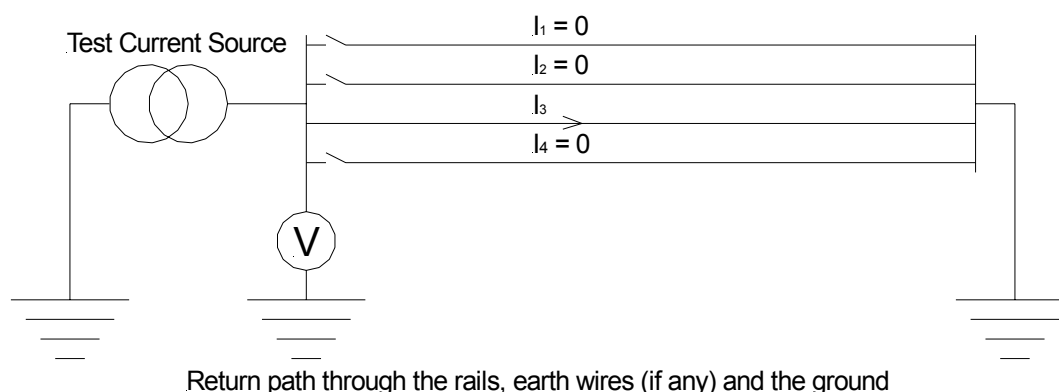
5 Explanation of the method for representing the impedances

The overhead lines have a self-inductance as well as a resistance. At 50 Hz the inductance gives a reactive voltage drop which is typically 2.5 to 3 times the resistive voltage drop, for the same current. Therefore the impedances are represented by complex numbers.

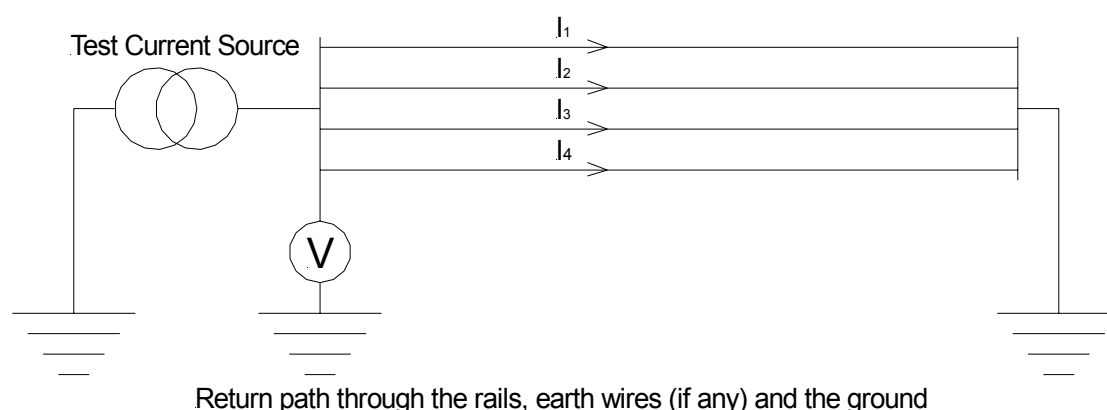
If there are two or more tracks running parallel to each other, the mutual inductances are significant. The voltage drop in one overhead line is the result of its own current acting on its own impedance, plus the effects of the currents in all the other overhead lines, acting through the mutual impedances.

These effects can be seen if the impedances of the overhead lines are measured using a source of test current. A test generally covers one section of each track, between a Feeder Station bus-bar and the next Track Sectioning Location along the route. The bus-bar at the TSL is earthed, and the sections are fed from the feeder station. The test current source can be the transformer of an electric locomotive, which draws its power from the overhead line at the opposite side of the neutral sections at the feeder station. Alternatively a low-voltage a.c. supply may be connected via an isolating transformer.

The impedance of each track can be measured separately, by opening the circuit breakers which feed the other tracks. For example, in the following 4-track scenario, the impedance of track 3 is V/I_3 ohms.



If the same system is then tested with all tracks in parallel, a single value of voltage is associated with the current in each track, as in the following sketch.



The effective impedances of each track are then:

For track No. 1	V/I_1
For track No. 2	V/I_2
For track No. 3	V/I_3
For track No. 4	V/I_4

It is found that the effective impedances of the tracks when connected in parallel are higher than the impedances when each track is tested separately.

Therefore this document provides, for each configuration considered, two sets of impedances, covering the separately-energised case (effectively, single-track stub-end feeding), and the all-tracks-in-parallel case.

In addition, for four-track layouts without booster transformers, the figures are given for only two tracks in parallel, as this scenario occurs routinely during maintenance of the infrastructure and can lead to over-reaching of the Zone 1 protection of the tracks which are in use. This is not a significant effect where booster transformers and return conductors are provided.

NOTE 1: The full description of the impedances would provide the separately-energised figures, and in addition all of the mutual impedances. For example, the 4-track case would be represented by a 4 x 4 matrix of impedances. This is explained in more detail in Appendix B.

NOTE 2: The results of measurements which have been made using the above-mentioned principles are given in Appendix A.

6 The effect of booster transformers and return conductors

The description in 5 is understandable most easily for sections which use only the rails, earth wires and the ground as the return path. However the method of representation applies also to sections with booster transformers and return conductors. If a section with booster transformers and return conductors is tested as described in 5, the per-km impedances are found to be significantly higher than the impedances of sections with the same kind of overhead line, without booster transformers. The reason is that the return conductors carry a current (almost) equal to the current in the overhead lines. Therefore there is a voltage drop in the return conductors, which is reflected through the booster transformers to add to the voltage of the overhead line section.

Therefore the impedances of the return conductors are effectively combined with the impedances of the overhead lines.

In addition the booster transformers themselves have a small impedance which adds to the total impedance of each section.

The spacings between the booster transformers are site-specific. Therefore the tabulations given in this document consist of the combined values, per single-track km, of each overhead line and its respective return conductor, excluding the booster transformers themselves. To find the total impedance of a section, the per-km impedance is multiplied by the length of the section in km; then the impedance of the booster transformers is added; i.e. the impedance per booster transformer multiplied by the number of booster transformers in the section.

7 Use of the Single-Track figures and the Parallel-Tracks figures

When doing calculations, the Single-Track figures or the Parallel-Tracks figures should be used as appropriate to the scenario being considered. Examples are given below.

Protection calculations

The parallel-tracks figures should be used for all sections which are fed from both ends. If the circuit breaker at the other end of the section happens to be open already in the scenario being considered, the fault current will be higher than calculated, which is on the safe side for the purpose of detecting a fault.

Voltage drops in operating conditions (e.g. using the computer program 'OSLO')

Use the Parallel-tracks or the single-track figures as appropriate to the feeding arrangement being considered. The single-track figures should be used for all sections fed from one end only, whether or not there are other sections running alongside.

8 Tabulated figures of impedance

8.1 Two-track layouts with booster transformers and return conductors

These figures exclude the impedance of the booster transformers themselves. All figures are ohm/km

Type of OLE	Single-track stub feeding; each track		Both tracks in parallel: effective impedance of each track		Parallel combination of both tracks	
	Re	Im	Re	Im	Re	Im
Mk 1 Simple	0.26	0.70	0.26	0.73	0.13	0.36
Mk 1 Compound	0.24	0.67	0.24	0.70	0.12	0.35
Mk 2, copper catenary	0.24	0.70	0.24	0.72	0.12	0.36
Mk 3, copper catenary	0.24	0.70	0.24	0.73	0.12	0.36
Mk 3A/B, AWAC catenary	0.27	0.70	0.27	0.72	0.14	0.36
Mk 3A/B, AWAC catenary, with double-rail jointless track circuits and overhead earth wires	0.28	0.68	0.28	0.71	0.14	0.35
UK1, West Coast Route Modernisation	0.24	0.70	0.24	0.72	0.12	0.36

The above figures are based on single-rail return, except where stated. The following variations do not affect significantly the impedances of a system with booster transformers and return conductors:

- Use of double-rail return in axle-counter areas
- Use of double-rail jointless track circuits with earth wires installed at ground level.

8.2 Two-track layouts without booster transformers

All figures are ohm/km.

Type of OLE and type of return circuit	Single-track stub feeding; each track		Both tracks in parallel: effective impedance of each track		Parallel combination of both tracks	
	Re	Im	Re	Im	Re	Im
Mk 1 Simple, rail-return only, single-rail return	0.17	0.42	0.23	0.58	0.11	0.29
Mk 1 Simple, RC without boosters, single-rail return	0.17	0.37	0.20	0.48	0.10	0.24
Mk 1 Compound, rail return only, single-rail return	0.17	0.40	0.21	0.55	0.11	0.28
Mk 1 Compound, RC without boosters, single-rail return	0.16	0.34	0.19	0.45	0.09	0.23
Mk 3A/B, AWAC catenary, rail-return only, single-rail return	0.20	0.45	0.24	0.60	0.12	0.30
Mk 3A/B, AWAC catenary, RC without boosters, single-rail return	0.19	0.39	0.22	0.49	0.11	0.25
UK1, West Coast Route Modernisation, rail return only, single-rail return	0.17	0.42	0.21	0.58	0.10	0.29
UK1, West Coast Route Modernisation, rail return only, double-rail return in axle-counter areas	0.15	0.40	0.18	0.53	0.09	0.26
UK1, West Coast Route Modernisation, RC without boosters, single-rail return	0.15	0.37	0.18	0.48	0.09	0.24
UK1, West Coast Route Modernisation, RC without boosters, double-rail return in axle-counter areas	0.15	0.36	0.17	0.45	0.08	0.23

8.3 Four-track layouts with booster transformers and return conductors

These figures exclude the impedance of the booster transformers themselves. All figures are ohm/km

Type of OLE	Single-track stub feeding; each outer track		Single-track stub feeding; each inner track		All tracks in parallel: effective impedance of each outer track		All tracks in parallel: effective impedance of each inner track		Parallel combination of all four tracks	
	Re	Im	Re	Im	Re	Im	Re	Im	Re	Im
Mk 1 Simple	0.34	0.70	0.34	0.78	0.35	0.84	0.33	0.99	0.09	0.23
Mk 1 Compound	0.32	0.67	0.32	0.75	0.33	0.82	0.31	0.98	0.08	0.22
Mk 3A/B, AWAC catenary (M), single-rail return	0.34	0.70	0.34	0.77	0.36	0.89	0.33	1.05	0.09	0.24
Mk 3A/B, AWAC catenary (E), single-rail return	0.34	0.70	0.34	0.79	0.36	0.88	0.32	1.08	0.09	0.24
Mk 3A/B, AWAC catenary, with double-rail jointless track circuits and overhead earth wires (W)	0.36	0.70	0.37	0.77	0.39	0.85	0.37	0.99	0.09	0.23
UK1, West Coast Route Modernisation	0.31	0.67	0.31	0.75	0.32	0.82	0.30	0.98	0.08	0.22

Aside from the differing types of OLE, there is some variability in the return circuit and in the spacings between tracks, as follows.

The figures for Mk 3A/B equipment with single-rail return, and the figures for UK1 equipment, assume that the Mid-Point Connectors are split, to give 10% unboosted length, in accordance with NR/SP/ELP/21078. That arrangement is not applied with double-rail jointless track circuits, where there is a single MPC as normal.

The figures for UK1 equipment apply to single-rail return, and to double-rail return in axle-counter areas.

The spacings between tracks affect the results due to differing spacings between the inner tracks and their corresponding return conductors.

The Mk 1 and UK1 figures have all four tracks at the standard “6-foot” spacing as on the West Coast Main Line.

The Mk 3A/B figures assume spacings based on regional variations:

- (M) As on the St Pancras-Bedford line, with a Wide Way between the two inner tracks
- (E) As on the East Coast Main Line, with two Wide Ways; each between an outer track and an inner track
- (W) As on the Great Western main line, with the Main lines at Broad Gauge spacings and the Relief lines at normal spacings.

8.4 Four-track layouts without booster transformers

All figures are ohm/km

Type of OLE and type of return circuit	Single-track stub feeding; each outer track		Single-track stub feeding; each inner track		All tracks in parallel: effective impedance of each outer track		All tracks in parallel: effective impedance of each inner track		Parallel combination of all four tracks	
	Re	Im	Re	Im	Re	Im	Re	Im	Re	Im
Mk 3A/B, AWAC catenary (E), rail return only, single-rail return	0.19	0.43	0.19	0.42	0.25	0.62	0.27	0.78	0.06	0.17
Mk 3A/B, AWAC catenary (E), RC without boosters, single-rail return	0.18	0.39	0.18	0.40	0.24	0.54	0.23	0.67	0.06	0.15
UK1, West Coast Route Modernisation, rail return only, single-rail return	0.15	0.40	0.16	0.40	0.21	0.64	0.24	0.80	0.06	0.18
UK1, West Coast Route Modernisation, rail return only, double-rail return for axle-counter areas	0.14	0.38	0.14	0.37	0.19	0.59	0.18	0.68	0.05	0.16

8.5 Additional results for four-track layouts if two tracks are isolated

For systems with booster transformers and return conductors, the following apply:

If both outer tracks are in use and the inner tracks are isolated, the Single-Track figures for the outer tracks should be used.

If both inner tracks are in use and the outer tracks are isolated, the Single-Track figures for the inner tracks should be used.

If an outer track and the adjacent inner track are isolated, the Parallel-Tracks figures should be used for the outer track and the inner track which remain in use. *Reason:* in this case the two inductive loops, formed by each overhead line and its return conductor, overlap and so give a significant mutual inductance.

NOTE: where booster transformers and return conductors are used, it is not very likely that the differences in the impedances, arising from taking two tracks out of use, would be so great that it would be necessary to re-calculate the protection settings.

For systems without booster transformers, the following results apply.