The International Journal of Engineering and Science (IJES)
|| Volume || 14 || Issue 11 || November || Pages || PP 99-102 || 2025 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Technical Assessment of Underground Power Cable Routing and Capacity Planning for Supplying Liverpool Lime Street Station

Eng.Ayyaf Alayyaf * Eng.Adel Alsand**
*PAAET, HIE, Electrical Networks Department.
**PAAET, HIE, Electrical Networks Department.

--**ABSTRACT**--
The key criteria to consider in providing a reliable power supply to major railway stations are the proper routing of underground cables, voltage selection, thermal performance, and capacity planning. Liverpool Lime Street Station requires a peak of 60 MVA and a firm capacity of at least 20 MVA, and thus a relative comparison of 33 kV and 132 kV underground cable solutions needs to be done by the adjacent substations. A technical evaluation of routing constraints, cable ratings, thermal limitations, mutual heating, soil effects, and joint configurations is given in this paper, which incorporates recent studies on thermal performance and ampacity behavior of underground cables. Three 33 kV route solutions and several 132 kV solutions are analyzed based on feasibility, excavation, pulling operations, and cost using the results of an existing engineering assessment. Recent research on thermal resistivity and formation of dry zones in soil and cyclic loading and cooling serves as the input for a more thorough analysis of the ampacity, reliability, and thermal stability over time. These findings show that even though 33 kV solutions are viable, 132 kV tapping solutions are better performing, less expensive, and will have fewer impediments to installation. The paper has ended with practical recommendations for cable selection, routing, and supporting infrastructure of the power supply in urban railways.

Keywords
Underground cables; power distribution; thermal performance; ampacity; routing design; 33 kV; 132 kV.

Date of Submission: 14-11-2025 Date of acceptance: 30-11-2025

I. Introduction

City rails need strong and resilient power supply networks that can provide sustained high-capacity loads under complicated space limitations. The Liverpool Lime Street Station is a case that is difficult to handle because it has a cyclic peak load of 60 MVA, which is mandatory, while the firm capacity threshold is 20 MVA. This demand can be supplied by a number of adjacent substations, Lister Drive, Burlington Street, and Paradise Street, through underground cable routes of different lengths, voltages, and practicability. The choice of the best configuration requires a trade-off of electrical performance, thermal constraints, routing complexity, environmental conditions, mechanical constraints, and cost of installation.

The recent studies accentuate the significance of soil thermal behavior, moisture change, the behavior of cable joints, and the formation of hot spots in determining underground cable ampacity (Ahmad et al., 2025; Liu et al., 2022). Moreover, mutual heating of neighboring circuits, cyclic loading, and zone of dryness development of soils may have a significant effect on long-term rating (Ahmad et al., 2021; Enescu et al., 2020). The results emphasize that thermal modelling concepts should be incorporated in the real-life engineering analyses.

This paper reviews the 33 kV and 132 kV underground cable solution to power Liverpool Lime Street Station based on engineering information and route evaluation in the current project study. The aim is to find out the most technically and cost-effective approach and integrate the modern-day scientific knowledge on underground cable performance.

II. Background

Underground Cables' Thermal Behavior

The amount of heat produced in an underground cable should be properly removed by the use of the insulation, sheath, surrounding backfill, and native soil. The heat-conducting ability of these layers determines the maximum allowable current (ampacity). The thermal resistivity of soil is a key factor that depends on moisture content, compaction, and temperature. According to Ahmad et al. (2025), the operation of high-voltage cables may cause significant moisture evaporation near the conductor, creating local dry areas, which develop resistivity exponentially. The impact of this effect is that it reduces the heat loss and has a limiting ampacity that is conservative. Similarly, Enescu et al. (2020) reported that high-resistance soils, or those that do not absorb moisture, possess high temperatures, which rapidly increase, particularly when the soil is subjected to prolonged periods of peak loading.

Cyclic loading, as is found in traction power systems, causes a repetition of thermal gradients that spread out around the cable as time passes. Ahmad et al. (2021) showed that such cycles lead to dynamic expansion and contraction of the thermal boundary layer and can lead to cumulative drying of soils, high cumulative conductor temperature, and derating. In complicated urban settings like in central Liverpool, soils can be constituted of mixed granular materials, utility backfill, and compacted layers that further prevent heat flow.

The use of thermo-hydraulic modelling has become an effective predictive mechanism of such coupled thermal-moisture phenomena. Liu et al. (2022) demonstrated that conventional steady-state approaches can be inappropriate in estimating thermal resistance in soils whereby water movement and evaporation predominate in heat dissipation. The conductor temperature could grow faster and even higher, according to their realistic modelling of moisture-loss behavior, and this is why judicious choice of cable is self-expensed in high-demand infrastructures.

Routing and Installation Remarks

In city cabling, one must avoid underground utility cables, surface roads, and implementations of underground infrastructure. In most instances excavation should be done at night in order to avoid causing much disturbance. These limitations are extra expenses and advancement of project schedules. There are also cooling restrictions, such as where the cables line ducts, enclosed spaces, or cable tunnels, since heat cannot be readily carried away by stagnant air. Elsaid et al. (2024) mentioned that improper ventilation might result in the fast formation of hot spots and a considerable decrease of the ampacity. Though the Lime Street project mainly involves direct-buried cables, some of the transition sections might still experience biased confinement.

Routing design is also influenced by mechanical provisions like permissible pulling tension, bending radius, and joint spacing. Hot spots in cable systems are known as joints because they are more thermally resistant and may be the source of localized losses. The authors Wang et al. (2017) highlighted that joint heating may restrict ampacity by quite a considerable amount in cases not thoroughly evaluated, especially when it comes to high-voltage systems with a long service life perspective.

III. Methodology

The analysis compares various options of 33 kV and 132 kV underground cables, and each has its own route length, thermal parameters, and installation issues. The comparison is based upon the engineering information as part of the original Lime Street project and underpinned with scientific literature to derive thermal and operational implications.

33 kV System Assessment

The 33 kV options employ 240 mm 3-core copper cable with fluid contents of 478 A under the specified soil conditions (thermal resistivity 1.5 KmW, burial depth 0.9 m). The 60 MVA demand requires three circuits. The three nearby substations were evaluated at 1400 m, 2414 m, and 3862 m.

Some of the important engineering considerations were:

- Several crossings with underpasses and crossings with roads.
- Closeness to already existing power cables that lead to mutual heating.
- Severe working hours limitations on traffic.
- Need to excavate specialized nearby sensitive infrastructure.
- Calculations of mechanical pulling force with acceptable tension in all sections.

The 33 kV routes are technically feasible, but they are complicated to trench and install.

132 kV System Assessment

The 132 kV options are based on single-core 120 mm² fluid-filled copper cables having 363 A current-carrying capacity at 1.2 KmW soil resistivity. The firm capacity requirement will require two parallel circuits. The route lengths are identical to those in the 33 kV choices, but trench widths are reduced since the circuit has fewer cores.

The 132 kV solutions benefit from:

- Lower current per conductors, eliminating thermal stress.
- Downtrodden cross-phase heating.
- Less complicated joint structures.
- Fewer cables overall

The longer 132 kV routes, however, have the same excavation and congestion problems as the 33 kV options.

132 kV Tapping Approach
A simple and shorter 170 m cable tap into an already existing 132 kV line serving Paradise Street would be a more efficient solution. This technique needs little excavation, fewer components, and significantly less cost. According to the bonding setup that Ardiansha (2025) talks about, it is possible to have a guideline on how to bond sheathing and jointing on such setups.

IV. Results and Analysis

Thermal Performance
Long cable paths have long thermal interaction surfaces with the soil around them. The 33 kV routes, especially the 3862 m route, used in the Lime Street case subject cables to soil areas of different thermal resistivity, compaction, and access to moisture. Enescu et al. (2020) indicate that, with this kind of variability, ampacity is greatly affected and the risk of dry-zone formation increases. On the same note, Ahmad et al. (2021) note that the cyclic heating of the soil caused by railway load profiles enhances the local soil drying near cables.
The lower current per conductor solutions of 132 kV generate less thermal output and are not prone to expansion in dry zones. This thermal benefit is especially significant in the limited urban trenches where cooling could be minimal because of surrounding utility or compacted fill.
The shortest length is that of the 132 kV tap, and this explains why it performs the best. It has a minimum exposure to soil, and therefore propagation of heat is minimized and the sustained rating is very stable.

Mutual Heating Effects
Mutual heating is generated when new cable circuits are laid in parallel with already existing high-voltage lines. The existing infrastructure is adjacent to the 33 kV route options (and some 132 kV), which poses the risk of cumulative heating. Wang et al. (2017) demonstrated that joint heating and bonding interface heating can greatly improve the temperature of interfaces between joints. Extended high temperature also promotes aging of insulation.
The 132 kV tap in the Lime Street project is the only one that does not require long parallel runs, and thus the long-term thermal reliability of this tap is evident.

Mechanical and Installing Factors
Mechanical pulling inspections ensure that tensile limits are not exceeded in all the proposed sections, irrespective of the level of voltage. But there is a wide range of complexity in installation. The 33 kV options involve a lot of trenching across high-traffic corridors and many crossings and considerable reinstatements. Time and cost of installation are also increased by working-hour restrictions.
The 132 kV full-route solutions require fewer cables and still have high civil engineering loads. Compared to the 132 kV tapping technique, the technique only requires a single trench, two connectors, and less reinstatement.

Cost Evaluation
According to the engineering assessment:

- 33 kV options: £1.05M – £2.90M
- 132 kV full routes: £0.93M – £2.56M
- 132 kV tap: cable and minor installation cost: ~£68,000.

Price is proportional to trench length, the number of cables, and the complexity of excavation. The most cost-effective of all is the 132 kV tap which has more than a 10-fold lower cost.

V. Discussion

The combination of scientific knowledge with engineering information shows significant discrepancies in the performance and the usefulness of the cable choices. Thermal behavior in the soil is a key factor in ampacity, and long routes expose vehicles more to varying soil conditions. Studies by Ahmad, et al. (2025) support that the functioning of underground cables considerably changes the distribution of soil moisture, whereby it has the possibility of causing long-term dry periods. These effects are more acute at high currents, and thus, the 33 kV circuits are relatively susceptible.

The evidence of thermo-hydraulic models presented by Li et al. (2022) provides an excellent increase in the temperature of conductors in soils with a low moisture level, especially when cyclic loads occur. This effect is in line with the peak-and-trough demand pattern of rail stations, and it adds to the infeasibility of long-distance 33 kV routes.

In spite of the fact that 132 kV full-route solutions are more thermally stable, they are still subject to numerous civil engineering issues: congestion, underpass crossings, and the short working hours. The tapping technique has almost all the disadvantages of routing removed, but the technique also enjoys the advantages of low conductor currents, less mutual heating, and fewer joints.

The necessity to keep in mind the heat accumulation in confined spaces is also supported by studies on cable tunnel ventilation (Elsaid et al. 2024). Even though direct burial is mostly used in Lime Street, any passage to ducts will need special thermal evaluation. Joints are also important features since they become hot during load-bearing loads (Wang et al. 2017), and thus the reduction in the number of them, as in the tapping option, directly increases the reliability of the system.

Overall, there is great compatibility between the results of the literature and the practical needs: short cables with a stable temperature and low capacity in terms of congestion are the best in terms of long-term performance and cost-efficiency.

VI. Conclusion

This paper evaluated the available options in underground cable routing and capacity planning in the delivery of 60 MVA peak power and 20 MVA firm capacity to Liverpool Lime Street. Through the combination of the project engineering data with modern thermal and ampacity research, the analysis demonstrates that there is a multitude of both 33 kV and 132 kV full-route solutions that are technically feasible but suffer significant thermal, mechanical, and economical limitations. The long paths, interaction of the soils, and mutual heating cause significant derating risks.

The best solution would be the 132 kV tapping solution, as it has a high thermal performance, the minimum excavation, a low project cost, and low complexity in installation. This is the best solution, as it is well associated with the recent discoveries of thermal stability, soil behavior experiments, and cable joint performance, thereby being the best and soundest way of delivering power to a large urban railway station.

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