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Feasibility of Converting Overhead Transmission Lines to Underground – A Case Study

Thursday 23 September | Technical Topic Webinar

Presented By

Professor Akhtar Kalam | EIT Academic Board Chairman

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Introduction - Presenter

Professor Akhtar Kalam

- Chair of the EIT Academic Board.
- Head of External Engagement and Professor at Victoria University.
- Director of Al-Kalam Educational Solutions.
- Editor-in-Chief of AJEEE

Distinguished Professor/Adjunct Faculty in Australia, India, Malaysia and Oman.
Published over 610 publications in his area of expertise and written over 29 books in the area.
Supervised 49 postgraduate research students to graduation consisting of 38 PhDs and 11 MEng.
Currently, 12 postgraduate research students being supervised (one MEng student).
Public, University and Motivational Lecturer.
Consultant for the electricity supply industries.
Assisted in change management plans to Universities and higher education sector.

- Education
  - The University of Bath, Bath, UK, PhD, Electrical Engineering
  - The University of Oklahoma, Norman, USA, MS, Electrical Engineering
  - Aligarh Muslim University, Aligarh, India, BScEng, Electrical Engineering
  - St Xavier's College, Calcutta, India, Applied Science
- Professional Society Activities
  - Australian Institute of Energy – Fellow
  - Engineers Australia – Fellow
  - The Institution of Engineers and Technology, UK – Fellow
  - The Institution of Electrical and Electronic Engineers, USA –Life Senior Member.

Agenda

1	Welcome & Introduction
2	Waverley Park Estate
3	220 kV High Voltage Power Line
4	Financial cost comparison
5	Conclusion and Q&A

Existing Location of Transmission Lines and Towers

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- 220kV transmission lines crossing the Waverley Park estate in Mulgrave, Victoria.
- Evaluate the feasibility of diverting the transmission lines underground.
- Mirvac had originally intended to underground the transmission lines by means of a transition enclosure constructed at each end of the estate and approximately 530 metres of buried cable between the two locations.

Waverley Park Estate

Temporary pole in use while replacing traditional lattice pylons with steel monopoles

In 2002 property Mirvac promised home buyers at Waverley Park that the 220 kV transmission line through the middle of the estate would be placed underground. However due to escalating costs this plan was abandoned in 2015, with the traditional steel lattice towers being replaced with smaller steel monopole structures in 2018.

Mirvac told to pay up over Waverley Park compo work

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Existing Location of Transmission Lines and Towers

The ugly high-tension powerlines will stay above ground, and homeowners are furious with the compensation offer!

The market capitalization of Mirvac is almost $12 billion, according to the Australian Stock Exchange. Yet it still tried to avoid paying an extra $84,000 as part of a compensation package for a broken promise to Waverley Park homeowners.

Problem?

- Identify an alternative, preferred undergrounding solution compared to the original proposal advanced by Mirvac.
- Although broadly the same as the Mirvac's initially proposed concept, the alternative solution is modelled on the 220kV Brownhill Road substation located in Auckland, New Zealand.
- From a public amenities' perspective, the Brownhill Road scenario is very similar to that existing on the Waverley Park estate, but is demonstrably superior in terms of visual amenity, open space and financial cost.

Preliminaries (1/2)

- The undergrounding of high voltage transmission lines, including 220 kV and up to 500 kV lines, has been commonplace for many decades.
- The increasingly popular practice of diverting high voltage transmission lines underground is occurring in city, urban and industrial settings, and is being largely driven by environmental concerns.
- Thousands of kilometers of underground cable, over both long and short distances, have been installed in many countries all over the world.
- New materials, new processing technology, new installation techniques and steady reduction in relative costs have all contributed to the growth in the popularity of underground cables.
- Also contributing to the growth is an increasing realisation that when compared to overhead cables, underground cables have distinct advantages in terms of reliability and life expectancy, as well as maintenance and operating costs.

Preliminaries (2/2)

- Depending on the specific situation and social context, either tower-mounted terminations or practical transition enclosures would provide an undergrounded 220 kV high voltage powerline with the least visual amenity impact.
- The most economical means of undergrounding a 220 kV high voltage powerline as of 2012 would have been to ensure that the chosen infrastructure utilised that latest technology and installation techniques, and that the infrastructure footprint and associated tower/pole heights were minimised.

What technology is available to put the existing power lines underground? (1/3)

- Economic considerations have ensured that development of power transmission networks over past decades has mainly proceeded on the basis of overhead (OH) lines.
- Extra high voltage (EHV) underground (UG) cable systems have been available for some considerable time, their use has been largely restricted to providing interconnections between OH transmission lines and specified locations within cities, urban and industrial areas.
- EHV underground cables have also been used where environmental factors have taken precedence in terms of expanding or improving transmission networks.

What technology is available to put the existing power lines underground? (2/3)

- In many countries, thousands of kilometers of undergrounded HV and EHV cables already exist, but the length of these underground circuits is usually between 2 – 20km.
- Today, however, many UG or sub-sea cable circuits being established are between 50 - 150km in length.
- Special factors need to be considered when designing such links compared to the normal considerations associated with shorter links.

What technology is available to put the existing power lines underground? (3/3)

- The reason for the rapid growth in undergrounding solutions is very much related to the new materials, processing technology, ancillary equipment and installation techniques available today.
- These factors have succeeded in overcoming some of the problems of capacitance, dielectric losses and the relatively low current rating compared to OH lines to such an extent that constraints on maximum length and power transfer have become much less important than previously.

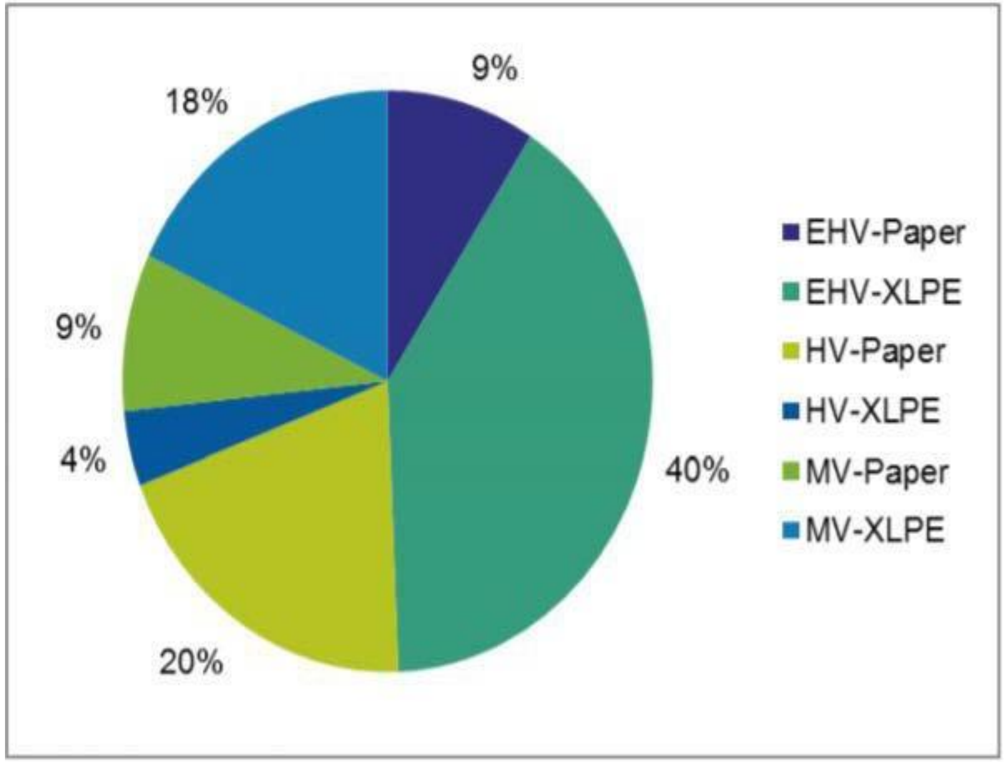
The Victorian electricity transmission network asset (1/2)

- Underground Power Cable Summary

Cable Voltage	Circuits (each)	Installed Length (km)
Extra High Voltage (220 kV)	15	**10.932**
High Voltage (66 kV)	17	**5.316**
Medium Voltage (22 kV)	101	**3.955**
Medium Voltage (11 kV)	30	**1.530**
Medium Voltage (6.6 kV)	**12**	**0.420**

The Victorian electricity transmission network asset (2/2)

- Summary of Victoria's UG power cable population by voltage level and insulation design. EHV power cables make up 49% of the cable population, 24% are HV power cables while the remaining 27% are MV power cables.



Power Cable Population

The ability to underground 220 kV HV powerlines as of 2012 (1/3)

- High-voltage transmission lines of various lengths and voltages, have been buried successfully since at least the 1980s. To illustrate this, the Canadian website RETA (Responsible Electricity Transmission for Albertans) lists representative examples of the many successfully buried 400kV and 500kV lines located in various countries in Asia, Europe and the Middle East. The RETA examples are shown in the next two Tables.

Overseas Examples of Major 400kV Projects

Location	Project	Length (m)	Year
Copenhagen (Denmark)	Elimination of overhead lines in urban area	34,000	1999
Berlin (Germany)	Connect West/East system	24,000	2000
Vale of York (UK)	Area of outstanding beauty	24,000	2001
Madrid (Spain)	Barajas Airport Expansion	26,000	2003
Jutland (Denmark)	Area of outstanding beauty, waterway /semi urban areas	28,000	2003
London (UK)	London Ring	20,000	2005
Rotterdam (Netherlands)	Randstad waterway crossings	4,200	2005
Vienna (Austria)	Provide power to the entire city	11,000	2005
Milan (Italy)	Section of Turbigo-Rho line	17,000	2006
Switerland/Italy	Mendrisio - Cagno	8,000	2008

The ability to underground 220 kV HV powerlines as of 2012 (2/3)

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Overseas Examples of 500kV Projects

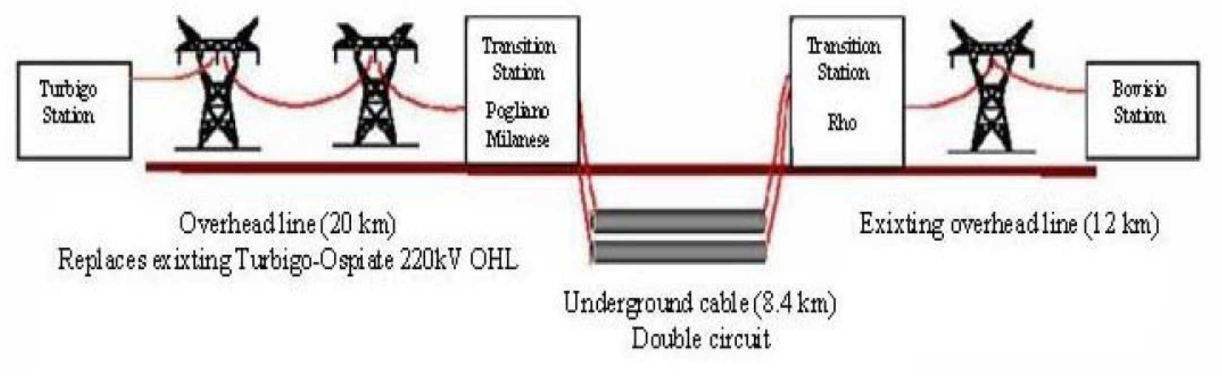
Name of project	Conductor size (mm²)	Cable length (m)	Year
Tianhungping - China	800	2,100	1999
Dachaoshan - China	800	7,200	2001
Bureyskaya - Russia	800	2,650	2004
Bureyskaya - Russia	800	2,850	2007
Man Wan - China	800	950	2007
Merowe - Sudan	1,200	3,900	2009
Merowe - Sudan	800	3,900	2009
Sidi Kvir – Egypt	800	8,550	2009
ETS – Russia	800	600	2009
Groupitan – China	800	10,050	2009
Shibo Shanghai – China	2,000	52,000	2010
Poree III - Colombia	800	5,400	2010
Xianshuijian - China	1,000	2,370	2011

The ability to underground 220 kV HV powerlines as of 2012 (3/3)

- The Waverley Park HV transmission lines are rated at 220kV. And considering the earlier examples, it cannot be denied that transmission lines up to 500kV have been successfully diverted underground in many countries. Indeed, as the RETA website points out:
- The fact is there are thousands of examples of successfully buried 240kV transmission lines and lines of lower voltage. Many cities and towns around the world have many miles and kilometers of buried high voltage lines, especially in densely populated and “downtown” areas.
- The inescapable conclusion is that as of 2012 there definitely existed well-honed ability to successfully underground 220kV high voltage powerlines.

Type and structure of a 220kV HV powerline with least visual amenity impact (1/3)

- The Turbigo-Rho line scenario in Italy, shown in adjacent Figure, is like the OH-UG transmission lines situation on the Waverley Park estate.



Partial Undergrounding of 380 kV Turbigo-Rho Line

Type and structure of a 220kV HV powerline with least visual amenity impact (2/3)

The salient features of the Turbigo-Rho line infrastructure are:

- The maximum power rating of the circuit is 2200MVA.
- The project was conceived to facilitate regulatory clearance for transmission line projects passing through sensitive areas (high population density, closeness to environmental parks etc.) which, otherwise, find opposition from local communities. Many OH-Underground Cable-OH projects fall into this category and underground cable is selectively used in a `sensitive' span where OH is not acceptable.
- For reliability, double circuit (one circuit on each side of road is used) has been used. The current capacity of the double circuit under normal operating conditions is matched with that of OH lines by suitable choice of cable conductor size.
- Use of XLPE cables.
- Special provisions to limit electromagnetic interference (EMI) to 3µT when human presence above 5 hours within the vicinity is expected. Otherwise, EMI to be restricted to 100µT. For places where the lower limits are applicable, trefoil formation is preferred.
- Claims that reduction in losses benefits the environment and the economy.
- Alleviation of congestion.

In New Zealand, undergrounding of 1,300m of the Henderson-Otahuhu 220kV line occurred in 2007 (adjacent Figure). Two separate routes were required and the termination options at the Hillsborough end were limited. The existing line is shown in solid green and the new cable routes for each circuit is shown in orange.

220 kV Henderson–Otahuhu, New Zealand Line

Mirvac's Proposal

Mirvac had originally proposed two transition enclosures – one at each end of the Waverley Park estate, with approximately 530 meters of underground cable between the two terminations. The two enclosures, one adjacent to Jacksons Road and the other adjacent to the Monash Freeway, were to contain the same electrical infrastructure, but the size of the compounds surrounding that infrastructure would be significantly different.

The 2015 Waverley Park Transmission Lines Advisory Committee Report, provides a description of the events that shaped the initial Mirvac strategy for dealing with the 220 kV transmission lines crossing the Waverley Park estate

Mirvac’s Proposed Jacksons Road Transition Enclosure

The electrical infrastructure consists of six staggered height poles having heights of 17 meters, 22.1 meters and 30 meters. The enclosure footprint is 4,600 m^2.

Mirvac's Proposed Monash Freeway Transition Enclosure

The electrical infrastructure also consists of six staggered height poles having heights of 17 meters, 22.1 meters and 30 meters. But the enclosure footprint is much larger at 8,700 m^2.

220 kV cable termination system installed near Barajas Airport in Spain

245 kV cable termination system installed near a Canadian highway

More practical transition enclosure

The Mirvac's proposed transition enclosure solution involved large compound footprints (4,600 m^2 and 8,700 m^2), with each compound containing six staggered height poles having heights of 17 meters, 22.1 meters and 30 meters.

However, a more practical and more efficient example of a 220 kV transition enclosure can be found in New Zealand. Transpower NZ is the owner of the Brownhill Road substation in the southeastern Auckland suburb of Whitford. The termination is part of the 186-kilometer double-circuit 400 kV Whakamaru to Brownhill Road transmission line. The line, which is predominantly an overhead cable, currently operates at 220 kV, but will be upgraded in future to 400 kV, possibly by 2030. The underground cable has a length of 11 kilometers, and runs from Brownhill Road to the Pakuranga substation in eastern Auckland. The Brownhill Road substation was commissioned in November 2012.

Brownhill Road Substation Electrical Infrastructure

The electrical infrastructure consists of four poles having a uniform height of 20 meters. The enclosure footprint is a mere 1,709 m^2.

Brownhill Road Substation Electrical Infrastructure

The aerial view provides a stark of assessment of the size of enclosure footprint relative to the electrical infrastructure contained within the compound.

Conduit Insulator

NCIT on selected termination towers

220kV Transition Ground Type, Auckland, New Zealand includes the surrounding

220kV Transition Ground Type, Auckland, New Zealand only the transition tower is included

Final Primary Arrangement (selected termination towers, during construction) (1/2)

Final Primary Arrangement (selected termination towers, during construction) (2/2)

BUILDER's proposal – Jacksons Road end	
Pole configuration:	6 staggered height poles per enclosure
Pole height:	17 metres, 22.1 metres and 30 metres
Enclosure footprint:	Jacksons Road end 4,600 m^2
	Monash Freeway end 8,700 m^2
Financial cost:	$10.013 million in 2012 (two transition stations)

Mirvac's proposal – Monash Freeway end

Brownhill Road, Auckland, New Zealand – ground view

Brownhill Road, Auckland, New Zealand – aerial view (1/2)

Pole configuration:
4 uniform height poles per enclosure

Pole height:
20 meters

Enclosure footprint:
1,709 m^2

Financial cost:

Brownhill Road, Auckland, New Zealand – aerial view (2/2)

For high-pressure, fluid-filled pipe (HPFF) systems, a pressurizing plant maintains fluid pressure in the pipe. The number of pressurizing plants depends on the length of the underground lines. It may be located within a substation. It includes a reservoir that holds reserve fluid. A high-pressure, gas-filled pipe (HPGF) system does not use a pressurizing plant, but rather a regulator and nitrogen cylinder. These are in a gas-cabinet that contains high-pressure and low-pressure alarms and a regulator. The XLPE system does not require any pressurization facilities.

At 400 and 500 kV, the size and weight of terminations and the necessary clearances dictate the use of a separate, high security transition compound on the ground. The compound can require an area of 2,500 m^2 depending on the power level and the amount of equipment installed. The overhead line tower at this location is more substantial because the line terminates at this point and hence the mechanical forces on the tower are unbalanced.

400 kV Transition compound

Proposed Transition station

Cost (inclusive of all parameters) to underground the high voltage powerlines as at 2012 and as at 11/2016 (1/2)

- 2 solutions were suggested as possible alternatives to the proposed transition enclosures Mirvac claimed would be needed to underground the 220 kV Waverley Park transmission lines. Specifically, the two alternative solutions were:

    1. Tower-mounted terminations and
    2. More practical transition enclosures.

- The two alternatives were advanced as direct rebuttal to an incorrect observation made by the Waverley Park Transmission Lines Advisory Committee. Established in 2014 by then Victorian Minister for Planning, the Hon Matthew Guy, the Committee stated at page 47 of its February 2015 report:

    - *…. the transition enclosures were first mentioned in 2001 and have been the subject of discussion, analysis, estimating and reporting from a number of engineering firms, and that AusNet have been involved in such discussions from the start. The Committee is satisfied that the transition enclosures as they are currently configured are the most appropriate engineering solution if the underground option is to proceed, and that if any other viable options had been available, they would have been presented by now.*

Cost (inclusive of all parameters) to underground the high voltage powerlines as at 2012 and as at 11/2016 (2/2)

- However, and even though the 220 kV Waverley Park transmission lines lend themselves to tower-mounted terminations, this not the preferred solution for purposes of the current Witness Statement. Instead, the preferred solution for Waverley Park is a more practical transition enclosure modelled on the 220 kV Brownhill Road substation located in Auckland, New Zealand. The reasons for preferring the Brownhill Road substation over a tower-mounted termination are threefold:

  a) From a purely practical point of view, a solution implemented within Australia's immediate geographic region is more likely to find favour among decision- makers than one that has been implemented in Europe or North America.

  b) The financial cost of the Brownhill Road substation is very reasonable.

  c) From a public amenities point of view, the Brownhill Road scenario is very similar to that existing on the Waverley Park estate.

Financial cost comparison

- The Mirvac solution to undergrounding the Waverley Park transmission lines was to construct a transition station adjacent to the Monash Freeway having a footprint of 8,700 m^2, and a transition station adjacent to Jacksons Road having a footprint of 4,600 m^2. Each transition station was to contain six staggered poles of 17 meters, 22.1 meters and 30 meters in height.

- The preferred alternative solution is to construct two transition stations in roughly the same locations as the Mirvac solution but modelled on the Brownhill Road substation in Auckland. Each transition station would have a much smaller footprint of 1,709m^2, and would contain only four poles having a uniform, and the much smaller, height of 20 meters.

Summary Comparison of Financial Costs in 2012 and 2016 Dollars

Item	Mirvac solution		Alternative solution	
	$ Oct 2012	$ Nov 2016	$ Oct 2012	$ Nov 2016
Monash line deviation	1,147,000	1,236,961	1,060,000	**1,143,137**
Jacksons Road line deviation	1,478,000	1,593,922	1,250,000	**1,348,039**
Monash transition station	5,044,000	5,439,608	3,503,826	**3,778,636**
Jacksons Road transition station	4,969,000	5,358,725	3,503,826	**3,778,636**
220 kV cable	20,199,000	21,783,235	13,072,454	**14,097,745**
Sub Total	32,837,000	35,412,451	22,390,107	**24,146,194**
Contingency / risk allowance	3,104,000	3,347,451	1,538,245	**1,658,892**
Total	**35,941,000**	**38,759,902**	**23,928,352**	**25,805,085**

Calculation basis

- The remaining October 2012 amounts for the Alternative solution were estimated by Professor Akhtar Kalam.
- All October 2012 dollar amounts were translated into November 2016 dollars using historical Australian Consumer Price Index data – an index of 110 for the December quarter of 2016 and an index of 102 for the December quarter of 2012.
- A contingency of 10% was applied to the Alternative solution costs in accordance with AECOM guidelines for Class 3 estimates.

Visual amenity and transition enclosures (1/2)

- A major justification Mirvac advanced for retaining the Waverley Park 220 kV transmission lines aboveground was that the overhead option removed the requirement for "unsightly infrastructure". On pages 16 to 17 of its submission to the Advisory Committee (Collie, August 2013), Mirvac asserted:

> *The proposed amendment removes the requirement to construct above ground unsightly transition enclosures and associated electrical infrastructure on the frontages of Jacksons Road and the Monash Freeway. Removing the requirement to construct these transition enclosures will greatly improve the appearance of these areas and the amenity of existing and future residents and commuters along Jacksons Road and the Monash Freeway. In particular, the transition enclosure adjacent to Jacksons Road would have caused a detrimental impact to the amenity of residents outside Waverley Park on the east side of Jacksons Road, where existing dwellings would face that transition enclosure. Removing the need for a transition enclosure adjacent to Jacksons Road will also improve significantly the appearance of Waverley Park from Jacksons Road.*

Visual amenity and transition enclosures (2/2)

- The Advisory Committee agreed with Mirvac's 2015 submission. The Executive Summary:

  If the transmission lines are placed underground there will be no tower in the centre of the easement corridor, however, the transition enclosures could create significant new visual amenity impacts for the two abutting residential precincts.

  These enclosures will have new and intrusive public realm impacts which are undesirable having regard to the urban design objectives and philosophy for Waverley Park.

- Notwithstanding Mirvac's claims, and the Advisory Committee's support for those claims, it is not a foregone conclusion that transition enclosures will inevitably fall within the category "unsightly infrastructure". The recently completed Olympic Park Substation in Sydney, New South Wales, and the recently upgraded Richmond Terminal Station illustrate this proposition.

CONCLUSIONS AND ADVICE (1/2)

- The Mirvac of Waverley Park estate, had originally intended to underground the transmission lines by means of a transition enclosure constructed at each end of the estate and approximately 530 meters of buried cable between the two locations.

- However, the Mirvac's proposal was ultimately abandoned, and the slightly realigned transmission lines are now being retained aboveground. Included in the formal reasons for abandoning the company's original underground proposal were visual amenity, open space and financial cost concerns.

CONCLUSIONS AND ADVICE (2/2)

- Report has been framed within the context of comparing Mirvac's original undergrounding proposal with an alternative, preferred undergrounding solution.
- The alternative solution, although broadly the same as Mirvac's initially proposed concept, is modelled on the 220 kV Brownhill Road substation located in Auckland, New Zealand.
- From a public amenities' perspective, the Brownhill Road scenario is very similar to that existing on the Waverley Park estate, but is demonstrably superior in terms of visual amenity, open space and financial cost.

ADVANTAGES OF THE ALTERNATIVE SOLUTION – SUMMARY

- Comparative Advantages of the Alternative Solution

Project Parameter	Alternative Solution
Number of poles per compound	33% fewer
Maximum pole height	33% shorter
Monash Freeway compound footprint	80% smaller
Jacksons Road compound footprint	63% smaller
Total financial cost	33% cheaper

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Q&A

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