Appendix G

Hazards & risks tables

PRELIMINARY REVIEW OF RISKS AND HAZARDS

Item	Risk Description / Element	Potential Impacts and Consequences	Proposed Mitigation Measures
Construction - Environmental / Social Risks			
	Geology / Geotechnical Risks; ▪ Poor Ground Conditions ▪ Settlement; ▪ Contamination and Disposal; ▪ Geological faults.	▪ Reduction if progress of works; ▪ Ground settlement, settlement of building foundations and potential cracking/structural damage to building structures; ▪ Health impacts associated with contamination issues; ▪ Adverse environmental impacts associated with ground contamination; ▪ Disruption to businesses and general public amenity.	▪ Geotechnical investigations and analysis; ▪ Building structural design based on interpreted ground conditions and known areas of risk; ▪ Dilapidation and basement survey of buildings potentially affected by building works; ▪ Contamination studies and management plans to be developed to deal with the disposal of contaminated soil.
	Hydrogeology / Groundwater Groundwater Chemistry, Treatment and disposal;	▪ Contamination issues affects from PASS; ▪ Contamination of receiving waters	▪ Geotechnical investigations and analysis; ▪ Building structural design based on interpreted ground conditions and known areas of risk; ▪ Contamination studies and management plans to be developed to deal with the disposal of contaminated soil.
	Surface Water ▪ Erosion and Sedimentation; ▪ Stormwater runoff and disposal;	▪ Pollution of waterways as a result of erosion and sedimentation; ▪ DEC sanctions and fines; ▪ Potential undermining/damage to above ground structures	▪ Local site controls and management plans; ▪ Implementation of checking/maintenance of sedimentation and erosion controls; ▪ Water treatment before disposal. Collection and analysis of water samples during construction.
	Ecology / Flora and Fauna ▪ Clearing of vegetation / flora; ▪ Groundwater disposal and affect on aquatic habitat in receiving waters	▪ Damage to aquatic ecology; ▪ Turbidity / algae blooms in receiving waters.	▪ Water treatment before disposal. Collection and analysis of water samples during construction;
	Existing / Proposed Underground Assets ▪ Building clearances and undermining of existing buildings and other underground services; ▪ Clearances and undermining of existing building basements	▪ Settlement and structural damage to existing buildings, other underground services; ▪ Collapse of existing buildings; ▪ Stray currents and electrocution	▪ Geotechnical investigations and analysis; ▪ Review as-built data and survey from existing underground structures; ▪ Building structural design based on interpreted ground conditions; ▪ Dilapidation and basement survey of buildings potentially affected by building works

Item	Risk Description / Element	Potential Impacts and Consequences	Proposed Mitigation Measures
Construction - Environmental / Social Risks			
	Noise and Vibration / Regenerated Noise ▪ Surface Construction Activity; ▪ Ground Vibration / Regenerated Noise; ▪ Rock Breaking; ▪ Traffic / Construction Plant; ▪ Ventilation Plant.	▪ Structural damage to buildings; ▪ Loss of public amenity; ▪ Complaints ▪ Sleep and general public disturbance;	▪ Limited hours of operation for surface works; ▪ Limited hours for rock-breaking activities; ▪ Noise attenuation structures used at surface; ▪ Measurement of background levels and noise monitoring during construction works; ▪ Community consultation and liaison; ▪ Investigate alternate / multiple haulage routes for spoil disposal; ▪ Selection of specialist equipment to suit likely ground conditions and minimise regenerated noise; ▪ Dilapidation and basement survey of buildings potentially affected by building works;
	Settlement / Property Impacts ▪ Settlement (ground, roads and buildings);	▪ Reduction if progress of works; ▪ Ground settlement, settlement of building foundations and potential cracking/structural damage to building structures; ▪ Disruption to businesses and general public amenity.	▪ Geotechnical investigations and analysis; ▪ Building structural design based on interpreted ground conditions and known areas of risk; ▪ Dilapidation and basement survey of buildings potentially affected by building works; ▪ Selection of specialist equipment to suit likely ground conditions;
	Dust / Air Quality ▪ Surface Works; ▪ Shaft Excavation; ▪ Trenching for cable routes; ▪ Building Excavation; ▪ Spoil stockpiles, handling and transport; ▪ Construction Ventilation; ▪ Bulk excavation (substation sites); ▪ Equipment exhausts;	▪ General health to the public and works; ▪ Air pollution; ▪ General public amenity and comfort; ▪ Breach of environmental standards; ▪ Worksite aesthetics; ▪ Public complaints;	▪ Environmental management plans; ▪ Dust suppression measures utilised on site; ▪ Covering of spoil stockpiles and trucks leaving the site; ▪ Filtration /scrubbers for ventilation plant; ▪ Regular maintenance of vehicles /plant used on site; ▪ Monitoring and measurement of air quality during construction works;
	Social Issues ▪ Public perception of risks associated with building (ie building collapse, fatalities etc);	▪ Loss of reputation; ▪ Increase in objections to the project; ▪ Poor publicity; ▪ Scare mongering;	▪ Community consultation; ▪ Planning / information forums; ▪ Regular project updates.

Item	Risk Description / Element	Potential Impacts and Consequences	Proposed Mitigation Measures
Environmental / Social Risks			
	Traffic and Transport ▪ Disruption to local traffic; ▪ Haulage Routes; ▪ Road Dilapidation; ▪ Road Closures; ▪ Loading / Unloading Materials and equipment; ▪ Pedestrians and other road users; ▪ Spoil disposal; ▪ Parking; ▪ Queuing in the vicinity of construction sites; ▪ Disruption to special events;	▪ Noise and vibration; ▪ Air quality and pollution; ▪ General public safety; ▪ Erosion and sedimentation tracking onto roads; ▪ Complaints and access restrictions to local residents and businesses; ▪ Traffic congestion; ▪ Damage to roads; ▪ Loss or disruption of parking;	▪ Traffic assessment and route/intersection analysis; ▪ Traffic modelling; ▪ Traffic management plans during construction; ▪ Restrictions on working hours for loading/unloading of materials; ▪ Environmental Management Plans dealing with erosion and sedimentation; track washes, street cleaning etc; ▪ Dilapidation surveys along affected roads/haulage routes; ▪ Assess alternate routes for haulage and general construction traffic; ▪ Rerouting of bussing and other public transport; ▪ Consultation with RTA, CoS, MoT and State Transit; ▪ Dedicated pedestrian walkways to be maintained around construction sites; ▪ Signage in and around construction sites;
	Waste Management and/or Reuse ▪ Control of hazardous wastes; ▪ Contamination (Surface Works); ▪ Recycling and/or Disposal; ▪ Hazardous materials associated with demolition of existing assets / buildings;	▪ Health and safety of workers and the general public; ▪ Environmental harm and contamination as a result of waste disposal; ▪ Hazardous materials associated with demolition causing damage to the environment or health of employees; ▪ Use of landfill – inefficient use of resources;	▪ Waste management plans; ▪ Contamination assessment; ▪ Assessment of options for re-use of spoil (VENM) and other waste materials; ▪ Treatment and isolation of hazardous materials during construction activities; ▪ Assessment of sites for disposal of materials; ▪ EMP to include mitigation measures for control and storage and handling of hazardous materials;
	Heritage / Archaeology ▪ Known heritage sites affected by works; ▪ Areas of Archaeological significance; ▪ Spoil removal; ▪ Buried or unknown heritage items	▪ Damage to heritage buildings and other assets; ▪ Delay to works; ▪ Legal and statutory issues;	▪ Cultural and heritage assessment; ▪ Monitoring during construction; ▪ Dilapidation survey of heritage buildings; ▪ Awareness on notification and treatment during construction (eg stop work provisions);
	Visual Amenity / Landscape/Disturbance ▪ Construction sites; ▪ Pedestrian access and management; ▪ Night works / lighting; ▪ Waste and rubbish; ▪ Dust and air quality; ▪ Tracking of sediments onto public roadways; ▪ Noise ▪ Parking; ▪ Visual amenity of new buildings; ▪ Urban planning;	▪ Complaints; ▪ General public disturbance and perception; ▪ Potential to delay works; ▪ Inappropriate urban design;	▪ Consultation and planning; ▪ Design review; ▪ Environmental Management Plans; ▪ Landscape design and planning;

Item	Risk Description / Element	Potential Impacts and Consequences	Proposed Mitigation Measures
Environmental / Social Risks			
	Land Use ▪ Land use/re-use after construction;	▪ Inadequate use /waster of redundant land after construction works;	▪ Assess options for land use / development after construction works that maximise public amenity;
	Other Risks ▪ Security;	▪ Damage / vandalism to construction sites and equipment; ▪ OH&S risks to workers and the general public;	▪ Security management plan to be developed during construction to restrict public access to worksites;

Item	Risk Description / Element	Potential Impacts and Consequences	Proposed Mitigation Measures
Operating Risks			
	Structural Integrity / Settlement ▪ Settlement; ▪ Building collapse or other structural failures;	▪ Injury or death to maintenance workers or the general public; ▪ Ground settlement, settlement of building foundations and potential cracking/structural damage to building structures; ▪ Damage to electrical assets within the building; ▪ Disruption to businesses and general public amenity.	▪ Building structural design based on interpreted ground conditions and likely permanent groundwater and earth pressure loads during construction; ▪ Building lining to be designed to accommodate all in-service loads; ▪ Structural inspections to be undertaken regularly throughout the operation phase of the building;
	Operating Noise Impacts ▪ Noise from ventilation systems and other operating plant.	▪ Loss of public amenity; ▪ Complaints ▪ Sleep and general public disturbance;	▪ Noise generating operational plant to be designed with acoustic enclosures/dampers, if and where required;
	EMF, Earthing and Electrolysis ▪ Stray currents and electrocution	▪ Public exposure and /or perception to EMF; ▪ Electrocution as a result of stray currents; ▪ Corrosion and/or other damage to assets adjacent to the building and substations;	▪ Design of substation structure based on the principle of prudent avoidance in regard to EMF issues; ▪ Earthing design; ▪ Use of fibre-glass and steel-fibre structural elements and support to mitigate stray currents; ▪ Monitoring of EMF levels during operation.
	Air Quality and Ventilation ▪ Dust and other pollutants from operating ventilation plant systems; ▪ SF6 discharges from substation	▪ General health to the public and workers; ▪ Air pollution; ▪ General public amenity and comfort; ▪ Breach of environmental standards; ▪ Worksite aesthetics; ▪ Public complaints	▪ Design of filtration systems, where required, for operating ventilation systems; ▪ Design locations of ventilation outlets to minimise exposure of nearby residents and businesses. Outlets to be located away from likely or sensitive receivers; ▪ Design of monitoring of SF6 operating systems; ▪ Minimise/exclude the use of polluting generating equipment and materials during maintenance and operating tasks.
	Traffic Management during operation ▪ Disruption to local traffic; ▪ Material / equipment deliveries.	▪ Noise; ▪ Air quality and pollution; ▪ General public safety.	▪ Road closures / local traffic management plans during delivery of major equipment or maintenance tasks; ▪ Major equipment to be delivered during normal operating hours;
	Groundwater Management and Stormwater ▪ Groundwater Chemistry, Treatment and Disposal;	▪ Pollution / contamination of waterways and parklands;	▪ Design of permanent building lining to minimise water ingress; ▪ Design and construction of permanent water treatment plant to treat groundwater before disposal; ▪ Regular maintenance of WTP facilities; ▪ Regular disposal of wastes (eg. sludge) generated from water treatment ▪ Regular monitoring, testing and analysis of water samples during operation.
	Fire / Explosion; ▪ Substation plant and equipmen.	▪ Injury to staff and/or general public; ▪ Damage to electrical infrastructure.	▪ Design of permanent fire systems included in building/substation design; ▪ Monitoring systems included in building/substation design; ▪ Access restrictions to substation facilities; ▪ Minimise / prevent the use of fire generating materials during operation; ▪ Emergency evacuation and response procedures;

Item	Risk Description / Element	Potential Impacts and Consequences	Proposed Mitigation Measures
Operating Risks			
	Cable / Substation Security	▪ Injury to the general public; ▪ Vandalism and other damage to electrical infrastructure;	▪ Design of substations to include security measures to prevent access from unauthorised personnel; ▪ Monitoring of substation entrances; ▪ Operational security management plans to be developed;
	Operational Safety Risks	▪ Injury to the operational / maintenance staff.	▪ Operational safety management plans ▪ General operating PPE; ▪ Emergency evacuation procedures.
	Other Operating Risks ▪ Waste / contamination; ▪ Visual amenity and landscape; ▪ Land use and zoning.	▪ Health and safety of workers and the general public; ▪ Environmental harm and contamination as a result of waste disposal; ▪ General public amenity and complaints.	▪ Operational waste management plans to be developed, including waste disposal protocols; ▪ Urban design of substation and other above-ground structures to take into account general public and visual amenity; ▪ Consider land-use options after construction that maximise public amenity and use.

Item	Risk Description / Element	Potential Impacts and Consequences	Proposed Mitigation Measures
Construction Safety Risks			
	Building Collapse	▪ Injury or death to construction personnel or members of the general public; ▪ Damage to existing underground or above-ground infrastructure.	▪ Geotechnical investigations and analysis; ▪ Building structural design based on interpreted ground conditions and known areas of risk;; ▪ Selection of other specialist equipment to suit likely ground conditions; ▪ Emergency response and evacuation procedures.
	Fire / Explosion / Smoke Management	▪ Injury or death to construction personnel or members of the general public; ▪ Damage to existing underground or above-ground infrastructure.	▪ Fire suppression fire engineered systems to be utilised throughout all construction sites; ▪ Control of hazardous / flammable materials. ▪ Emergency response and evacuation procedures.
	Dust / Air Quality / Ventilation	▪ Injury to construction personnel or members of the general public.	▪ Design of filtration systems, where required, for construction ventilation systems; ▪ Personnel PPE such as dusk masks, re-breathers; ▪ Design of monitoring of SF6 operating systems; ▪ Minimise/exclude the use of polluting generating equipment and materials during construction;
	Access / Egress / Emergency Evacuation	▪ Injury to construction personnel or members of the general public.	▪ Construction Safety Management Plans ▪ Building site safety induction; ▪ Building communication systems; ▪ Emergency response and evacuation procedures.
	Hazardous Materials	▪ Injury to construction personnel or members of the general public.	▪ Safety Management Plan to include protocols/procedures for the control, storage and use of hazardous materials; ▪ Emergency response and evacuation procedures.
	Flooding	▪ Injury to construction personnel or members of the general public.	▪ Temporary drainage and pump systems; ▪ Bunding of surface facilities and structures; ▪ Emergency response and evacuation procedures.
	Traffic /Plant Management	▪ Injury to construction personnel or members of the general public.	▪ Construction traffic management plans; ▪ Safety Management Plans and Induction;
	General OH&S Risks and Management ▪ Tools and equipment; ▪ Trips and falls; ▪ Drugs and Alcohol; ▪ Electrical Hazards /Substation works; ▪ Confined spaces; ▪ Work at Heights.	▪ Injury to construction personnel or members of the general public.	▪ Construction Safety Management Plans; ▪ Construction safety inductions; ▪ Hazard and Risk Assessments; ▪ Safe Work Method Statements; ▪ Emergency response and evacuation procedures.

Appendix H

Air quality and greenhouse gas assessment

REPORT

AIR QUALITY ASSESSMENT FOR ENERGYAUSTRALIA'S SYDNEY CITYGRID PROJECT INCLUDING GREENHOUSE GAS ASSESSMENT FOR THE BELMORE PARK ZONE SUBSTATION

PlanCom Consulting Pty Ltd

17 October 2008 Job 2587

PACIFIC AIR & ENVIRONMENT

A PEI

PROJECT TITLE:	Air Quality Assessment for EnergyAustralia's Sydney Citygrid Project including Greenhouse Gas Assessment for the Belmore Park Zone Substation
JOB NUMBER:	2587
PREPARED FOR:	Julian Ardas PlanCom Consulting Pty Ltd
STATUS:	17 October 2008
PREPARED BY:	Matt Scholl & Kelsey Bawden
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ES1 EXECUTIVE SUMMARY

PlanCom Consulting Pty Ltd (PlanCom) engaged Pacific Air & Environment (PAE) to provide an air quality assessment for the Sydney CityGrid Project including a greenhouse gas assessment for the Belmore Park Zone Substation. The work has been commissioned by EnergyAustralia as part of the contract for "Environmental Planning & Assessment Services for the Sydney CityGrid Project".

To meet licence obligations, cater for future demand and ensure timely replacement of older infrastructure, EnergyAustralia wishes to carry out various and staged new construction works as well as upgrading and refurbishing of existing infrastructure and assets within the Sydney Central Business District (CBD) (the "Project").

The Project will be assessed by the NSW Department of Planning under Part 3A of the Environmental Planning and Assessment Act 1979 (EP&A Act). It will broadly include the following works:

- construction of up to three zone substations (including, if necessary, the demolition and/or refurbishment of existing zone substations and integrated commercial developments constructed on or in conjunction with the zone substations);
- replacement of and upgrades to high voltage cable network; and
- construction of tunnels for the installation of high voltage cables and associated communications infrastructure.

The Project components and required timeframes for delivery are described in Table ES1.1.

Table ES1.1: Project Components and Required Timeframes for Delivery

Project Component	Required Timeframe for Delivery [a]
Extension to the existing City South Cable Tunnel from Wade Place to Riley Street, Surry Hills (approximately 150m)	Mid 2012
Stub tunnel connection from the existing City South Cable Tunnel (nominally 20m below Campbell Street) to Belmore Park Zone Substation	Mid 2012
Belmore Park Zone Substation, encompassing commercial/retail development (at the corner of Pitt, Hay and Campbell Streets	Mid 2012
City East Cable Tunnel (approximately 3.2km) from Riley Street, Surry Hills to Erskine Street, in the northern end of the CBD, inclusive of potential ventilation shaft and Services Control Room at an intermediate point along the alignment	Mid 2015
City East Zone Substation, potentially encompassing commercial/retail development (at a site yet to be determined)	Mid 2015
New Sub-transmission Switching Station (STSS) at Riley Street, Surry Hills, and potentially a tunnel services control and access to the City East Cable Tunnel (in the alternative the control and access would be located at a midway point along the tunnel alignment)	Mid 2015
Potential refurbishment or replacement of the existing Dalley Street Zone Substation or building at a nearby site	2018

[a] pers comm J. Ardas, PlanCom Consulting Pty Ltd, 28/05/2008

The objectives of this study are to consider the potential air quality impacts of the Project during construction and operation and assess whether mitigation is required. Where mitigation is required, appropriate measures are recommended. In addition, the greenhouse gas assessment is provided for the Belmore Park Zone Substation component of the Project.

Air quality was assessed based on an indicative construction activity plan and scheduling sequence, taking into account the location and the context of the surrounding area to determine the potential for exposure and or adverse impacts.

A review of construction equipment and vehicles and materials handling was conducted to identify emission sources from the works.

The main concern for air quality is the potential for emissions of dust and PM_{10} during construction. However, air quality impacts are predicted to be insignificant if best practice dust management procedures are practised. Mitigation measures were proposed to reduce emissions where possible and these recommendations could be included in a Construction Environmental Management Plan (CEMP) for the Project.

Potential for air quality impacts during operation of the Project have also been considered, however there are no predicted adverse impacts on air quality during the operation of the substations and high voltage tunnel.

Direct (Scope 1) greenhouse gas emissions are produced from sources within the boundary of an organisation and as a result of an organisation's activities. Scope 1 greenhouse gas emissions will be generated during construction of the Belmore Park Zone Substation from combustion engines of construction equipment.

During operation of the proposed Belmore Park Zone Substation there is potential for Scope 1 greenhouse gas emissions from leakage or spillage of insulating gas used in transformers and switchgear. These emissions will be minimised by adhering to industry best practice procedures for handling and disposal of the insulation gas, sulfur hexafluoride (SF_6).

Indirect greenhouse gas emissions (Scope 2 & 3) are generated in the wider economy as a consequence of an organisation's activities (particularly from its demand for goods and services), but which are physically produced by the activities of another organisation. The most important category of indirect emissions is from the consumption of electricity.

The greenhouse gas assessment only considers the Belmore Park Zone Substation. Scope 2 emissions from electricity consumption to operate the substation are addressed and emissions from Transmission and Distribution (T&D) losses will be reported by EnergyAustralia elsewhere.

Provided that the appropriate management and mitigation measures are followed the impacts on air quality from the Project and emissions of greenhouse gases from the Belmore Park Zone Substation are considered to be acceptable.

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Abbreviations and Glossary

Term	Definition
μg/m³	Micrograms per cubic metre. A measure of particulate concentration in ambient air.
Air NEPM	National Environment Protection Measure for Ambient Air Quality
AIS	Insulation of air
CBD	Sydney Central Business District
CECT	City East Cable Tunnel
CEMP	Construction Environmental Management Plan
CO	Carbon monoxide
CO_{2-e}	Carbon dioxide equivalents
ENA	Energy Networks Australia
EP&A Act	NSW Department of Planning Environmental Planning and Assessment Act 1979
GIS	Insulation by SF6
GJ	Gigajoules or 1,000,000,000 Joules. A measure of energy.
GHG	Greenhouse gases i.e. carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, perfluorocarbons, hydrofluorocarbons.
GMR	Sydney Greater Metropolitan Region. Area that covers 57,330 km^2, which includes the greater Sydney, Newcastle and Wollongong regions.
GWP	Global warming potential relative to carbon dioxide over a 100 year period.
kg	Kilogram or 1,000 grams. A measure of mass.
kL	Kilolitres or 1,000 litres or cubic metre. A measure of volume.
kV	Kilovolts or 1,000 volts. A measure of the strength of an electrical source.
kWh	Kilowatt hours or 1,000 watt hours.
LCA	Life Cycle Assessment
m^2	Square metres. A measure of area.
m^3	Cubic metre or kilolitre or 1,000 litres. A measure of volume.
MVA	Megavolt amperes
n-2 licence conditions	Design, Reliability & Performance Licensing Conditions by the Minister for Energy for the Sydney CBD by 2014
NGA	National Greenhouse Accounts
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen i.e. nitric oxide (NO) and nitrogen dioxide (NO2)
NSW	New South Wales
NSW DECC	NSW Department of Environment and Climate Change
PAE	Pacific Air & Environment
PlanCom	PlanCom Consulting Pty Ltd
PM_{10}	Particulate matter with an aerodynamic diameter of less than 10 micrometres. Also referred to as fine particulate matter.
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of less than 2.5 micrometres.
ppm	Parts per million (mass basis)
Riley Street STSS	Riley Street Sub Transmission Switching Station
Roadheader	Mechanical excavating machines that have a large rotating cutting head mounted on a moveable boom. They are able to turn tight corners during tunnel construction.
Scope 1 greenhouse gas emissions	Direct emissions produced from sources owned or controlled by the entity.
Scope 2 greenhouse gas emissions	Indirect emissions from the generation of purchased electricity consumed by the entity.
Scope 3	Indirect emissions that are a consequence of the activities of an entity, but which arise

Term	Definition
greenhouse gas emissions	from sources not owned or controlled by that entity (with the exception of electricity generation).
SF_6	Sulfur hexafluoride
SO_2	Sulfur dioxide
STSS	A sub-transmission switching station – generally 132kV (without transformers)
Stub tunnel	A short section of tunnel which links to a main tunnel
t	Tonne or 1,000 kilograms. A measure of mass.
T&D	Transmission and Distribution
TBM	Tunnel Boring Machine
TEOM	Tapered-element oscillating microbalance. An instrument used to measure ambient concentrations of particulate matter.
TSP	Total suspended particulate

1 INTRODUCTION

PlanCom Consulting Pty Ltd (PlanCom) engaged Pacific Air & Environment (PAE) to provide an air quality assessment for the Sydney CityGrid Project including a greenhouse gas assessment for the Belmore Park Zone Substation. The work has been commissioned by EnergyAustralia as part of the contract for "Environmental Planning & Assessment Services for the Sydney CityGrid Project".

To meet licence obligations, cater for future demand and ensure timely replacement of older infrastructure, EnergyAustralia wishes to carry out various and staged new construction works as well as upgrading and refurbishing of existing infrastructure and assets within the Sydney Central Business District (CBD) (the "Project").

The Project will be assessed by the NSW Department of Planning under Part 3A of the Environmental Planning and Assessment Act 1979 (EP&A Act).

1.1 Project Summary

Peak electricity demand in the Sydney CBD is growing at an average rate of 1.7% per annum driven primarily by new residential, hotel and office developments.

EnergyAustralia, over the next 10 years, needs to construct new, or upgrade and refurbish existing, zone substations and replace high voltage cables supplying the substations in order to:

- meet n-2 licence conditions;
- cater for future demand and introduce new technologies that are likely to reduce electricity 'losses' by reducing the resistance of the electricity network; and
- ensure timely replacement of infrastructure which is due for retirement to maintain a reliable supply of electricity for the CBD.

Building works would include the construction of up to three zone substations (including, if necessary, the demolition and/or refurbishment of existing zone substations and would most likely include integrated commercial/retail developments on or in conjunction with the zone substations). The Project also involves the construction of up to three new tunnel sections in the Sydney CBD, and the city fringes, which would 'link' the existing tunnel networks and key zone substations servicing the city together.

1.2 Project components

1.2.1 Sydney CityGrid Project Concept Application

New and/or refurbished substations in the Sydney CBD and a tunnel network for 132 kV cables comprising:

1. Extension to the existing City South Cable Tunnel from Wade Place to Riley Street, Surry Hills (approximately 150m);

2. Stub tunnel connection from the existing City South Cable Tunnel (nominally 20m below Campbell Street) to Belmore Park Zone Substation;

3. Belmore Park Zone Substation, encompassing commercial/retail development (at the corner of Pitt, Hay and Campbell Streets);

4. City East Cable Tunnel (approximately 3.2km) from Riley Street, Surry Hills to Erskine Street, in the northern end of the CBD, inclusive of potential ventilation shaft and Services Control Room at an intermediate point along the alignment;

5. City East Zone Substation, potentially encompassing commercial/retail development (at a site yet to be determined);

6. New Sub-transmission Switching Station (STSS) at Riley Street, Surry Hills, and potentially a tunnel services control and access to the City East Cable Tunnel (in the alternative the control and access would be located at a midway point along the tunnel alignment); and

7. Potential refurbishment or replacement of the existing Dalley Street Zone Substation or building at a nearby site.

1.2.2 Belmore Park Zone Substation Project Application

1. Belmore Park Zone Substation, encompassing commercial/retail development (at the corner of Pitt, Hay and Campbell Streets); and

2. Stub tunnel connection from the existing City South Cable Tunnel (nominally 20m below Campbell Street) to Belmore Park Zone Substation.

Figure 1.1 provides an indicative plan showing the works for the proposed Project.

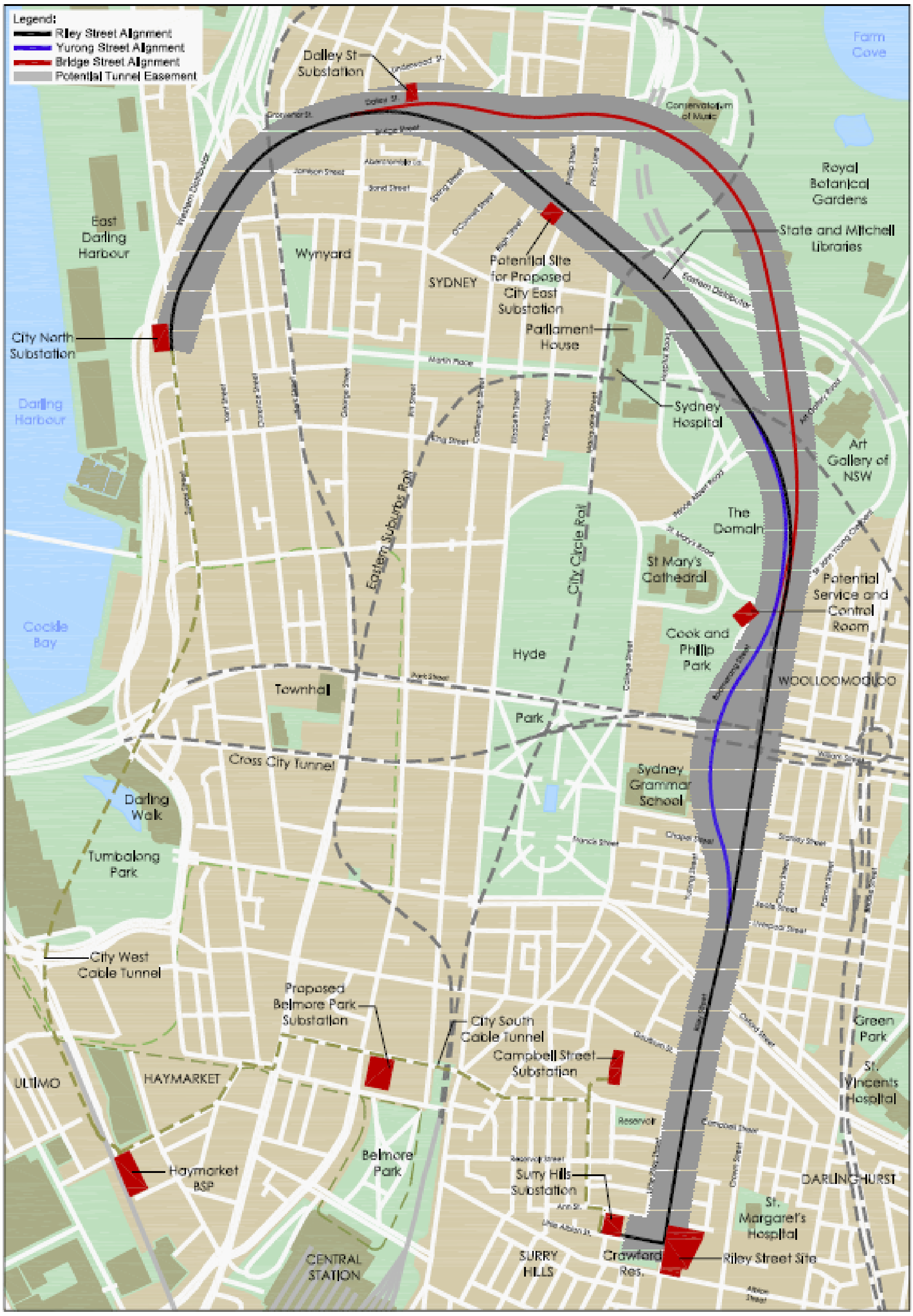

Figure 1.1: Indicative plan showing the works for the proposed Project

The Project components and required timeframes for delivery are described in Table 1.1.

Table 1.1: Project Components and Required Timeframes for Delivery

Project Component	Required Timeframe for Delivery [a]
Extension to the existing City South Cable Tunnel from Wade Place to Riley Street, Surry Hills (approximately 150m)	Mid 2012
Stub tunnel connection from the existing City South Cable Tunnel (nominally 20m below Campbell Street) to Belmore Park Zone Substation	Mid 2012
Belmore Park Zone Substation, encompassing commercial/retail development (at the corner of Pitt, Hay and Campbell Streets	Mid 2012
City East Cable Tunnel (approximately 3.2km) from Riley Street, Surry Hills to Erskine Street, in the northern end of the CBD, inclusive of potential ventilation shaft and Services Control Room at an intermediate point along the alignment	Mid 2015
City East Zone Substation, potentially encompassing commercial/retail development (at a site yet to be determined)	Mid 2015
New Sub-transmission Switching Station (STSS) at Riley Street, Surry Hills, and potentially a tunnel services control and access to the City East Cable Tunnel (in the alternative the control and access would be located at a midway point along the tunnel alignment)	Mid 2015
Potential refurbishment or replacement of the existing Dalley Street Zone Substation or building at a nearby site	2018

[a] pers comm J. Ardas, PlanCom Consulting Pty Ltd, 28/05/2008

1.3 Study Objectives

In terms of air quality the objectives of the study are to consider the potential impacts of the Project during construction and operation, including excavation works, construction of tunnels and demolition and/or construction or refurbishment of the substations and assess whether mitigation is required. Where mitigation is required then appropriate measures are recommended.

The objective of this study with respect to greenhouse gases is to assess emissions from the Belmore Park Zone Substation component of the Project during the construction and operation of the substation and the stub tunnel. Where information is not yet available in detail, a qualitative assessment is provided.

2 STUDY APPROACH

2.1 Air Quality

Air quality was assessed based on an indicative construction activity plan and scheduling sequence, taking into account the location and the context of the surrounding area to determine the potential for exposure and or adverse impacts.

A review of construction equipment and vehicles and materials handling was conducted to identify emission sources from the works.

Mitigation measures were proposed to reduce emissions where possible and these recommendations could be included in a Construction Environmental Management Plan (CEMP) for the Project.

Potential for air quality impacts during operation of the Project have also been considered.

2.2 Greenhouse Gases

Direct (Scope 1) greenhouse gas emissions are produced from sources within the boundary of an organisation and as a result of an organisation's activities.

Scope 1 greenhouse gas emissions will be generated during construction of the Belmore Park Zone Substation from combustion engines of construction equipment.

During operation of the proposed Belmore Park Zone Substation there is potential for Scope 1 greenhouse gas emissions from leakage of insulating gas from transformers and switch gear.

Indirect greenhouse gas emissions (Scope 2 & 3) are generated in the wider economy as a consequence of an organisation's activities (particularly from its demand for goods and services), but which are physically produced by the activities of another organisation. The most important category of indirect emissions is from the consumption of electricity. Scope 2 emissions are allocated to the organisation that owns or controls the plant or equipment where the electricity is consumed. Usually, the electricity consumer reports only the emissions from the electricity they use under Scope 2, and reports emissions associated with transmission and distribution (T&D) losses under Scope 3. However, companies that own or control T&D networks, i.e. EnergyAustralia, report emissions associated with all T&D losses on their networks under Scope 2.

This assessment only considers the Belmore Park Zone Substation. Scope 2 emissions from electricity consumption to operate the substation are addressed and emissions from T&D losses will be reported by EnergyAustralia elsewhere.

Where activity data are available, emissions are assessed using emission factors outlined by the *National Greenhouse Accounts (NGA) Factors (2008)*, which are published by the Australian Government Department of Climate Change. Activity data were provided by EnergyAustralia.

3 EMISSIONS TO AIR

3.1 Sources of Emissions

There is potential for emissions of combustion gases and dust to be generated during demolition and construction works of the existing zone substations and integrated commercial developments as well as during excavation and tunnelling construction works and spoil handling activities.

During operation of the substation, there is potential for Scope 1 greenhouse gas emissions of sulfur hexafluoride (SF_6) to be released via leakage from gas insulated transformers and other switchgear and circuit breaker applications.

During operation of the substation, emissions from electricity used to power the substation are considered as indirect (Scope 2) greenhouse gas emissions.

3.2 Pollutants of Interest

The main pollutants of interest are total suspended particulates (TSP) and particulate matter less than 10 micrometres in aerodynamic diameter (PM_{10}) that may be emitted due to the proposed demolition and construction works.

Combustion emissions, i.e. oxides of nitrogen (NO_X), fine particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide (CO) and sulfur dioxide (SO_2) from construction vehicles are also likely to be released.

During operation of the Belmore Park Zone Substation there is also potential for emissions of sulfur hexafluoride (SF_6) from gas insulated transformers and other switchgear and circuit breaker applications. SF_6 is a highly potent greenhouse gas. Its global warming potential (GWP) is 23,900, which means that over a 100-year period, SF_6 is 23,900 times more effective at trapping infrared radiation than an equivalent amount of carbon dioxide. With an atmospheric lifetime of 3,200 years, SF_6 is also a very stable chemical. Therefore, due to its long lifespan and high potency, even a relatively small amount of SF_6 can have a significant impact on global climate change.

Apart from its use as an insulating medium in the electricity transmission industry, SF_6 is also used as a cover gas in the magnesium industry, for plasma etching in semiconductor manufacturing, as a reactive gas in aluminium recycling to reduce porosity, as thermal and sound insulation and in atmospheric tracer studies and medical applications.

4 EXISTING AIR QUALITY

This section provides an overview of existing air quality in Sydney. These summaries for pollutants are from a technical paper provided by the NSW DECC, providing a review of air quality in NSW to support the Clean Air Forum 2007 (NSW DECC, 2007).

Air quality has been monitored in Sydney since the early 1950s. The NSW DECC operates a comprehensive state-wide air quality monitoring network comprising sites throughout NSW, with particular focus on the main population centres of Sydney, the lower Hunter and the Illawarra. The information provided below is based on monitoring data from that network.

4.1 Carbon monoxide

Carbon monoxide (CO) is currently monitored at five stations in the Sydney region (Chullora, Liverpool, Macarthur, Prospect and Rozelle).

The Sydney CBD station was the longest established station, with over 20 years of data and was the only station where high levels of CO were detected. It was located on George Street at a height just above that of bus and truck exhaust pipes and within an urban canyon typified by poor dispersion. Thus, the station was considered a peak site, likely to record the greatest concentrations of CO in the Sydney region. It was closed in 2004 following six years without recording an exceedance.

During the 1980s, CO concentrations in the CBD exceeded the standard on up to 109 days per year and the maximum level of 26.7 parts per million (ppm) was almost three times the standard.

Since the introduction of unleaded petrol and catalytic converters in 1985, peak CO levels in the CBD have plummeted. The last exceedance of the CO standard in NSW was recorded there in 1998, and since 2002, maximum 8-hour concentrations have been half the standard.

Apart from at the CBD monitoring station, levels of CO at other stations have never exceeded the standard and have fallen considerably over the past 13 years. The maximum recorded values in these areas are now typically less than 30% of the standard.

The National Environment Protection Measure for Ambient Air Quality (Air NEPM) standard for CO is no longer exceeded anywhere within the monitoring network in NSW.

4.2 Lead

Lead was measured at three sites in Sydney (the CBD, Earlwood and Rozelle) for over 20 years, until 2004. DECC began phasing out ambient lead monitoring for the Air NEPM during 2004, and all lead monitoring ceased from 1 January 2005.

The introduction of unleaded petrol in 1985, the progressive reduction of the lead content of petrol and the subsequent ban on lead in petrol from 2002 have reduced ambient concentrations of atmospheric lead in Sydney. Lead levels today are well below the Air NEPM standard of 0.5 micrograms per cubic metre (µg/m^3). Annual averages throughout NSW are now typically less than 0.03 µg/m^3 and many 24-hour average samples are below the minimum detection limit.

4.3 Nitrogen dioxide

In Sydney, the largest source of oxides of nitrogen (NO_X) emissions is on-road vehicles, which contribute over 71% of total NO_X emissions.

NO_X has been monitored continuously in NSW since the 1970s. NO_X is currently measured at 14 sites in Sydney.

During the 1980s, exceedances of the 1-hour nitrogen dioxide (NO_2) standard were common in Sydney, particularly during winter. Since then levels have fallen substantially, and the 1-hour standard has not been exceeded in Sydney since 1998. Maximum 1-hour concentrations are now well below the standard and annual average concentrations are typically less than 50% of the standard.

NSW has met the Air NEPM goal for NO_2, which allows for one exceedance per year, since 1994. The last exceedance of the 1-hour standard was recorded during 1998. Current maximum NO_2 concentrations are well below both the 1-hour and annual standards.

NO_X emissions from motor vehicles have fallen as a result of improvements to fuel and vehicle emissions standards. Emissions of NO_X from individual motor vehicles are predicted to continue falling as stricter vehicle emissions standards are introduced. However, some of these gains are countered by the increasing number of vehicles and vehicle-kilometres travelled.

4.4 Sulfur dioxide

Sulfur dioxide (SO_2) is monitored at eight stations in the Sydney region (Bargo, Bringelly, Chullora, Macarthur, Prospect, Randwick, Richmond and Vineyard).

There has never been a recorded exceedance of the 24-hour or annual SO_2 standard in NSW. Typically, maximum 24-hour averages range between 8% and 12% of the standard, and maximum annual averages range between 5% and 10% of that standard.

In Sydney, no exceedances of the 1-hour SO_2 standard have ever been recorded. The maximum 1-hour concentrations are typically less than 20% and less than 30%, respectively, of the standard.

Historically, with the exception of stations located close to major industrial sources, SO_2 levels in NSW have been significantly below the Air NEPM standards.

SO_2 levels are well below the standards and are expected to remain low.

4.5 Fine particles

There are many sources of particles in the air, arising from both natural processes and human activity. The dominant source of PM_{10} from human activity in Sydney is industry (37%), but domestic sources and on-road mobile sources make up a greater proportion of PM_{10} emissions in Sydney than in the rest of NSW.

The annual domestic sector contribution to PM_{10} emissions in Sydney comes largely from wood heating (93%). Wood heating provides a good example of the seasonal variation in emissions. In Sydney, wood heaters account for 3% of total PM_{10} particle emissions in summer (January weekday), but 43% in winter (July weekday).

In rural areas, broadacre agricultural activities (e.g. stubble burning and cultivation) and the use of solid fuels for heating and cooking are the major anthropogenic sources of particles.

Emissions from natural events, such as bushfires and dust storms, also contribute significantly to fine particle levels in NSW. Almost 20% of PM_{10} emissions in the Sydney Greater Metropolitan Region (GMR) come from agricultural burning, bushfires, prescribed burning and windborne dust.

Particles less than 10 µm in diameter (PM_{10}) and less than 2.5 µm in diameter ($PM_{2.5}$) are measured in NSW by using tapered-element oscillating microbalance (TEOM) instruments, which provide continuous, real-time particle mass measurement.

At present there is no Australian Standard method for measuring $PM_{2.5}$. A national program, the $PM_{2.5}$ Equivalence Program, is assessing the accuracy and precision of various $PM_{2.5}$ instruments. The Air NEPM $PM_{2.5}$ advisory reporting standards of 25 and 8 µg/m3 for 24-hour and annual averages are not based on $PM_{2.5}$ data measured by TEOM instruments.

In NSW, the highest exposure to fine particles occurs during severe bushfires and dust storms. During these events, peak PM_{10} and $PM_{2.5}$ levels can greatly exceed the relevant standards or goals. These events are also responsible for the greatest spatial extent (dust storms) and longest exposure to elevated levels (severe bushfires) of fine particles in NSW.

The highest ever recorded 24-hour average PM_{10} level in NSW was 921.4 µg/m^3, recorded at Albury during the severe dust storm of 19–20 March 2003. This was an extreme event that resulted in a peak concentration more than 18 times the Air NEPM standard. This same event also resulted in the highest PM_{10} levels ever recorded in Sydney.

There is a strong seasonality to PM_{10} levels. In Sydney, the majority of exceedances occur in spring and summer (81%).

The use of solid-fuel heaters, particularly older, inefficient models, during winter can be a significant source of fine particle emissions. However, winter exceedances in Sydney occur on average less than 1 day per year.

The few exceedances of the PM_{10} standard in Sydney during winter are usually localised events. Of the ten winter exceedance days from 1994 to 2006, nine were days when an exceedance was recorded at a single monitoring station. In autumn, half of the exceedances were single-station events.

In contrast, during summer, more than two thirds of PM_{10} exceedances in Sydney are multiple-station events, indicating that these events are more likely to be widespread or regional-scale. The events may be influenced by bushfires or dust storms, or they could be indicative of secondary particles produced during the formation of photochemical smog.

Exceedances of fine particle standards are common in NSW. Exceedances of the PM_{10} standard have been recorded in all monitored regions. Levels above the $PM_{2.5}$ Air NEPM standard are regularly recorded in the GMR. Since 1994 there has been no significant improvement in fine particle levels in the GMR.

There is significant seasonality to particle levels in NSW. PM_{10} exceedances occur most often in the warmer months and days above the $PM_{2.5}$ advisory reporting standard peak in winter and summer. The $PM_{2.5}$ advisory reporting strandard are exceeded more often than the PM_{10} standard.

Although background levels of fine particles in Sydney increase during the cooler months, exceedances of fine particle standards in winter are primarily local events.

Exceedances of the PM_{10} standard are common in NSW during the warmer months. Extreme values, many times greater than the standard, have been recorded. These extreme levels are the result of natural events such as dust storms and bushfires. The severe drought conditions experienced across NSW over the past few years have contributed to an increased incidence of PM_{10} levels above the standard.

5 ASSESSMENT

5.1 Air Quality

5.1.1 Construction

Excavation of shafts (for access to tunnelling operations and to remove spoil material) is required at a number of locations at different phases throughout the proposed Project. Shaft excavations and spoil removal will involve surface earthworks and construction and materials handling activities, which have potential to generate dust emissions. However, disturbed surface areas around access shafts would be maintained to an area as small as possible and most likely between 20 m^2 and 50 m^2. Dust emissions from these areas are predicted to be negligible when managed appropriately and would have localised impacts only, if any. Exposed surface areas will be managed via dust mitigation measures such as those provided in Section 6.1.1 of this report.

Table 5.1 provides the proposed locations and estimated amounts of spoil to be removed during the Sydney CityGrid Project. Note that these items of work will be conducted in phases and mitigation measures will be focussed on each phase as it is conducted. An indicative construction program is further detailed in Appendix A.1.

Table 5.1: Locations of shafts and estimated amount of spoil material removed during the Project[a]

Description	Location of Spoil Removal	Estimated Spoil Quantity (m^3)[b]
Belmore Park Zone Substation	Belmore Park Substation works	47,250
Belmore Park Commercial	Belmore Park Commercial works	23,250
Stub Tunnel to CSCT	Campbell Street	963
Riley Street STSS	Bulk excavation of entire site	42,000
CECT Launch Cavern	Riley Street Site	3,000
CBD Tunnel Extension	Riley Street Site	3,543
City East Cable Tunnel	Riley Street Site	57,000
Potential Stub Tunnels (x3)	From shaft locations	5,670
Underwood St Shaft	Underwood Street (or potentially Gresham Street)	1,620
Yurong Street Shaft	Yurong St / Sir John Young Cres	3,240
City East Shaft	City East Zone Substation Location	3,240
Surface Works (General)	Around Dalley , Bent, Bridge and Gresham Streets	3,480
Contingency	Various	3,606
	Total	**197,862**

a Source: pers comm J. Ardas, PlanCom Consulting Pty Ltd, 28/05/2008 & 03/10/2008.
b Allows for a 50% bulking factor.

Preparation of the site for construction of the Belmore Park Zone Substation and Riley Street Sub Transmission Switching Station (STSS) would also create disturbed surface areas with potential to cause dust emissions. However, if the construction site for the Belmore Park Zone Substation is managed using dust mitigation measures such as those provided in Section 6.1.1 of this report, it is expected to cause negligible dust impacts.

Excavation in the tunnel using a roadheader and/or a Tunnel Boring Machine (TBM) would generate dust at the working face and during handling and transport of spoil material. Both types of tunnelling machines use cutting or cooling fluid, predominantly water, which would reduce the amount of dust generated. The tunnel would be mechanically ventilated to ensure that clean air is available to workers in the tunnel. During the construction period, dust laden air from the tunnel would be treated via a filtration system to remove dust particles before the air is exhausted from the tunnel. The design of the filtration system would meet the requirements of the *Protection of the Environment Operations (Clean Air) Regulation 2002* (as amended) and the filtration system would control any dust emissions at acceptable levels.

Spoil material would be stockpiled and loaded into trucks after being removed from the tunnel via the access shafts. The majority of the spoil would be removed via the Riley Street site. It should be noted that Riley Street site is an excavated area, where the low point is approximately 10 metres deep. Loading of spoil into trucks for transport off-site will occur at the low point of the site, which will help to reduce potential dust impacts on nearby receptors. The depth of the site will help to protect the loading operations from wind and if dust emissions are generated, then a higher proportion is likely to resettle within the site than if the site was exposed. In addition, dust emissions from loading and transporting of spoil material would be minimised by adhering to management and mitigation procedures such as those outlined in Section 6.1.1 of this report.

Combustion emissions will be emitted from the construction equipment and transport vehicles used during construction. Appendix A.1 provides further detail of the indicative vehicle and construction equipment to be used, as well as the approximate number of movements for spoil transport and the proposed construction schedule. At the peak of construction activity for the Project a TBM, general delivery vehicles, spoil trucks, semi-trailers (for concrete segment delivery), grout rig, gantry crane, front-end loader, excavator, dump truck and general tools and equipment may be operating simultaneously, which could include up to 20 truck movements a day. Combustion emissions from the proposed Project activities are considered to have insignificant impact on air quality when compared to emissions from existing sources in the area such as motor vehicles on nearby roads.

The main pollutants of concern during construction activities for the proposed Project are TSP and PM_{10} from dust generating construction activities. These emissions are not expected to cause adverse impacts provided that management and mitigation practices are adhered to, as outlined in Section 6.1.1 of this report.

5.1.2 Operation

During operation, the high voltage cable tunnel would be ventilated through a tunnel air intake located near St Mary's Road (opposite the Domain) or from the Riley Street STSS and out of the existing ventilation exhaust at the City North Substation.

Air emissions during operation would be clean air and adverse air quality impacts are not expected.

5.2 Greenhouse Gas

5.2.1 Combustion

During construction, greenhouse gases will be emitted from combustion in engines of construction equipment and vehicles. When the construction phase of the Project is conducted, EnergyAustralia will be required to report these emissions under the *National Greenhouse and Energy Reporting Act 2007* if they trigger the reporting requirements.

Emission factors and equations for calculating greenhouse gas emissions from automotive fuel use are provided in the *National Greenhouse Accounts (NGA) Factors (2008)*. The activity data required is the amount of fuels used. The following fuel combustion estimates were provided by EnergyAustralia (pers comm J. Ardas, PlanCom, 02/07/08):

- During the bulk excavation approximately 300 litres of diesel per day for approximately 200 days (i.e. 60,000 litres).
- During the building works approximately 50 litres of diesel per day for approximately 560 days (i.e. 28,000 litres).

Estimated greenhouse gas emissions from the combustion of diesel in construction equipment are as follows:

- Scope 1 GHG Emissions (t) = Activity (kL) x Energy Content of Fuel (GJ/kL) x EF (kg $CO_{2\text{-}e}$/GJ)/1000 = (88 x 38.6 x 69.5)/1000= 236 tonnes $CO_{2\text{-}e.}$
- Scope 3 GHG Emissions (t) = Activity (kL) x Energy Content of Fuel (GJ/t) x EF (kg $CO_{2\text{-}e}$/GJ) /1000 = (88 x 38.6 x 5.3)/1000= 18 tonnes $CO_{2\text{-}e.}$

5.2.2 Insulation Gas

SF_6 gas which is contained in the gas insulated transformers and other switchgear is non-toxic and typically held in relatively small quantities within the switch room. The switchgear is very reliable equipment and therefore the risk of gas leakage is extremely low. However, should a major leak occur, gas leakage alarms and an appropriately designed ventilation system would ensure the safety of personnel. As the gas is non-toxic, there is no exposure limit.

However, due to its high global warming potential (GWP) and its long atmospheric lifetime, SF_6 gas is included in the greenhouse gases of the Kyoto protocol.

During construction of the substation there would be no SF_6 onsite. SF_6 gas would be added to equipment during the commissioning stage (under strict handling procedures) and equipment is also emptied onsite for maintenance, recycling or destruction.

Therefore, since this greenhouse gas assessment is for the Belmore Park Zone Substation only, the potential for SF_6 emissions to atmosphere are:

- as spillage during filling or maintenance of insulation gas to the transformers or other switchgear;
- as leakage during operation; or
- as spillage during decommissioning of the equipment.

Emission factors and equations for calculating greenhouse gas emissions from gas insulated switchgear and circuit breaker applications are provided in the *National Greenhouse Accounts (NGA) Factors (2008).*

Calculation of emissions from SF_6 leakage from the operation of transformers and switchgear

The Belmore Park Zone Substation will use 5 transformers (each using 1,000 kg SF_6) and 16 gas insulated circuit breakers (each using 120 kg SF_6). Therefore total amount of SF_6 in operation on site is 6,920 kg.

Applying the annual leakage rate of 0.005 (i.e. 0.5%) gives:

- An annual loss of SF_6 (kg) = 0.005 x 6,920 kg = 34.6 kg of SF_6.
- Multiplying the 34.6 kg of SF_6 by its GWP of 23,900 gives a total annual emission of approximately 827 tonnes of CO_{2-e}.

Emissions of any spills would be calculated using the same emission factors and equations. However, this should not be required if appropriate methods and procedures are followed to eliminate the risk of spills.

It should be noted that this assessment has identified only those emissions from the Belmore Park Zone Substation. A full environmental Life Cycle Assessment (LCA) of gas insulated switchgear would also take into account other factors such as energy losses across the network, longer operating life of gas insulated gear compared with air insulated gear as well as disposal methods and procedures of decommissioning equipment.

Literature on SF_6 emissions from the electricity transmission and distribution industry supports the idea that gas insulated switchgear has better overall environmental performance than air insulated systems, as outlined in the following extract from Bessede et al (2004).

> *[Bessede et al. (2004)] "The relative contribution of SF_6 to man-made global warming effect can be calculated by taking into account the SF_6 concentration in the atmosphere and its GWP. This value is approximately 0.1%* (from all industries)*. When searching only the SF_6 gas coming from the world electrical industry, many people estimated it at 0.012%.*
>
> *On another hand, many attempts have been done to evaluate the environmental impact of SF_6 from electrical equipment via environmental Life Cycle Assessment (LCA). For example, when considering the LCA of High Voltage Circuit Breakers, it has been proven that SF_6 losses due to leakage in service or during manufacturing and commissioning are not the major contributors to Global Warming. In fact, most of the global warming impact is due to the energy losses during the life of the apparatus. On a more global approach, full LCA of Medium Voltage networks has been done. For example,*

the impact of AIS (insulation by air) and GIS (insulation by SF_6) products included in rural or urban networks were studied. These studies showed that the total environmental impact of AIS is higher than for GIS equipment (using SF6). Moreover, it was made clear that in such networks, the switchgear represents less than 10% of the total networks Global Warming impact, which is again mostly due, to the energy losses within the network."

There is also much emphasis directed at maintenance of equipment and improving disposal methods of decommissioned equipment since leakage after disposal is considered to be by far the highest contributor to SF_6 emissions from gas insulated switchgear and transformers. These issues are highlighted by the following extracts from Weston (2007) and Bessede et al. (2006) below.

[Weston (2007)] "Any mass balance approach must consider the much higher contributions of emissions from decommissioned equipment that is no longer monitored for gas loss as with equipment in service. These emissions far exceed any estimates of industry emissions percentages based on manufacturer's leakage rates (default loss rate 0.5%). As with other pollutants, responsibility should rest with the owner of the equipment, regardless of its operational status, until such time as it has been appropriately reclaimed and recycled or destroyed and documented."

[Bessede et al. (2006)] "...some losses occur when the switchgear is filled and tested, but the primary source of SF_6 gas releases are leaks from aging SF_6 gas-insulated switchgear."

The peak industry body for the Australian electricity distribution and networks industry, Energy Networks Australia (ENA), currently estimates SF_6 emission levels for the whole Australian sector to be approximately 21.8 tonnes per annum (ENA, 2008).

5.2.3 Electricity

Electricity used to run the Belmore Park Zone Substation would be considered as Scope 2 and emissions attributable to upstream energy production are considered as Scope 3, indirect greenhouse gas emissions. Emission factors and equations for calculating greenhouse gas emissions from electricity from the grid are provided in the *National Greenhouse Accounts (NGA) Factors (2008).* Note that transmission and distribution losses are reported by energy distributors elsewhere as Scope 2 emissions.

The estimated annual electricity consumption for Belmore Park is 14,000 kWh (pers comm J. Ardas, PlanCom, 02/07/08). Therefore, estimated emissions from electricity consumption are as follows:

- Scope 2 GHG Emissions (t $CO_{2\text{-}e}$) = (14,000 x 0.89 / 1000 = 12.5 tonnes per annum.
- Scope 3 GHG Emissions (t $CO_{2\text{-}e}$) = (14,000 x 0.085 / 1000 = 1.2 tonnes per annum.

6 MITIGATION MEASURES

6.1 Air Quality

6.1.1 Construction

An indicative construction program for the Sydney CityGrid Project is provided in Appendix A.1.

It should be noted that the construction phases of the Project will be staged over a timeframe of up to 10 years and potential impacts can be appropriately managed and mitigated.

It is not expected that any significant impacts will be experienced during construction. However, the following mitigation measures should be observed during demolition and construction, in order to minimise impacts as much as possible.

Demolition

- Sheet and screen buildings with suitable material and where possible strip inside buildings before demolition begins.
- Ensure that any asbestos is removed by a specialist contractor before demolition.
- Waste or materials for recycling should be removed from site as soon as possible. If stored, techniques to avoid emissions should be employed.
- Avoid explosive blasting where possible and consider using appropriate hand or mechanical alternatives.
- Bag and remove any biological debris or damp down before demolition.

Construction

- Access to construction sites would be via existing sealed roadways and the surface of trafficked areas within sites shall be sealed with bitumen or gravel.
- Wheels of all site plant and vehicles would be cleaned so that material with potential to generate dust is not spread on surrounding roads.
- Sealed roads around construction sites would be swept to remove deposited material with potential to generate dust, if necessary.
- Water shall be used to suppress particles potentially generated during the erection of boundary fences, barriers, screens and other ancillary structures.
- Areas of disturbed soils would be minimised during the construction period.
- Water may be used to suppress dust emissions during dry windy periods (as required).
- The height from which dust generating material is dropped would be minimised.

- Loaded trucks carrying spoil shall be covered at all times.
- The cutting/grinding of materials on site shall be kept to a minimum, but if necessary equipment and techniques to minimise dust will be used.
- Earthworks will be kept damp, as required, especially during dry weather.
- The tunnelling excavation face will be kept damp, as required, to minimise dust generation.
- Spoil stockpiles will be damped as necessary.
- Longer term spoil stockpiles would be treated with surface binding agents or sealed by seeding with vegetation or covered with secured tarpaulins.
- Potentially dusty materials will be handled as little as possible.
- Exhaust emissions will not discharge straight at the ground.
- Construction plant and vehicles will be well maintained and regularly serviced. Visible smoke from plant should be avoided. Defective plant will not be used.
- Engines will be switched off when vehicles are not in use and refuelling areas will be away from areas of public access.
- Loading and unloading will take place within the site.
- All waste will be removed from site and disposed to an appropriately licensed waste facility.
- A CEMP would also be prepared for the construction phase, specifically addressing measures to be implemented to minimise off-site dust emissions.

6.1.2 Operation

There are no adverse impacts on air quality predicted due to the operation of the proposed Project. Mitigation measures for air quality during operation of electricity substations and high voltage tunnels are therefore not required. The operation of the tunnel ventilation system is unlikely to adversely affect air quality in the vicinity of the City North Zone Substation, and as such, mitigation measures are not required.

6.2 Greenhouse Gases

Any measures to reduce fuel use or improve energy efficiency would reduce emissions of greenhouse gases due to combustion.

Options for mitigating SF_6 gas from the Belmore Park Zone Substation that are within EnergyAustralia's control are focussed on best practice monitoring of leakage during operation, maintenance and end of life dismantling procedures.

Avoiding leakages during operation requires attention to the type of gaskets used in the equipment. Leakages during operations occur as gaskets age and harden with use, suffer from chemical attack and corrode. Equipment suppliers should fully evaluate the proposed environment and assess the appropriateness of gasket types for the operating life of the gas insulated transformers and switchgear.

Methods for improving leak detection monitoring and handling of SF_6 gas during operations and maintenance would also minimise emissions.

The management of the end of life gas insulated equipment should follow industry best practice guidelines. In particular, the treatment of SF_6 gas for recycling, i.e. ‘cradle to cradle’, or if the contamination due to arc switching is too high, from ‘cradle to grave’ should be managed.

Currently there are no ‘whole of industry’ best practice guidelines for SF_6 management within the Australian transmission or distribution network industry. The electricity distribution network industry via the peak body, Energy Networks Association, is currently developing a Guideline for the Management of SF_6.

The development of SF_6 management guidelines will assist the industry to reduce emissions of SF_6, by ensuring that all aspects of SF_6 management are addressed in a consistent manner by individual utilities. This will provide an opportunity for the Australian electricity industry, both through better handling practices and more reliable reporting, to reduce SF_6 emissions from the current estimated emissions level of 21.8 tonnes per annum (ENA, 2008).

If ENA decide to progress the Guideline, it could be completed in 2008.

7 CONCLUSIONS

This assessment has considered potential air quality impacts associated with EnergyAustralia's proposed Sydney CityGrid Project including a greenhouse gas assessment for the Belmore Park Zone Substation.

The main concern for air quality is the potential for emissions of dust and PM_{10} during construction. However, air quality impacts are predicted to be insignificant if best practice dust management procedures are practised. No further air quality assessment is required.

There are no predicted adverse impacts on air quality during the operation of the substations and high voltage tunnel.

There is potential for greenhouse gas emissions from the Belmore Park Zone Substation from combustion during construction and from leakage or spillage of insulating gas (used in transformers and switchgear) during operation, maintenance and decommissioning of equipment. Emissions of greenhouse gases will be minimised by adhering to industry best practice procedures for handling and disposal of the insulation gas, SF_6.

Provided that the appropriate management and mitigation measures are followed the impacts on air quality from the Project and emissions of greenhouse gases from the Belmore Park Zone Substation are considered to be acceptable.

8 REFERENCES

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Appendix A

Indicative CityGrid Project Construction Program

A.1 INDICATIVE CITYGRID PROJECT CONSTRUCTION PROGRAM

Construction Activity	Typical Equipment	Approximate Timing	Estimated Truck Movements (per day)
Establishment of Belmore Park Zone Substation	Mobile crane, trucks with work sheds, concrete trucks	Feb 2009	1-2 deliveries per day
Belmore Park Zone Substation site preparation (erect hoarding, service discon, site survey, services diversion	Saw cutting concrete, bitumen, backhoe, 10 truck, concrete truck, traffic control, air compressors, jack hammers	Mar 2009	1-2 deliveries per day plus truck movements
Belmore Park Zone Substation bulk excavation	Drill rig, trucks to remove spoil, concrete pumps, D7 bulldozer, rock saws, rock hammers, semi trailer trucks to remove spoil, rock anchor drills, shot crete	Mar 2009 – Dec 2009	1-2 deliveries per day plus peak of 20 spoil truck movements per day
Belmore Park Zone Substation construction of 13 levels combined substation and commercial site, commencement of zone development	Crane, scaffolding, concrete pumps, concrete vibrators, concrete delivery trucks, placement of steel reinforcement, builders lift, builders hoist, scabbling, air compressor, jack hammers, concrete/bitumen saw cutting	Jan 2010 – April 2010	1-2 deliveries per day plus peak of 20 spoil truck movements per day
Establishment of Riley St site and Preliminary Construction Activities	Power tools, concrete saws, rock hammers, excavator, concrete agitator and pump, delivery vehicles, crane.	Jun 2010 – Sep 2010	General deliveries of the period, approximately 1 per day.
Excavate TBM entry cavern and CBD Cable Tunnel Extension	Roadheader, gantry crane, delivery vehicles, spoil trucks, excavator, dump truck, front-end loader, power tools, ventilation fan.	Sep 2010 – Mar 2011	1-2 deliveries per day. 4-5 spoil trucks per day.
Construct lining for CBD Cable Tunnel Extension and Tunnel fitout.	Delivery vehicles, concrete agitator and pump, power tools and general equipment, ventilation fan.	Mar 2011 – May 2011	1-2 concrete deliveries per day during Apr 2011.
Mobilise and assemble TBM	TBM, gantry crane, delivery vehicles, front-end loader.	Feb 2011 – Mar 2011	Included above.
Excavate TBM Tunnel between Riley Street and City North.	TBM, general delivery vehicles, spoil trucks, semi-trailers (concrete segment delivery), grout rig, gantry crane, ventilation fan, front-end loader, excavator, dump truck, general tools and equipment.	Apr 2011 – Jun 2012	Segment Delivery – 5 trucks/day for approx 200 days. Spoil removal – 10-15 trucks/day.

Construction Activity	Typical Equipment	Approximate Timing	Estimated Truck Movements (per day)
Remove TBM backup assembly and demobilise	Gantry crane, transport vehicles, general plant and equipment.	Jul 2012	General construction traffic only.
TBM Tunnel Fitout	Delivery vehicles, power tools, gantry crane, ventilation fan, general plant and equipment.	Aug 2012 – Jul 2013	1-2 trucks every 3 days.
Services Shaft and stub tunnel (if required)	Boring rig, concrete agitator and pump, delivery vehicles, spoil trucks, power tools, excavator, front-end loader, roadheader, dump truck and crane.	Aug 2011 – Nov 2011	2-3 trucks per day for spoil removal plus general deliveries.
City East Shaft and stub tunnel (if required)	Boring rig, concrete agitator and pump, delivery vehicles, spoil trucks, power tools, excavator, front-end loader, roadheader, dump truck and crane.	Dec 2011 – Mar 2012	2-3 trucks per day for spoil removal plus general deliveries.
Dalley Street Shaft and stub tunnel.	Boring rig, concrete agitator and pump, delivery vehicles, spoil trucks, power tools, excavator, front-end loader, roadheader, dump truck and crane.	Apr 2012 – Jul 2012	2-3 trucks per day for spoil removal plus general deliveries.
General Surface Works (cable trenching around Dalley, Gresham, Bent Streets)	Excavator, spoil truck, delivery vehicles, concrete agitator and pump, asphalting.	Aug 2012 – Jan 2013	1-2 trucks / day.
Construct Riley Street Services Control Room and tunnel connections	Power tools, concrete agitator and pump, delivery vehicles.	Aug 2013 – Dec 2013	1-2 per day – general deliveries only.
Fitout Riley Street Services Control Room	Power tools, crane, delivery vehicles.	Jan 2014 – Apr 2014	1-2 per day – general deliveries only.
Reinstate Riley Street Site and Demobilise	Excavator, front-end loader, delivery vehicles, power tools.	May 2014 – Jun 2014	1 truck / day.
132kV Cable Installation	Cranes, semi trailers, delivery vehicles	Jun 2012 – Mar 2013	Semi trailer and crane (cable delivery) – once every 3 weeks. General deliveries over the period.
132kV Cable Installation	Cranes, semi trailers, delivery vehicles	Jan 2014 – Mar 2014	Semi trailer and crane (cable delivery) – once every 3 weeks. General deliveries over the period.
132kV Cable Installation	Cranes, semi trailers, delivery vehicles	Jan 2016 – Jun 2016	Semi trailer and crane (cable delivery) – once every 3 weeks. General deliveries over the period.

Construction Activity	Typical Equipment	Approximate Timing	Estimated Truck Movements (per day)
132kV Cable Installation	Cranes, semi trailers, delivery vehicles	Oct 2016 – May 2016	Semi trailer and crane (cable delivery) – once every 3 weeks. General deliveries over the period.
132kV Cable Installation	Cranes, semi trailers, delivery vehicles	Jul 2016 – Jun 2018	Semi trailer and crane (cable delivery) – once every 4 weeks. General deliveries over the period.

Appendix I

EMF report

Magshield
Products (Aust.)
International Pty. Ltd.
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November 2008

Belmore Park Zone Substation
EMF Study (Rev. #6)

A. Assessment of EMF Emission from Equipment in 132kV/11kV Zone Substation.

1 Introduction

EnergyAustralia (EA) is proposing to construct a new 132/11kV Zone Substation at Belmore Park.

Magshield Products International Pty Ltd has been engaged to provide a reasonable prediction of the magnetic field levels along the proposed substation boundaries, based on its ultimate configuration and anticipated loading.

The elevation view of the proposed substation building with areas designated for different equipment is shown in Fig.1 below.

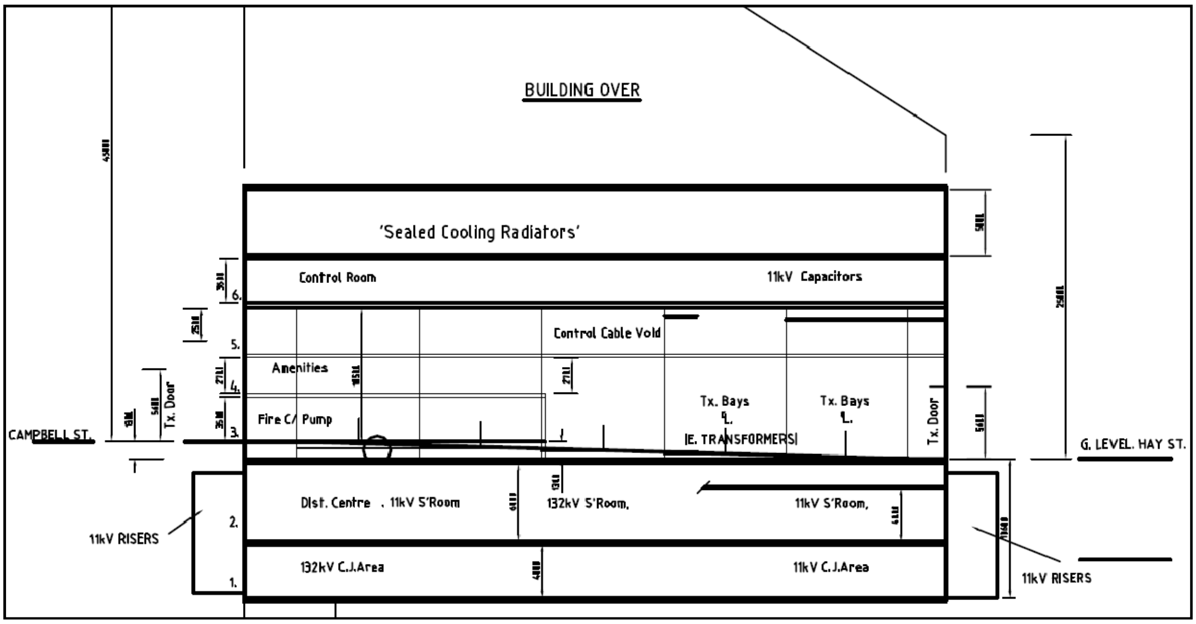


Fig.1 Elevation view of the proposed Belmore Park Zone substation

The magnetic fields from the proposed substation will vary over time and also spatially, depending on the loadings on the various components of the substation at the particular time. Within a substation, there is multiplicity of electromagnetic field (EMF) sources of varying physical size and electrical characteristics. Each of these sources emit EMF of different magnitude and in different direction in space. In addition the magnetic fields produced by each source can fluctuate independently of each other. For this reason, the characterisation of the magnetic fields associated with a substation is a complex exercise. However, a reasonable prediction of the range of the magnetic field emission from a substation can be made if the EMF is calculated only from the main sources.

A simple approach that allows us to identify and categorise substation equipment as strong sources of EMF is to use the following basic principle:

- The stronger the electrical current passing through the equipment the proportionally stronger is the EMF emitted by it.
- The larger the phase-to-phase separation distance the stronger is the EMF emitted by such equipment.
- EMF from a 3-phase line, cable or busbars loaded with symmetrical current reduces inversely proportional to the square of distance.

- EMF from transformers and reactors reduces inversely proportional to the cube of distance.
- The tank of oil-filled transformers is made from 3-4mm thick mild steel and as such it acts as a good shielding medium. The magnetic core of transformers largely contains the magnetic flux ensuring that only a small portion of it escapes outside. Due to lack of space and the requirement to locate strong sources of EMF far away from the adjoining property boundaries EnergyAustralia is intended to use at Belmore Park Zone substation the SF_6 insulated transformers. Such transformers are constructed inside a 9mm thick mild steel tank which, among other things, offers high level of shielding effectiveness against EMF emission.
- The air-core reactors that can be used for limiting fault current, in capacitor circuits or in harmonic filters can emit very strong EMF.
- Metal clad and compact design switchgear that is commonly used in modern substations emit relatively small EMF. This is characteristic for all modern type 11kV switchgear and all 3-phase gas insulated switchgear (GIS). The EMF emission is relatively strong from GIS switchgear where each phase is separately enclosed.

Using the above approach we can identify the following strong EMF sources within the proposed substation:

- 1-core 11kV transformer cable tails – they are spaced 650mm apart and carry large current.
- 1-core 132kV transformers cable tails and transformer bushings – they are spaced 1.8m apart and carry sufficiently large current to emit strong EMF.
- Inrush air-core reactors of 11kV capacitor banks – they carry strong current and can emit very strong EMF if not in metal cladding.
- 1-core transformer cables of distribution substation – load current up to 2000 A.
- Dry-type distribution transformers.
- Low voltage switchboard of distribution substation – load current up to 3000 A.

2. EMF from Transformers.

The power transformers are the other possible strong EMF sources in the substation.

The major cause of strong EMF emission from the transformers is the transformer bushings and connected to them cables. However, if the transformers are designed such that their primary and secondary sides are connected to the cables via cable termination boxes rather than through the bushings then the transformers become relatively small sources of EMF.

Computer modelling and calculation of EMF emission from transformers is a very difficult exercise requiring detailed information for 3-dimensional modelling of all its numerous elements including internal structure of the transformer and its windings. This type of information is not commonly available unless specifically requested from the transformer manufacturer.

Numerous EMF measurements taken by us and by other consultants in proximity of the high voltage transformers of the 30 MVA rating in different installation settings indicated that the EMF level at less than 1m distance from the transformer tank is usually not greater than 80mG. This level reduces to less than 5mG at a distance of 4m away from the transformer tank. It should be noted that the strongest EMF emitting elements of any power transformer are either its bushings or its cable tails on the low voltage side where the current is highest. The EMF emission from these elements can exceed the 80 mG level.

EMF emission measurements conducted near one 38 MVA, 132kV/11kV oil-filled transformer in Zone substation at Hornsby, NSW, indicated that the EMF at 1m distance from the transformer was 139 mG, at 5 m the level was 30 mG and at 10m it was 10.7 mG. Further magnetic field reduction with distance was not apparent due to the contribution from other sources. The transformer was loaded to 1004 A on its 11kV side. The data for SF_6 insulated transformer is not readily available as such transformers are relatively new.

Since the transformers in the proposed substation layout are oriented such that their cable termination side (both high voltage and low voltage terminals are on one side of the transformer) is more than 10m away from the substation eastern property line and more than 30m from the northern property line, the EMF emission level from the transformers into the area external to the substation is small.

2.1 EMF from Transformer Cable Tails

One of the large sources of EMF in the substation are the 11kV transformer cable tails.

Computer modeling was carried out to determine the worst case situation for EMF emission from 11kV transformer cable tails.

The following cases were modeled for EMF calculations:

Case #1 - Normal Operating Conditions (1)

- All five transformers are in service.
- Transformers are loaded to 1000 A per phase per each 11kV transformer winding.
- The separation distance between the centres of 11kV termination structure of each pair of adjacent transformers is 9500 mm.
- The separation distance between the plane of 11kV termination structures and the plane of the 132kV transformer cable tails is 2500 mm.
- The separation distance between the plane of the closest 11kV termination structures to the North-Western boundary wall of the substation is 24400mm.

Case #2 - Normal Operating Conditions (2)

- The same as Case #1, but with only 4 transformers in service and one in hot spare (Tx #4 – see the floor plan drawing on page 6).

Case #3 – Emergency Operating Conditions

- In the emergency three transformers are loaded to 2000 A per phase per each 11kV transformer winding.
- The two transformers Tx #4 and Tx #5 are out of service.

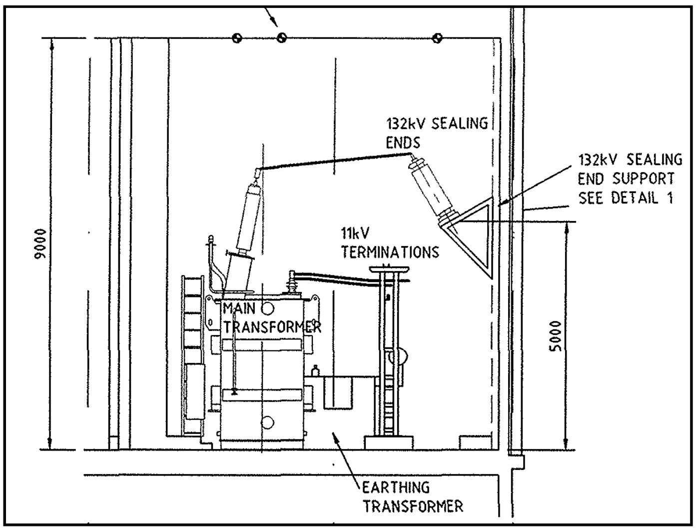
The Fig.3 & 4 below show the plan view of the site with colour dots marking the position and phase designation of the 11kV and 132kV transformer cable tails.

The current in the 132kV transformer cable tails is flowing towards the transformer, while in the 11kV tails it flows away from the transformer. In addition, the delta-star windings of the transformer results in 30^{o} phase shift between the 132kV and 11kV currents. All these are incorporated in the EMF modeling and calculations.

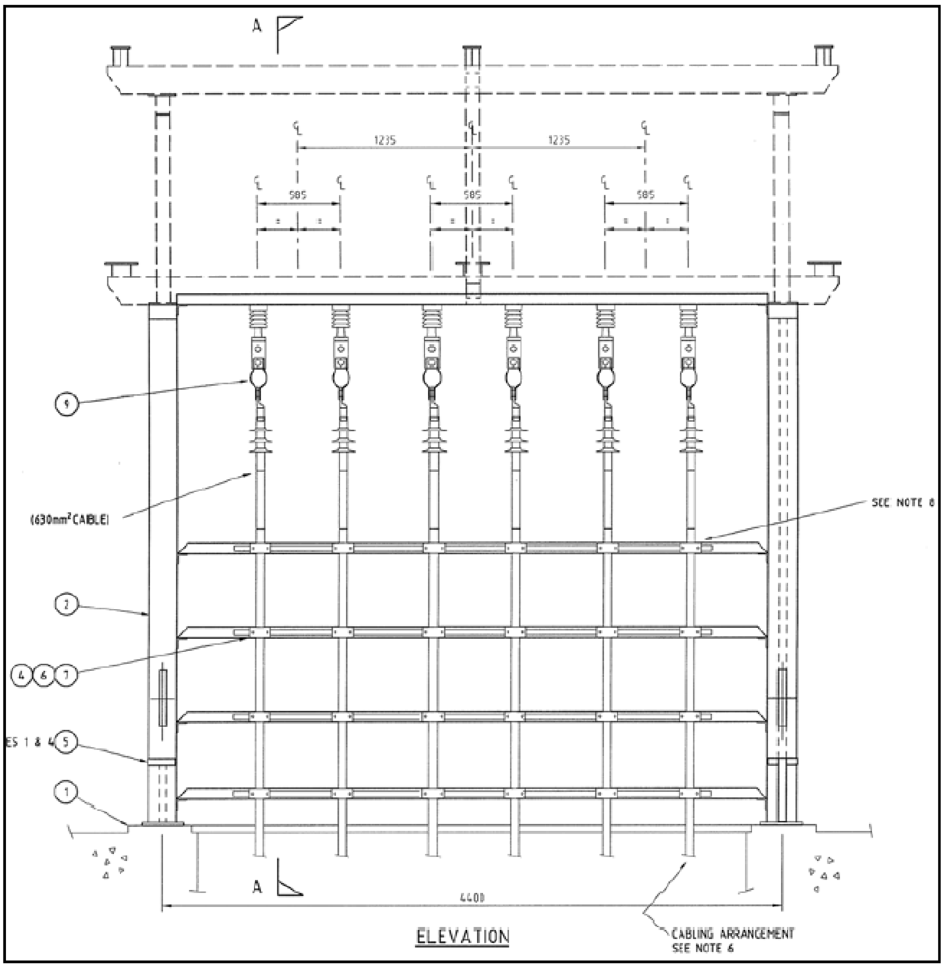
The results of EMF calculations are presented graphically in Fig.3 below. The three graphs show the magnetic field profiles for system normal (two graphs) and emergency conditions calculated at 1m height along the North-Western boundary wall of the substation site.

The EMF profile in Fig.5 below started from the Hay Street corner of the site and progressed towards the Campbell Street corner.

As can be seen from the graph in Fig.5 the highest possible EMF at the boundary wall can reach 16 mG during the “System Normal” operation of the substation and it can increase to 28 mG during the “Emergency” situation.

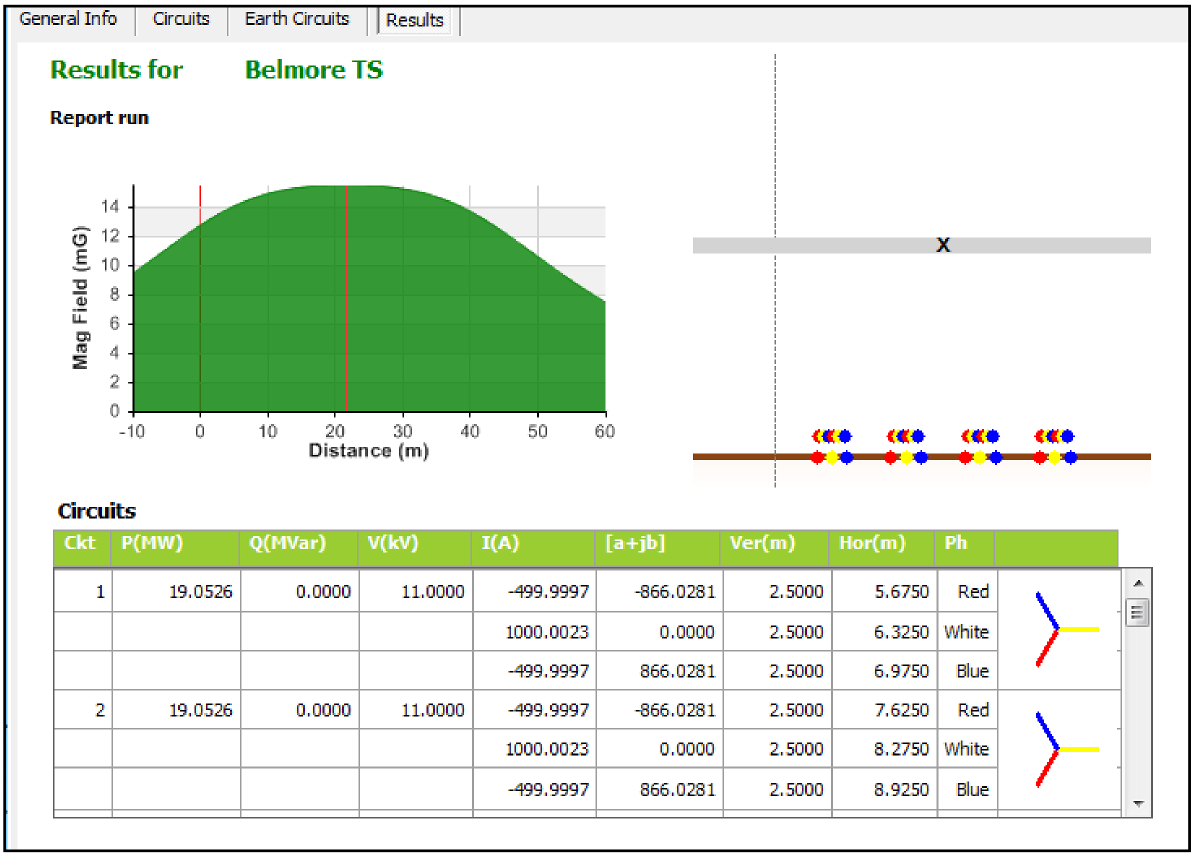


(a)



(b)

Fig.2 Transformer with 132kV and 11kV cable tails
(a) - side view, (b) – elevation view of 11kV cable tails



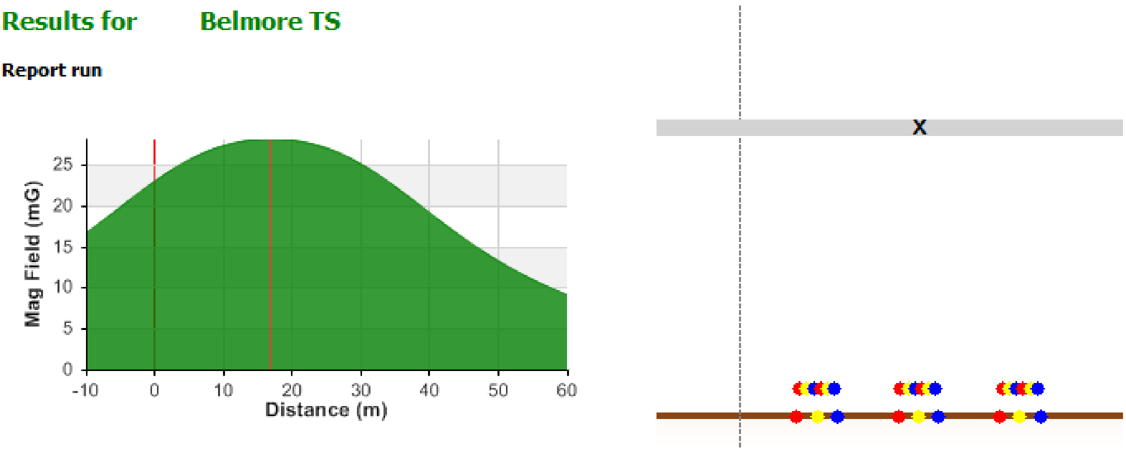
Ckt	P(MW)	Q(MVar)	V(kV)	I(A)	[a+jb]	Ver(m)	Hor(m)	Ph
1	19.0526	0.0000	11.0000	-499.9997	-866.0281	2.5000	5.6750	Red
				1000.0023	0.0000	2.5000	6.3250	White
				-499.9997	866.0281	2.5000	6.9750	Blue
2	19.0526	0.0000	11.0000	-499.9997	-866.0281	2.5000	7.6250	Red
				1000.0023	0.0000	2.5000	8.2750	White
				-499.9997	866.0281	2.5000	8.9250	Blue

Fig.3 System Normal Case #2 - Plane view of 11kV and 132kV transformer cable tails with colour dots representing position and phase designation of cables.

General Info | Circuits | Earth Circuits | Results

Results for Belmore TS

Report run



Circuits

Ckt	P(MW)	Q(MVar)	V(kV)	I(A)	[a+jb]	Ver(m)	Hor(m)	Ph
6	38.1050	0.0000	11.0000	-999.9941	-1732.0470	2.5000	26.6250	Red
				1999.9938	0.0000	2.5000	27.2750	White
				-999.9941	1732.0470	2.5000	27.9250	Blue
7	-76.2100	0.0000	132.0000	0.0004	333.3323	0.0000	5.4000	Red
				-288.6747	-166.6653	0.0000	7.3000	White
				288.6735	-166.6674	0.0000	9.2000	Blue

Fig.4 System Emergency Case #3 - Plane view of 11kV and 132kV transformer cable tails with colour dots representing position and phase designation of cables.

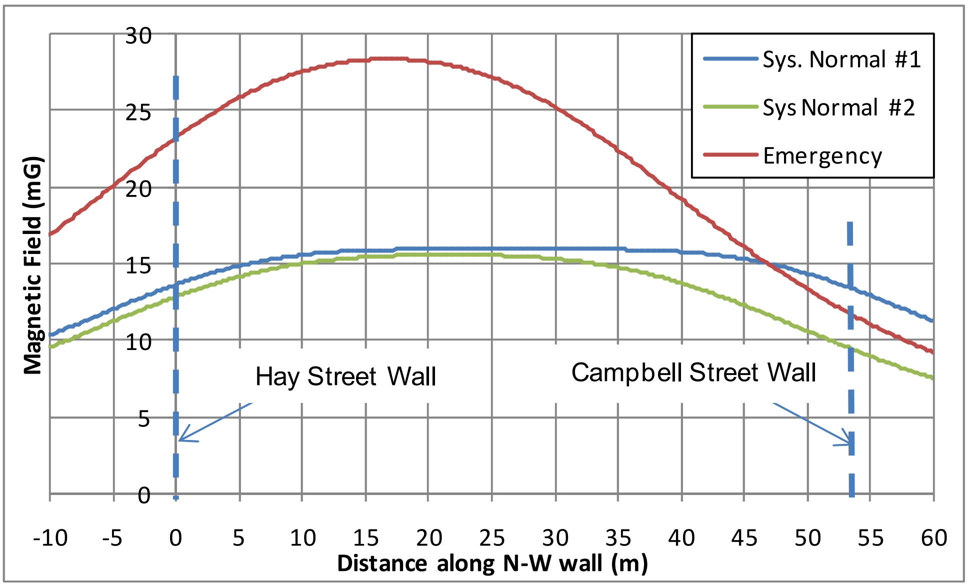


Fig.5 EMF profile along North-Western boundary wall of substation.

An additional buffer zone introduced by EnergyAustralia the between the north-western wall of the substation building and the nearest adjacent property (see Fig.6 below) would result in further substantial reduction of the EMF to the level not exceeding 5 mG for the System Normal #1 and #2 conditions.

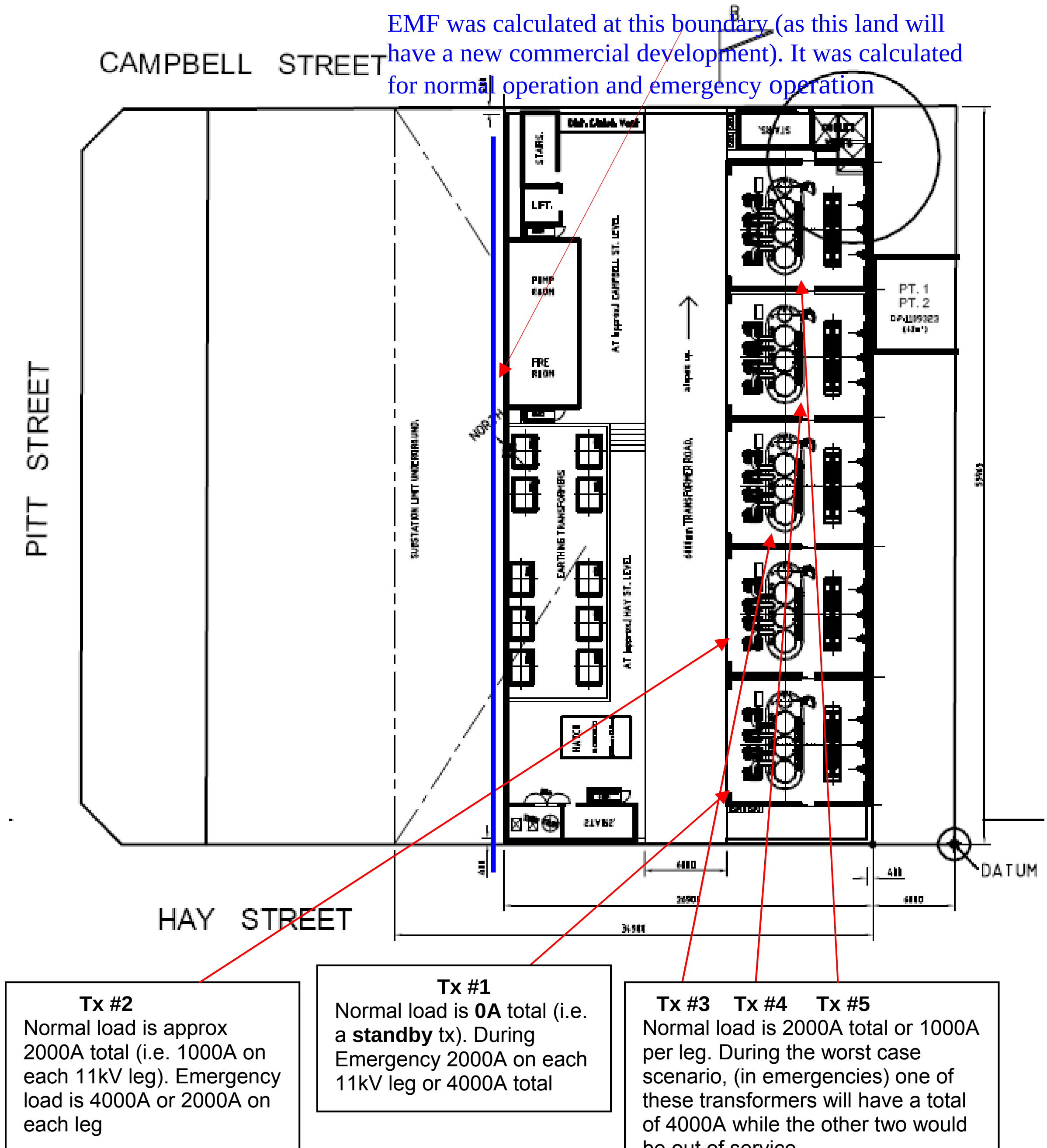


Fig.6 Level 4 floor plan with 132kV/11kV transformers a

The plan view of the transformer with 132kV and 11kV cables is shown in Fig.7 below. The corresponding elevation view is shown in Fig.2(a).

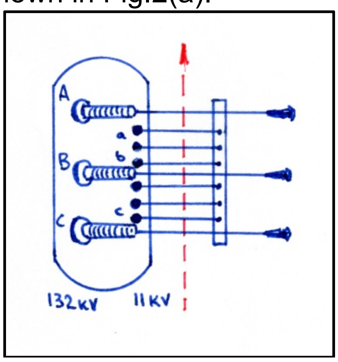


Fig.7 Plan view of transformer with 132kV and 11kV cable tails

The EMF profile along the red arrow in Fig.7 at 25m above the transformer floor (the bottom floor of the proposed commercial building constructed above the substation) due to emission from the horizontally run 11kV and 132kV cable tails is given in Fig.7 below.

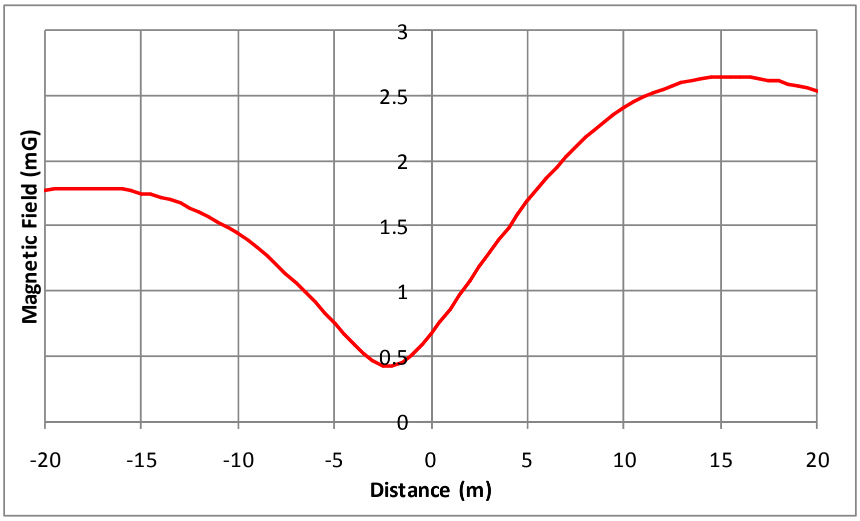


Fig.8 EMF profile at 25m above the transformer floor due to load current in cables connected to 132kV and 11kV bushings of one transformer.

3 EMF from Earthing Transformers

A group of ten earthing transformers (two for each power transformer) connected to the 11kV windings of the 132kV/11kV power transformers will be located in a separate room on Level 4 (see Fig.6).

The earthing transformers are used for provision of artificial neutral on the 11kV side where the transformer winding is connected in delta.

The earthing transformer emits EMF due to the flow of electric current though their windings.

Under the system normal condition, if the impedances of each phase winding of the power transformer are equal and the impedance of each phase winding of the earthing transformer are equal, then, the only current that will be flowing in the windings of each earthing transformer will be a zero sequence current injected from the 11kV distribution network.

Several electrical and EMF measurements carried out on zig-zag of 11kV earthing transformers indicated that the current in the windings and subsequently in the neutral can be in the order of several amps. The current in the windings of a zig-zag earthing transformer is a combination of two currents: a) magnetising current; b) zero sequence current.

In the 11kV distribution system operated by EnergyAustralia, the 11kV/415V distribution transformers are of delta-star type with delta connected winding on the 11kV side. The 11kV network is largely constructed with the radial type feeder. That is no 11kV feeder commencing from one Zone Substation is interconnected with any other 11kV feeder belonging to other Zone Substations. The two above mentioned features of the 11kV distribution system suppresses the magnitude of the zero sequence current of the fundamental frequency. The harmonic currents through the zig-zag transformers are also reasonably small due to their design and winding connections.

EMF measurements made in proximity of commonly used zig-zag earthing transformers indicated that the highest field at a short distance from the transformer (at a distance of 0.2m) can be approximately 50 mG. At a distance of 1m the EMF is less than 5 mG.

However, during the normal operation of the 11kV distribution system, when a feeder, which is connected to the substation with zig-zag Earthing transformers can be subjected to routine switching, the transitory current in the neutral of the zig-zag transformer can be rather high. This is due to asynchronous switching of all three blades of 11kV circuit breaker or an isolator. This transient current produces transient EMF.

During a 1-phase-to-ground fault in the 11kV system the highest current in the zig-zag transformer is limited to 1.5kA. However, such strong transient current can produce strong transient EMF at short distances from the zig-zag transformer.

4. EMF from 132kV Gas Insulated Switchgear (GIS)

As part of the EMF mitigation strategy the proposed Belmore Park Zone substation will be fitted with gas insulated switchgear at 132kV side. The GIS equipment will be erected on Level 2 (at least 7 m below the street level) in the north-western quarter of the substation building.

By comparison with the conventional air-insulated switchgear of the same nominal voltage and rated current, the 132kV GIS equipment is a very low source of EMF. This is primarily due to much smaller phase-to-phase separation distances inside the GIS chamber due to superior insulating quality of SF_6 gas as compared to the insulating quality of air in the conventional open air switchgear. In addition the aluminium pipes that serve as equipment enclosures and containers of SF_6 gas, also act as the EMF shielding medium. Being a good electrical conductor and located close to the heavy current busbars and other current carrying elements, the aluminium pipes become carrier of induced current which flows in reverse direction to the 3-phase load current. The EMF produced by this induced current is almost at 180° angle to the EMF produced by the 3-phase current, hence, they effectively cancel each-other.

EMF emission measurements taken in the vicinity of the 110 kV energised and heavily loaded 3-phase GIS switchgear, of a similar type to the proposed for the Belmore Park substation, showed the following:

- at a distance of 0.5m from the straight section of the GIS buss chamber (the chamber was 650 mm in diameter and 5m long) which was loaded with 1100 A current the measured EMF was 210 mG;
- at a distance of 1m the EMF was 93 mG;
- at a distance of 2m the EMF was 18 mG;
- at a distance of 3m the EMF was 10 mG and judging by the strength of the magnetic field in three orthogonal directions most of the EMF in that location was due to the emission from other sources in the substation.

The section of the 3-phase GIS switchgear that emitted strong EMF was one connection via bare wires to the overhead air-insulated equipment external to the GIS. The GIS switchgear for the Belmore Park Zone substation will have no such part as all the connections to it will be made by underground cables. Therefore, it is anticipated that the highest EMF at the eastern boundary line of the substation ground due to emission from the GIS equipment will be less than 1 mG.

Finalising this section of the report it can be safely concluded that, due to compactness of its design and relatively large distances to the property boundaries, the proposed 132kV GIS switchgear will emit very small EMF into the nearby properties.

5. EMF from 11kV Switchboard

The 11kV switchboards are located on Level 2 which is located at some 7m below the ground. The 11kV switch room is located directly below the transformers. The switchboards are running lengthwise in the north-south direction.

The switchboards will be of the compact type, metal clad, floor mounted construction.

The switchboard will be supplying power to large number of outgoing 11kV feeders. These feeders will be in the form of the underground cables. Each such cable will be constructed from 3-core 11kV XLPE insulated cables.

The supply cables from each transformer will be connected to each end of the switchboard and the outgoing cables will be connected to the switchboard in the space between the two incoming transformer feeds. In such electrical arrangement the maximum possible load current that can flow in any part of the main 11kV busbars will be 1000 A if each transformer is normally loaded and it will be 2000 A during the emergency operation.

The internal design of the typical compact, metal clad, floor mounted 11kV switchboard is shown in Fig. 9 below.

As can be seen from the drawing the main busbars are located in the upper part of the switchboard. The three busbars are in trefoil arrangement with approximately 160 mm separation between the adjacent phases.

Due to the switchboard orientation in the substation and its longitudinally installed main busbars the major direction of the magnetic field emission from the switchboard will be in the direction across the switchboard length. This means that the main impact of the magnetic field emitted by the switchboard would be in the area behind the substation western boundary.

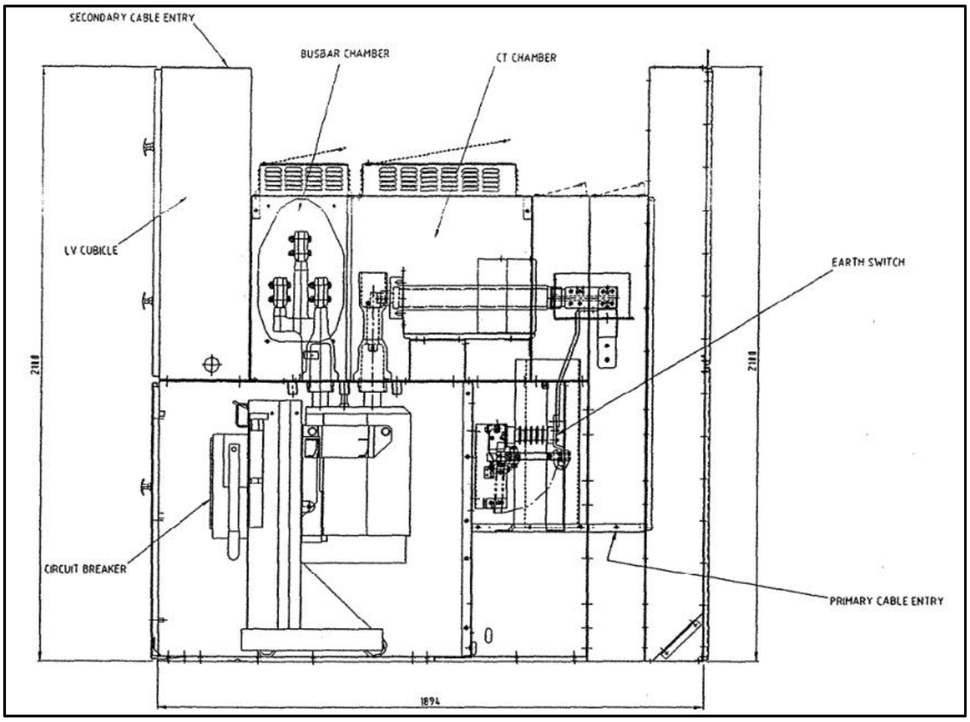


Fig. 9 ***Section view of typical 11kV switchboard with incomer circuit breaker***

For the calculation of the magnetic field emission from the switchboard it was assumed that the busbars are located inside the bus chamber (see the drawing in Fig. 9) and as such they are inside a double-skin metal cladding of the switchboard. If each skin is made of 2 mm thick mild steel plates such metal cladding of the switchboard would result in better than 50% of shielding effectiveness.

The results of the magnetic field calculations at 1m above ground are shown in the graphical form in Fig. 10 below.

As can be seen from the graphs in Fig. 10, the magnetic field in the area outside the substation western boundary line (11m from the switchboard) is less than 3 mG if the shielding effectiveness of the metal cladding is ignored and is less than 2 mG if the shielding effectiveness is included in the calculations.

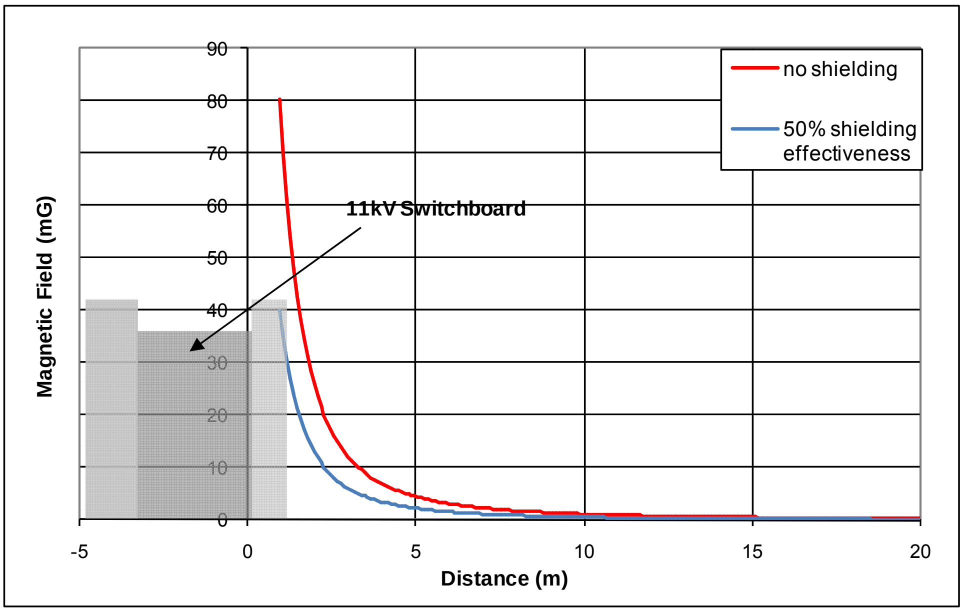


Fig. 10 ***Magnetic field profiles in the direction orthogonal to 11kV switchboard.***

6 EMF from Air-core Reactors

One other strong source of EMF among the substation equipment is an air-core reactor. The air-core reactors are used in various applications such as:

- for limiting fault current;
- for limiting inrush current in the capacitor banks;
- in harmonic filters.

The Belmore Park Zone substation will be fitted with 24 (twenty four) sets of 4MVar capacitor banks for the reactive power generation. Each capacitor bank unit will be containing one inrush reactor connected in series with the capacitors (see Fig.11 below).

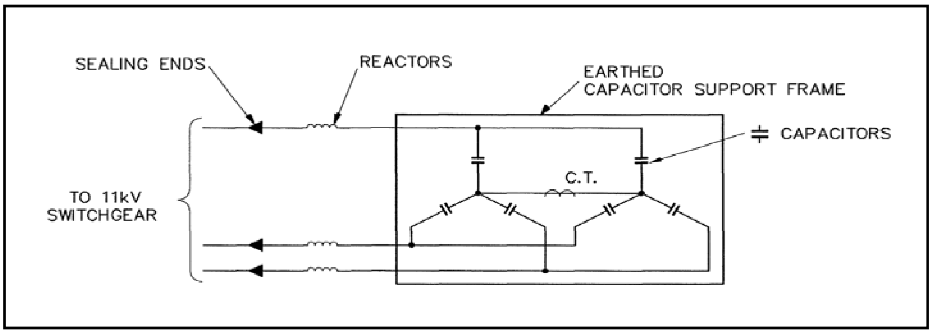


Fig.11 Schematic diagram of capacitor bank unit

The reactor is usually assembled with three coils in a vertical stack arrangement (see Photo #1 below).

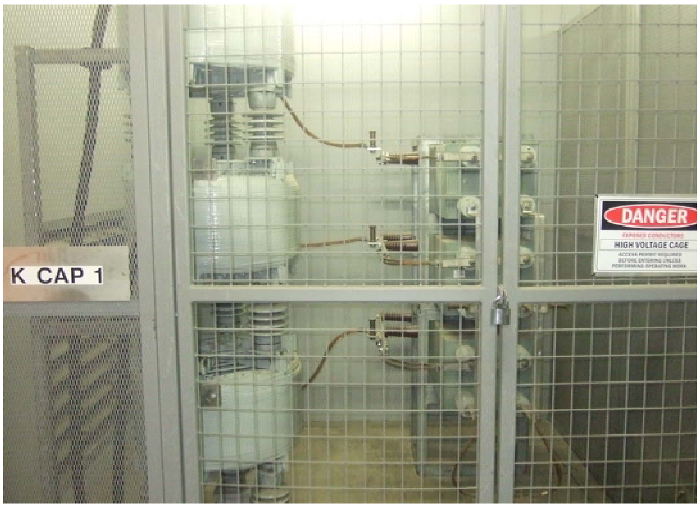
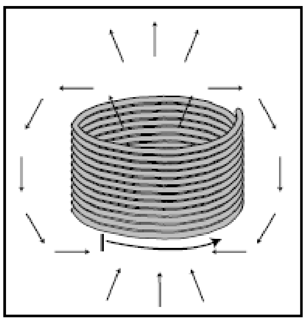


Photo #1 Air-core reactor (on the left) and capacitor bank (on the right)

Each reactor coil is 724mm in diameter and the height of the reactor stack is approx 2500mm.

At the rated 4 Mvar capacity and 12kV applied voltage the reactive current passing through each coil (phase) of the reactor stack is 192.5 A.

The pattern of magnetic field produced by an air-core coil is shown in the Sketch #1 below.



Sketch #1 Magnetic field pattern around air-core coil with current

The magnetic field produced by a stack of three air-core reactors with current is strong both in the axial and the radial directions.

There is no simple equation for the field at an arbitrary point in space near the air-core coil, but for a point lying along the central axis perpendicular to the plane of the coil, the field is:

$$B = \frac{\mu_0 \cdot N \cdot r^2 \cdot I}{2 \cdot (r^2 + z^2)^{3/2}}$$

where:

N – the number of turns in the coil,
r - the radius of the coil (m)
I – current in the coil;
μ_0 – permeability of free air;
z - distance from the observation point to the plane of the coil.

Due to the lack of relevant technical data, it is impossible to determine the level of the magnetic field produced by such reactors at various distances from them.

The cumulative magnetic field produced by several reactors (the total of 24 identical reactors will be installed on the same floor within a short distance away from each other) is difficult to determine with the acceptable accuracy. However, it can be said with certainty that due to the same parameters and construction details, the same phase sequence and the same current flow in all 24 reactors, the magnetic field on the floor of the future commercial building constructed above the substation will be stronger than that produced by one reactor only. It is expected that the steel reinforcement mesh and rods in the two 500mm thick floor slabs that separate the reactors floor from the commercial floor will provide some EMF shielding.

One of the practical ways of reducing the level of magnetic field emission from the air-core reactor is to enclose the reactor in the enclosure made of either ferromagnetic or conductive metals. One other method is to place inductive loops in locations where the magnetic field should be mitigated.

B. Assessment of EMF Emission from Distribution Substation

1 Introduction

One of the EnergyAustralia chamber type indoor high voltage power distribution substation is planned to be constructed on Level 2 of the Belmore Park Zone Substation building adjacent to its north-western boundary wall.

The purpose of this study is to assess the level of electromagnetic field emission from the substation into the adjoining area across the north-western wall of the proposed Belmore Zone substation.

The substation room will be fitted with three 1500kVA, 11kV/415V dry-type transformers, one E-type low voltage (LV) switchboard, three sets of single-core transformer LV cables installed in three separate under floor cable trenches, four LV mains cable feeders installed in four floor encased conduits and two incoming 11kV cable supply feeders connecting the three transformers to the ring main isolators located in the HV switchgear room on Level 2 of the building.

The substation equipment layout drawing is shown in Fig. 12.

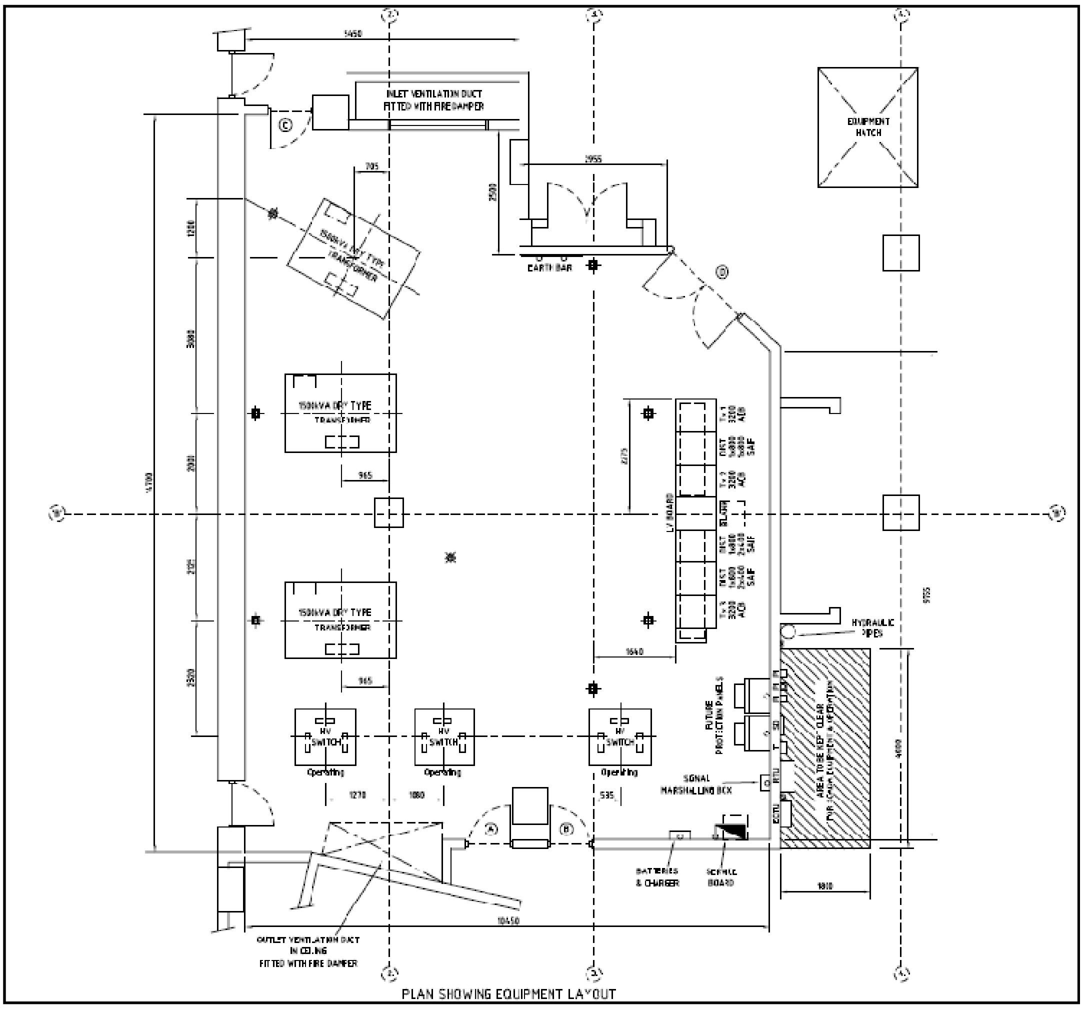


Fig. 12 Substation plan with equipment layout

2 EMF Emission from Dry-Type Transformers

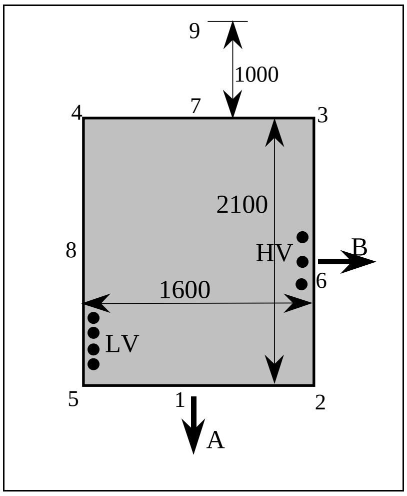
In the study the EMF emission from each separate strong source of EMF was analysed and the level of EMF emission either calculated from computer modelling or determined from measurements taken previously from similar EA installations.

The three 1500 kVA transformers that will be installed in the substation are the dry-type transformer constructed without an oil tank.

The transformer oil tank is usually made from mild steel of several mm thick. Besides serving its primary purpose of containing the oil, the tank also acts as an effective electromagnetic shielding structure as it is made of 3-4mm thick mild steel with permeability greater than 250 units.

The dry-type transformer, on the other hand, has no oil-containing tank as its windings are insulated by epoxy-resin. Because of this, the dry-type transformer is covered by very thin sheets of mild steel that provide very little shielding effectiveness to the magnetic field. Such transformers usually emit much higher EMF than the oil filled transformers and such high field extents to larger a distance.

In order to assess the level of the EMF emission from the dry-type transformer, the measurements of the field emission level were conducted around an operating dry-type transformer of 2000 kVA power rating. The results are presented below.



Sketch #2 ***Plan view of the 2000kVA dry-type transformer.***
Numbers around the perimeter indicate the points where the EMF was measured. Arrows that are labelled as A and B indicate the direction of the EMF measurements with distance away from the transformer.

The results of the EMF measurements around the perimeter of the transformer are presented in the table while the graphs in Fig.13 represent the level of magnetic field as a function of distance from the transformer. It should be noted that all measurements were taken at 1 m above the floor.

Point	B_{res}	B_x	B_y	B_z
1	542	90	144	520
2	630	133	245	554
3	500	67	160	500
4	835	120	320	740
5	658	90	92	674
6	543	99	165	515
7	663	66	100	650
8	480	70	125	460
9	160			

Notes:
1. The magnetic field was measured in milliGauss at 1m above the floor.
2. The transformer load current on the LV side was 1200 A per phase which was only 43% of its rated capacity.
3. B_{res} - is the resultant EMF level at a point of measurement
4. B_x - is the field component in the direction parallel to the transformer side at which the measurement was made.
5. B_y - is the field component in the direction perpendicular to the transformer side at which the measurement were made
6. B_z - is the field component in the vertical direction.

Fig. 13 ***Magnetic field (resultant value) as a function of distance away from 2000 kVA dry-type transformer*** *(direction along arrow A in Sketch #2)*

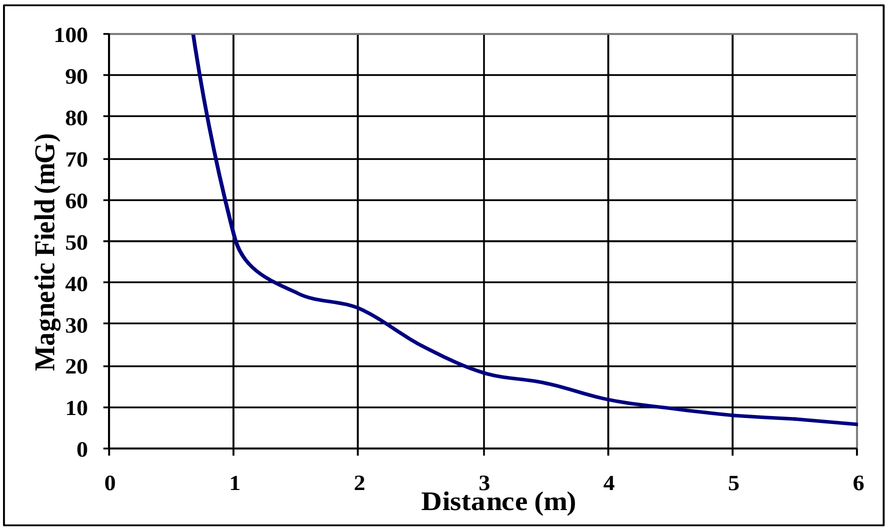


Fig. 13a Same graph as in Fig.13 but with expanded vertical axis.

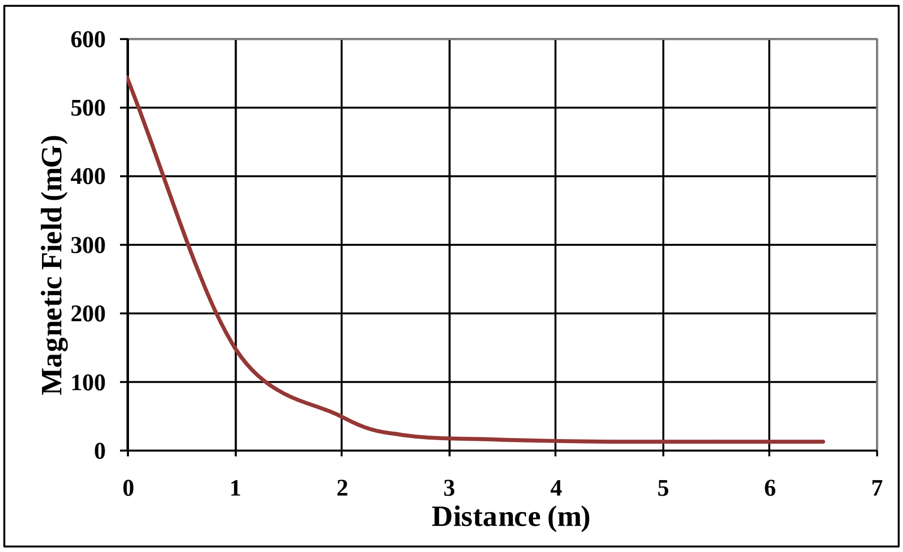


Fig. 14 Magnetic field level as a function of distance away from the 2000 KVA dry-type transformer *(direction along arrow B in Sketch #2)*

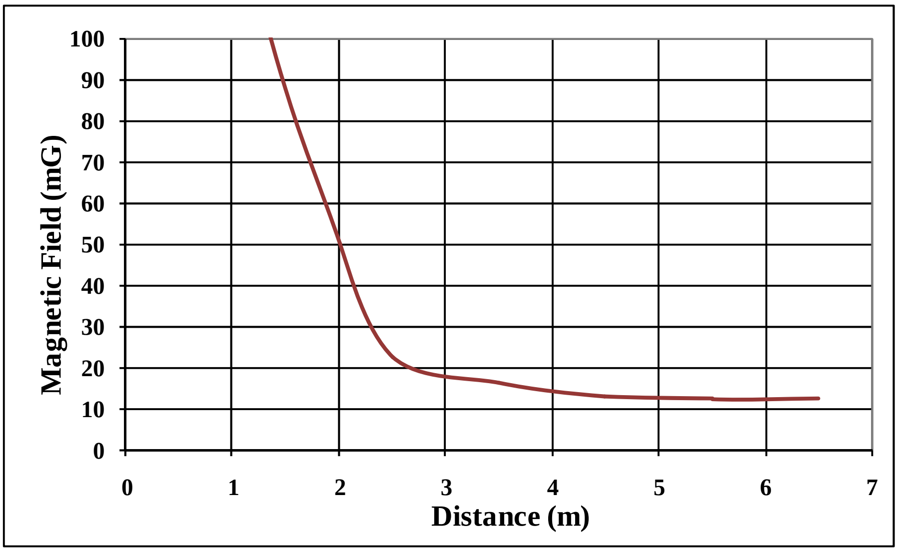


Fig. 14a Same graph as in Fig.14 but with expanded vertical axis.

The measurements indicated the following:

- At short distances from the transformer (less than 2m away) the strongest of the three orthogonal components of the EMF is in the vertical orientation (B_z component is the strongest),
- Up to 2.5m from the transformer the EMF reduces rapidly with distance, but then the rate of reduction slows down.

- The EMF at 3.6 m away from the transformer (on the ceiling) is 16 mG and is 11 mG at 6 m distance from the transformer (equal to the vertical distance between the top of transformer and the street level above the substation room).
- The EMF around the perimeter of the transformer does not vary significantly.

It should be noted that the measurements were made only at horizontal distances around and away from the tested 2000 kVA dry-type transformer when it was loaded to the average current of 1200 A per phase. While there were no measurements made in the space above or below the transformer. However, due to the vertical orientation of the transformer cylindrical windings, the magnetic field in the space above and below the transformers would be greater than in the horizontal direction. Experience with other dry-type transformers showed that such difference can be as high as 40%.

Based on the power ratings of the transformers and allowing for 75% utilisation it can be assumed that each of the three 1500 kVA transformers could be loaded with the average of 1600 A, although the transformers themselves are rated at 2086 A load current each.

This means that the 1500 kVA transformers can be loaded with 33% higher current than the test transformer. As the level of EMF emission is directly proportional to the load current, it means that the EMF from each transformer could be proportionally higher.

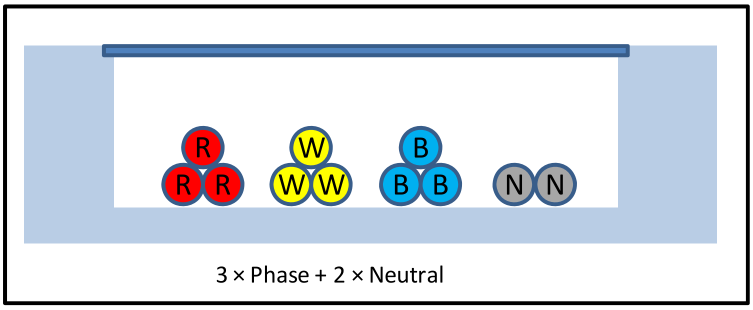
In addition, since the three transformers have the almost similar orientation within the substation room, and are located relatively close to each-other the EMF at any radial point away from the group of three transformers will be a sum of the EMFs emitted by each transformer at that point.

Considering all of the above, it can be concluded that the highest EMF in the area across the north-western wall of the Zone Substation due to emission from the dry-type transformers would be in the order of 25 mG on the wall and 15 mG at 1m away from the wall.

3 EMF Emission from Transformer LV Cables

Each transformer will be connected to the substation LV switchboard by a set of 11 x 1C, Copper 500 mm^2, XLPE insulated cables. The cables would be installed on a 600mm wide cable tray suspended from the ceiling slab on the level below the substation floor.

The cables are either randomly laid or grouped in the most convenient way for termination at both ends. The worst case scenario, in regards to the EMF emission, would be when the cables are grouped as shown in Sketch #3 below.



Sketch #3 Cross-section of cable tray with transformer LV cables.
11 x 1C, 500mm^2 Cu, XLPE insulated cables. Cable diameter is 37mm. The gap between each group of cables is one cable diameter.

The magnetic field profiles emitted from the LV cables of one transformer only are presented as graphs in Fig. 15 below. The graphs show the profiles calculated on the floor on Level 2 and at 1m above the floor when the cables are grouped as shown in Sketch #3.

As can be seen from the graphs the highest EMF on the floor is 72 mG and is 165 mG at 1m above the floor. If we consider that the steel reinforcement mesh of the concrete slab provides some limited shielding effectiveness, then the highest EMF emitted by the cables on only one tray (there will be 1 cable tray per transformer) could be as high as 57 mG on the floor and up to 132 mG at 1m above the floor.

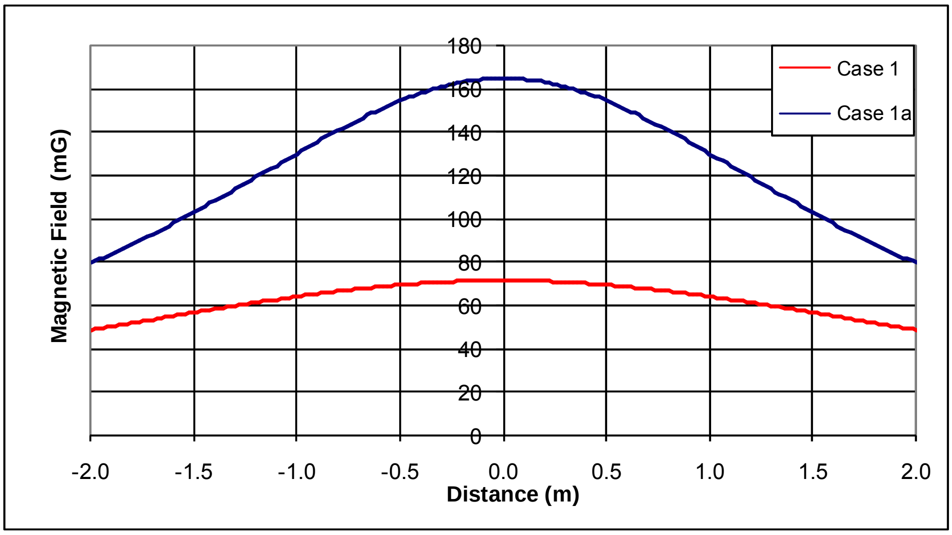


Fig. 15 Magnetic field profiles from one set of transformer cables.
Case 1 – calculated on the floor, Case 1a – calculated at 1m above the floor.

As the 11 single-core cables can also be randomly installed in the trench (this is more common installation practice) it is safe to assume that the EMF emitted from the trench would be smaller than the calculated highest values. Our measurements in other EA substations indicate that the EMF emitted from the similar cable trenches is approximately 50% smaller when the cables are randomly installed as compare to the installation shown in Sketch #3.

However, it should be noted that since there are three 1500 kVA transformers connected to the common LV bus of the LV switchboard, then each transformer will be loaded equally and hence the cables in the second and third trays will emit similar EMF. The combined effect of the EMF emission from three cable trays, that run almost parallel to each other at an average distance of 1.7m between centres, would be higher EMF than that calculated and presented in Fig. 15.

4 EMF Emission from LV Switchboard

The substation will be fitted with new type-E LV switchboard. The new LV switchboard, among other important features incorporates the low EMF emission design. The low EMF emission of the switchboard resulted from small separation distances between four main horizontal and all vertical busbars (three active and one neutral) and metal cladding of the switchboard.

EMF emission tests carried out by EnergyAustralia demonstrated that a section of such switchboard, when loaded with electric current of approximately 3060 A per phase (I_R= 3043 A, I_W = 3061 A, I_B = 3079 A, I_N = 410 A) produced 22 mG at a distance of 3m away from the switchboard.

Considering that the highest expected load current in any part of the main busbars of the substation LV switchboard will be 1430 A (see the diagram in Fig.16) and accounting for shielding effectiveness of steel reinforcement rods in the floor slab, we have estimated that the EMF on the floor above the substation room due to emission from the LV switchboard would not be greater than 15 mG and it would be 11 mG at 1m above the floor.

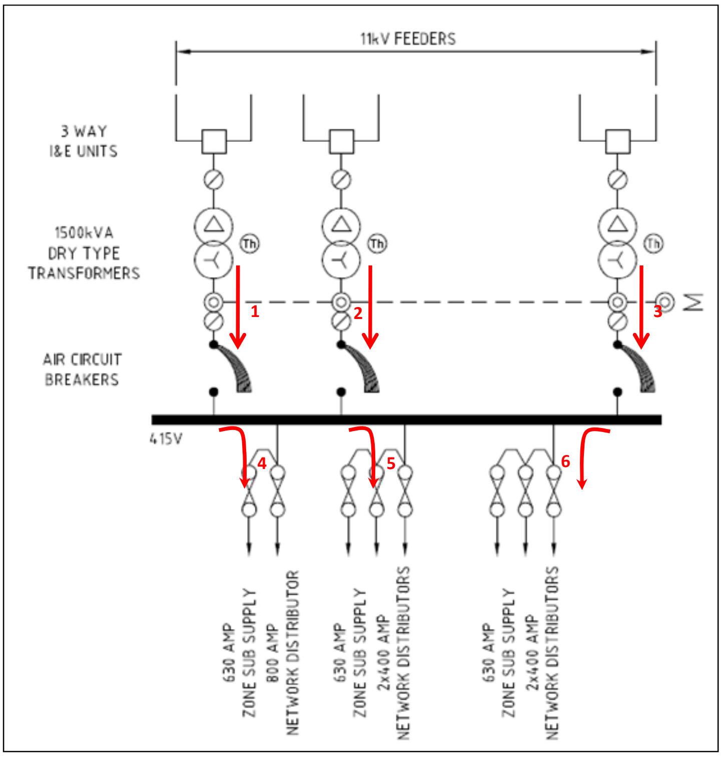


Fig. 16 Schematic diagram of distribution substation.
At system normal the highest load current in each section of the main busbars of the LV switchboard is 1430A

5 EMF Emission from LV Mains Cables

The electric power from the distribution substation will be supplied to the Zone Substation and also to several Network Distributors.

The supply will be provided by three 630 A, one 800 A and four 400A rated LV mains feeders that will be installed in eight separate conduits encased in the substation concrete floor.

Our calculations show that, if each LV main feeder is made of four 500mm^2, 1-core Cu cables tightly bundled together and loaded with symmetrical current, then the EMF from a group of eight LV mains will be approximately 30mG at 1m height above the floor on Level 4.

However, if each of the four LV mains will be loaded with asymmetrical current and, in addition, each feeder will carry a net residual current due to paralleling of four neutrals at two ends of the cable run, then the EMF in the same location from eight LV mains could be twice as high.

6 EMF Emission from 11kV Power Supply Cables

The 11kV cables (3 cables) that provide primary power supply to three distribution substation transformers are installed in cable trays below the distribution substation floor.

Each 11kV cable supply will be in the form of triplex cables.

The triplex cable is a set of three 1-core XLPE insulated cables twisted together into one bundle. The picture of the Triplex 11kV cable is given in Fig. 17 and 17a below.

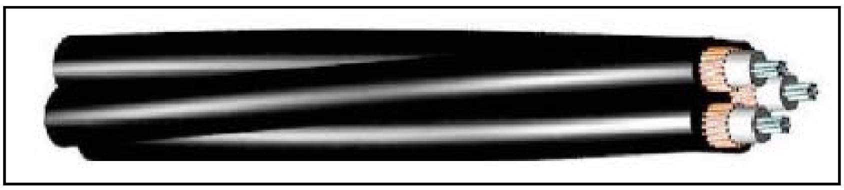


Fig. 17 11kV XLPE insulated cable in Triplex arrangement

Fig. 17a 11kV XLPE insulated cable in Triplex arrangement

Three 11kV feeders made of the 240mm^2 XLPE insulated cables in Triplex arrangement would be approaching the substation under the floor conduits. Then inside the substation room the cables will be installed in three floor encapsulated conduits running towards each transformer and then raised up and connected to the transformer 11kV terminals located in the upper part of each transformer.

During the system normal operation, when each transformer is loaded to the maximum current of 1600 A per phase on its LV side, the corresponding per phase load current on its 11kV side would be 60.4 A.

Due to the magnetic field cancellation effect resulting from close proximity of the three phases to each other in the Triplex cables and due to very small load current in the cables, the EMF from the 11kV transformer cables will be relatively small. Our calculations show that the EMF from each of the Triplex cable will be less than 0.5 mG at 1m above the floor.

However, it should be noted that the Common Multiple Earth Neutral (CMEN) system presently used by EA and all other major supply authorities in Australia, requires that the sheath of the 11kV Triplex cables be connected to the substation Earth bar which is the common earthing terminal for all LV and HV earths. Such common system of earthing results in the flow of the net 50Hz and harmonic currents through the metallic sheets of the HV cables while being generated in the LV reticulation network. Our numerous measurements indicated that the net currents in the metallic sheets of HV currents can be as high as 10-15 A. If such net current is flowing in the Triplex cable then the EMF resulting from this current at a distance of 2.5m from the cable will be 12 mG.

C. EMF Exposure Standards and Guidelines

1. IRPA and NHMRC Guidelines

In 1989, the International Radiation Protection Association (IRPA) approved interim EMF human exposure guidelines prepared by its International Non-Ionising Radiation Committee. In the same year these guidelines were adopted as the interim guidelines by the National Health and Medical Research Council of Australia (NHMRC). The guidelines recommended the following limits:

Exposure	**Magnetic Flux Density**
Occupational	
Whole working day	**0.5 mT (=5,000 mG)**
Short term	**5.0 mT (= 50,000 mG)**
For limbs	**25.0 mT (=250,0000 mG)**
General public	
Up to 24 hours per day	**0.1 mT (=1,000 mG)**
Few hours per day	**1.0 mT (=10,000 mG)**

Notes:

a) IRPA guidelines were developed *"primarily on established or predicted health effects produced by currents induced in the body by external [EMFs]".*

b) The guidelines were based on limiting current densities induced in the head and trunk by continuous exposure to 50/60 Hz electric and magnetic field to no more than about 10 mA/m^2.
c) Immediately observable minor biological effects have been reported in human studies in respect to induced current densities between 1 and 10 mA/m^2
d) The occupationally exposed population consists of adults exposed under controlled conditions in the course of their duties, who should be trained to be aware of potential risks and to take appropriate precautions.

The NHMRC guidelines state that: *"The occupationally exposed population consists of adults exposed under controlled conditions in the course of their duties, who should be trained to be aware of potential risks and to take appropriate precautions".* Based on this definition, the occupational exposure limits should only be applicable to skilled and trained workers who are directly involved with operation and maintenance of EMF emitting equipment and installations and who know how to limit the severity and duration of exposure to the power frequency electric and magnetic fields.

2. ICNIRP Guidelines

In 1998 the International Commission on Non-Ionising Radiation Protection (ICNIRP) published the new "Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz)". The new document replaces the previous IRPA guidelines.

The principal limitation of the guidelines is stated in the "BASIS FOR LIMITING EXPOSURE" section as follows:

> *Induction of cancer from long-term EMF exposure was not considered to be established, and so these guidelines are based on short-term immediate health effects such as stimulation of peripheral nerves and muscles, shocks and burns caused by touching conducting objects, and elevated tissue temperatures resulting from absorption of energy during exposure to EMF.*

The guidelines further state that:

> *In the case of potential long-term effects of exposure, such as an increased risk of cancer, ICNIRP concluded that available data are insufficient to provide basis for setting exposure restrictions, although epidemiological research has provided suggestive, but unconvincing, evidence of an association between possible carcinogenic effects and exposure at levels of 50/60 Hz magnetic flux densities substantially lower than those recommended in these guidelines.*

The table below contains the ICNIRP reference levels for occupational and general public exposure to time-varying electric and magnetic fields.

Frequency range	**E-field strength (V/m)**	**B-field density in μT, (mG)**
	Occupational exposure	
Up to 1 Hz	-	200000, (2000000)
1 - 8 Hz	20,000	$2\times10^3/f^2$, $(2\times10^4/f^2)$
8 - 25 Hz	20,000	$2\times10^4/f$, $(2\times10^5/f)$
0.025 - 0.82 kHz	**500/f**	**25/f, (250/f)**
0.82 - 65 kHz	610	30.7, (307.0)
…	…	…
	General public exposure	
Up to 1 Hz	-	40000, (400,000)
1 - 8 Hz	10,000	$4\times10^4/f^2$, $(4\times10^4/f^2)$
8 - 25 Hz	10,000	5,000/f, (50,000/f)
0.025 - 0.8 kHz	**250/f**	**5/f, (50/f)**
0.8 - 3 kHz	250/f	6.25, (62.5)
…	…	…

Notes: a) 1μT = 10 mG
b) f - is the frequency of EMF in units given in the first column of the table.

From the ICNIRP table the maximum EMF exposure limit at the power frequency of 50Hz should be 100μT or 1000 mG.

3. World Health Organisation - Fact sheet N°322 (June 2007)

3.1 Electromagnetic fields and public health - Exposure to extremely low frequency fields

The use of electricity has become an integral part of everyday life. Whenever electricity flows, both electric and magnetic fields exist close to the lines that carry electricity, and close to appliances.

Since the late 1970s, questions have been raised whether exposure to these extremely low frequency (ELF) electric and magnetic fields (EMF) produces adverse health consequences. Since then, much research has been done, successfully resolving important issues and narrowing the focus of future research.

In 1996, the World Health Organization (WHO) established the International Electromagnetic Fields Project to investigate potential health risks associated with technologies emitting EMF. A WHO Task Group recently concluded a review of the health implications of ELF fields (WHO, 2007).

This Fact Sheet is based on the findings of that Task Group and updates recent reviews on the health effects of ELF EMF published in 2002 by the International Agency for Research on Cancer (IARC), established under the auspices of WHO, and by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 2003.

3.2 ELF field sources and residential exposures

Electric and magnetic fields exist wherever electric current flows - in power lines and cables, residential wiring and electrical appliances. **Electric** fields arise from electric charges, are measured in volts per metre (V/m) and are shielded by common materials, such as wood and metal. **Magnetic** fields arise from the motion of electric charges (i.e. a current), are expressed in tesla (T), or more commonly in millitesla (mT) or microtesla (μT). In some countries another unit called the gauss, (G), is commonly used (10,000 G = 1 T). These fields are not shielded by most common materials, and pass easily through them. Both types of fields are strongest close to the source and diminish with distance.

Most electric power operates at a frequency of 50 or 60 cycles per second, or hertz (Hz). Close to certain appliances, the magnetic field values can be of the order of a few hundred microtesla. Underneath power lines, magnetic fields can be about 20 μT (200 mG) and electric fields can be several thousand volts per metre. However, average residential power-frequency magnetic fields in homes are much lower - about 0.07 μT (0.7 mG) in Europe and 0.11 μT (1.1 mG) in North America. Mean values of the electric field in the home are up to several tens of volts per metre.

3.3 Task group evaluation

In October 2005, WHO convened a Task Group of scientific experts to assess any risks to health that might exist from exposure to ELF electric and magnetic fields in the frequency range >0 to 100,000 Hz (100 kHz). While IARC examined the evidence regarding cancer in 2002, this Task Group reviewed evidence for a number of health effects, and updated the evidence regarding cancer. The conclusions and recommendations of the Task Group are presented in a WHO Environmental Health Criteria (EHC) monograph (WHO, 2007).

Following a standard health risk assessment process, the Task Group concluded that there are no substantive health issues related to ELF electric fields at levels generally encountered by members of the public. Thus the remainder of this fact sheet addresses predominantly the effects of exposure to ELF magnetic fields.

3.4 Short-term effects

There are established biological effects from acute exposure at high levels (well above 100 μT or 1000 mG) that are explained by recognized biophysical mechanisms. External ELF magnetic fields induce electric fields and currents in the body which, at very high field strengths, cause nerve and muscle stimulation and changes in nerve cell excitability in the central nervous system.

3.5 Potential long-term effects

Much of the scientific research examining long-term risks from ELF magnetic field exposure has focused on childhood leukaemia.

In 2002, IARC published a monograph classifying ELF magnetic fields as "possibly carcinogenic to humans". This classification issued to denote an agent for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals (other examples include coffee and welding fumes). This classification was based on pooled analyses of epidemiological studies demonstrating a consistent pattern of a two-fold increase in childhood leukaemia associated with average exposure to residential power-frequency magnetic field above 0.3 to 0.4 μT (3 to 4 mG). The Task Group concluded that additional studies since then do not alter the status of this classification. However, the epidemiological evidence is weakened by methodological problems, such as potential selection bias. In addition, there are no accepted biophysical mechanisms that would suggest that low-level exposures are involved in cancer development. Thus, if there were any effects from exposures to these low-level fields, it would have to be through a biological mechanism that is as yet unknown. Additionally, animal studies have been largely negative. Thus, on balance, the evidence related to childhood leukaemia is not strong enough to be considered causal.

Childhood leukaemia is a comparatively rare disease with a total annual number of new cases estimated to be 49,000 worldwide in 2000. Average magnetic field exposures above 0.3 μT (3 mG) in homes are rare: it is estimated that only between 1% and 4% of children live in such conditions. If the association between magnetic fields and childhood leukaemia is causal, the number of cases worldwide that might be attributable to magnetic field exposure is estimated to range from 100 to 2400 cases per year, based on values for the year 2000, representing 0.2 to 4.95% of the total incidence for that year. Thus, if ELF magnetic fields actually do increase the risk of the disease, when considered in a global context, the impact on public health of ELF EMF exposure would be limited.

A number of other adverse health effects have been studied for possible association with ELF magnetic field exposure. These include other childhood cancers, cancers in adults, depression, suicide, cardiovascular disorders, reproductive dysfunction, developmental disorders, immunological modifications, neurobehavioural effects and neurodegenerative disease.

The WHO Task Group concluded that scientific evidence supporting an association between ELF magnetic field exposure and all of these health effects is much weaker than for childhood leukaemia. In some instances (i.e. for cardiovascular disease or breast cancer) the evidence suggests that these fields do not cause them.

3.6 International exposure guidelines

Health effects related to short-term, high-level exposure have been established and form the basis of two international exposure limit guidelines (ICNIRP, 1998; IEEE, 2002). At present, these bodies consider the scientific evidence related to possible health effects from long-term, low-level exposure to ELF fields insufficient to justify lowering these quantitative exposure limits.

3.7 WHO's guidance

For high-level short-term exposures to EMF, adverse health effects have been scientifically established (ICNIRP, 2003).

International exposure guidelines designed to protect workers and the public from these effects should be adopted by policy makers.

EMF protection programs should include exposure measurements from sources where exposures might be expected to exceed limit values.

Regarding long-term effects, given the weakness of the evidence for a link between exposure to ELF magnetic fields and childhood leukaemia, the benefits of exposure reduction on health are unclear. In view of this situation, the following recommendations are given:

- Government and industry should monitor science and promote research programmes to further reduce the uncertainty of the scientific evidence on the health effects of ELF field exposure. Through the ELF risk assessment process, gaps in knowledge have been identified and these form the basis of a new research agenda.

- Member States are encouraged to establish effective and open communication programmes with all stakeholders to enable informed decision-making. These may include improving coordination and consultation among industry, local government, and citizens in the planning process for ELF EMF-emitting facilities.

- When constructing new facilities and designing new equipment, including appliances, low-cost ways of reducing exposures may be explored. Appropriate exposure reduction measures will vary from one country to another. However, policies based on the adoption of arbitrary low exposure limits are not warranted.

3.8 Further reading

WHO - World Health Organization. Extremely low frequency fields. Environmental Health Criteria, Vol. 238. Geneva, World Health Organization, 2007.

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Non-ionizing radiation, Part 1: Static and extremely low-frequency (ELF) electric and magnetic fields. Lyon, IARC, 2002 (Monographs on the Evaluation of Carcinogenic Risks to Humans, 80).

ICNIRP - International Commission on Non-Ionizing Radiation Protection. Exposure to static and low frequency electromagnetic fields, biological effects and health consequences (0-100 kHz). Bernhardt JH et al., eds. Oberschleissheim, International Commission on Non-ionizing Radiation Protection, 2003 (ICNIRP 13/2003).

ICNIRP – International Commission on Non-Ionizing Radiation Protection (1998). Guidelines for limiting exposure to time varying electric, magnetic and electromagnetic fields (up to 300 GHz). Health Physics 74(4), 494-522.

IEEE Standards Coordinating Committee 28. IEEE standard for safety levels with respect to human exposure to electromagnetic fields, 0-3 kHz. New York, NY, IEEE - The Institute of Electrical and Electronics Engineers, 2002 (IEEE Std C95.6-2002).

4. Interference with Electronic Devices

Electromagnetic immunity levels for electronic devices used in residential, commercial and light industry are specified in the Australian Standard AS/NZS 4251.1 "Electromagnetic Compatibility-Generic Immunity Standard", Part 1: Residential, commercial and light industry. 1:1994. The standard is technically equivalent to the European standard EN 50082-1 published in August 1997.

The immunity limits specified in the standards for low frequency EMF are summarised in the table below.

Device type	Residential / commercial environment
CRT displays	1.25 uT (12.5 mG)
Other equipment	3.75 uT (37.5 mG)

The cathode-ray-tube (CRT) based computer monitors which are commonly used in homes and offices are susceptible to EMF interference. The threshold level of sensitivity to the EMF for most 14” and 15” CRT based computer monitors is 10 mG. The monitors with 17” screens can be affected by the magnetic field less than 7 mG, while the monitors with 20”-21” screens can be affected by the magnetic fields less than 5mG.

The jittery screen of the EMF affected computer monitors could also be a source of adverse health effect through causing eye strain and headache for computer users.

D. Conclusions

It should be mentioned here that one of the important parameter that was taken into consideration during the design phase of the proposed Belmore Park 132kV/11kV Zone substation was the level of EMF emission from the substation site into the adjacent properties.

As part of the interactive design process the following changes from the standard design were implemented for this substation site:

1. Use of the 132kV GIS switchgear instead of the conventional air-insulated equipment.

2. Appropriate positioning of the EMF emitting equipment in the building – on the ground floor the transformers have been specially designed to fit all 5 transformers in a single file that reflects the optimum location furthest away from neighbouring buildings on both sides of the site.

3. Locating the 132kV and 11kV cables and switchgear on lower floors below the street level.

4. The layout has been optimised to minimise the impact of any additional EMF on neighbouring properties.

5. The 132kV and 11kV switchgear have been located 7m below ground which also reduces any impact.

The mitigation measures primarily related to the layout of equipment within the substation include:

- Access to the site will be restricted thus limiting exposure to higher fields within the substation to the general public.
- Where possible (taking into account the site constraints), equipment which produces the highest magnetic fields such as cables, busbars, transformers and switchgear have been positioned furthest away from adjoining property boundaries.
- Where possible (taking into account the site constraints), items which produce the lowest magnetic fields such as control rooms, equipment rooms, amenities, stairs, walkways, air vents/ducts and pilot isolation rooms have been positioned closest to the adjoining property boundaries.
- 11kV and 132kV loads will be balanced with minimum zero sequence current.
- Where possible, cables will be positioned in trefoil arrangement to reduce phase separation distances. Trefoil has the lowest fields compared to other configurations.
- Where possible, phase-by-phase grouping of single core cables in parallel circuits will be avoided.
- Where possible, cable trays will be positioned away from adjacent adjoining property boundaries.
- No exposed busbars will be present within the substation apart from the transformer connections within the transformer bays. Separation between the phases in the transformer bays is controlled by the transformer design and phase separation requirements.
- The incoming and outgoing connections will be installed underground using the most compact construction technically practicable.

Analysing the design of the proposed substation for the possible EMF emission levels into the area outside of its property boundaries the following conclusions can be made:

1. The proposed substation design and equipment layout resulted in substantial mitigation of the power frequency EMF emission from the substation into the area outside its property lines.
2. Analysing the substation design it is evident that thought all layers of the design process EnergyAustralia applied the principle of prudent avoidance that would result in low EMF emission from the proposed substation into the adjacent properties.
3. The anticipated maximum level of EMF emitted by the proposed substation into the area outside its boundaries both, in the horizontal and vertical directions will be lower than the EMF emitted by the common type overhead low voltage and high voltage open wire power distribution lines that exist in almost every residential suburban street.
4. Based on the results of the computer modelling and calculations it is determined that the highest EMF emission level from the substation electrical equipment is such that the magnetic field density at the substation boundaries will be less than 10% of the maximum permissible limit for safe human exposure recommended by the International Committee on Non-Ionising Radiation Protection in the guidelines published in 1998.
5. EMF emission from the proposed 24 air-core reactors of the capacitor banks warrants further investigation as the complete design data and installation details for this equipment is not yet available. Suffice to mention that the air-core reactors are strong emitters of EMF and, hence, their design, installation arrangement and position within the proposed substation is important for assessment of the EMF environment in all areas adjacent to the substation building.
6. The power frequency electric field to be emitted by the substation is negligibly small due to very effective shielding provided by metal enclosures of all main EMF emitting equipment and due to effective shielding by building materials such as brick, concrete, wood, etc.

7. Fast and high magnitude transient EMFs will be effectively suppressed and will not be emitted from the substation due to combination of measures such as enclosing the 132kV and 11kV switchgear into metal housings and provision of the underground cable connection to the substation instead of the overhead power lines.

The above conclusions and recommendations are based on the assumption that the background magnetic field near the proposed Belmore Park Zone Substation site and near the adjacent substation sites is equal to zero. In our EMF emission assessment study we assumed that the proposed substation site is not adjacent to any other source of EMF such as overhead power lines, underground cables or air-insulated outdoor substations.

EMF Consultant
Garry Melik

Appendix J

Study team

STUDY TEAM

SYDNEY CITYGRID PROJECT
ENVIRONMENTAL ASSESSMENT REPORTS

PlanCom Consulting Pty Ltd was commissioned by EnergyAustralia to prepare the Environmental Assessment Reports for the Sydney CityGrid Project Concept Application and the Belmore Park Zone Substation Project Application.

The following personnel were involved in the preparation of the Environmental Assessment Reports:

- Julian Ardas – Team Leader (PlanCom Consulting Pty Ltd)
- Margaret Harvie – Community Consultation (PlanCom Consulting Pty Ltd)
- Stuart Wilmot – Environmental Management (Urban Perspectives Pty Ltd)
- Alicia Hatton – Socio-Economics & Document Preparation
- Michael Gheorghiu – Environmental Assessment Support (Mecone Pty Ltd)
- Dick Godson – Noise & Vibration (Heggies Pty Ltd)
- Mark Irish – Noise & Vibration (Heggies Pty Ltd)
- Matthew Verth – Noise & Vibration (Heggies Pty Ltd)
- John Sleeman – Noise & Vibration (Heggies Pty Ltd)
- Robin Ormerod – Air Quality & Greenhouse Gas (Pacific Air & Environment Pty Ltd)
- Matt Scholl - Air Quality & Greenhouse Gas (Pacific Air & Environment Pty Ltd)
- Mary Casey – Non-Indigenous Archaeology (Casey & Lowe Pty Ltd)
- Tony Lowe - Non-Indigenous Archaeology(Casey & Lowe Pty Ltd)
- Steve Hammond – Landscape & Visual Amenity (PoD Landscape Architecture Pty Ltd)
- Kris Peterson – Landscape & Visual Amenity (PoD Landscape Architecture Pty Ltd)
- Alan Samsa - Traffic & Transportation (Samsa Consulting Pty Ltd)
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- Kerry Navin – Aboriginal Archaeology (Navin Officer Heritage Consultants Pty Ltd)
- Lindsay Smith – Aboriginal Archaeology (Navin Officer Heritage Consultants Pty Ltd)