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Electromagnetic Radiation Emissions from RAPS Equipment

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ABSTRACT

In recent years there has been growing concern about the potential link between various health effects, such as cancer and chronic exposure to low level Electromagnetic Radiation (EMR).

A report on residential exposure to 50 - 60 Hz electromagnetic radiation, published by the United Kingdom's National Radiation Protection Board (NRPB) found: "that there is some epidemiological evidence that prolonged exposure to higher levels of power frequency magnetic fields is associated with a small risk of leukaemia in children (AGNIR, 2001)."

The report concluded that: "heavy exposures of 0.4µT (4 mG) or more are associated with a doubling of the risk of leukaemia in children under fifteen years of age. The evidence is, however, not conclusive (AGNIR, 2001)."

Even though there is no conclusive scientific evidence of a direct relationship between cancer and chronic exposure to low level EMR there is sufficient concern to justify minimising exposure levels.

Regions of particular interest in the electromagnetic spectrum are the Extremely Low Frequency (ELF) 50 - 60 Hz, Very Low Frequency (VLF) 10 - 100 kHz and Radio Frequency (RF) 100 kHz - 300 GHz bands.

Remote area power supply (RAPS) systems are becoming increasingly prevalent. These systems tend to use renewable energy sources and their associated technology rather than the conventual power supply systems. Recently some concerns have been raised about the levels of EMR being emitted from these new forms of technology. Some of the inverters transforming the generated direct current (DC) to alternating current (AC) have produced significant levels of EMR. These devices are often located close to living areas and therefore increase the hazards to residents.

While the main aim of these systems is to replace non-renewable energy sources and reduce greenhouse gas emissions, they should also be designed to minimise the doses of EMR to which users are exposed.

This paper examines the various frequencies of EMR produced by typical remote area power supply systems (RAPS). The strengths of these fields are measured using various types of monitoring equipment and the health hazards assessed.

This research was conducted on a range of RAPS equipment including diesel generators and inverters. Fields were measured at various orientations as a function of distance from the sources. Even though no levels above the current health standards were found some magnetic fields above the 4 mG mark were measured. This level has been identified as a possible action level for chronic exposure to EMR.

The analysis of these results enables the qualitative assessment of the hazards associated with RAPS systems. This leads to a set of recommendations to system designers and health authorities on sensible measures to be adopted to minimise the potential risks from EMR to the users of RAPS systems.

1. INTRODUCTION

Remote area power supply (RAPS) systems are usually designed to suit individual power supply needs. They contain different combinations of renewable and fossil fuel generators. The make-up of these combinations depends on the location and load requirements of the system.

In many situations the solar panels or inverters are placed close to the dwelling (eg solar panels on the roof or inverters against the outer wall) due to design or engineering constraints.

The placement of these components in close proximity to areas regularly occupied by the residents may result in them being exposed to the various electromagnetic radiation (EMR) emissions from them.

The purpose of this study is to measure the EMR from RAPS system components in order to assess whether they pose any health significant risk to humans and if this occurs to make recommendations to minimise exposure to EMR.

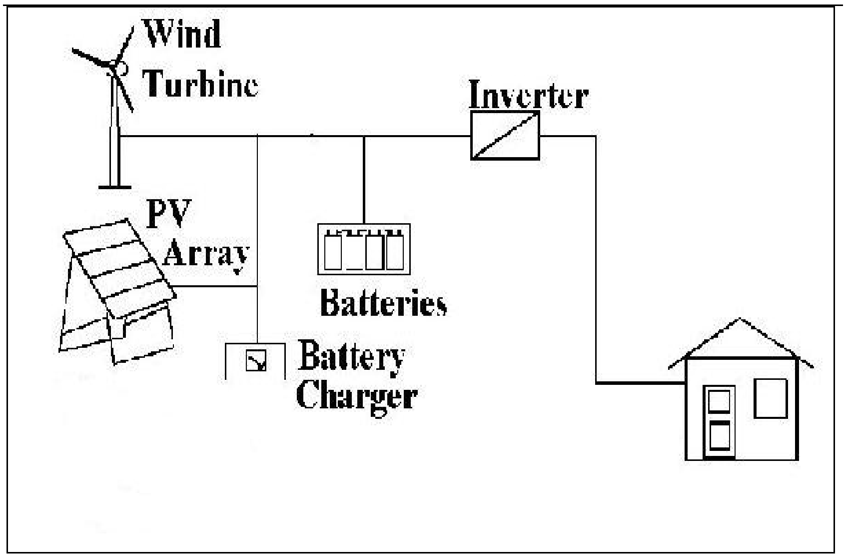
2 COMPONENTS OF A RAPS SYSTEM

There are three main categories of components in a RAPS system:

1. Energy Generation Equipment – such as diesel generators, solar panels and wind turbines.
2. Energy Storage Equipment – usually batteries.
3. Power Conversion and Control Equipment - controllers and inverters.

The schematic design of a typical RAPS system is shown in Figure 1.

Figure 1 Renewable Energy Powered RAPS System (Wilmot, 1994)



3 ELECTROMAGNETIC RADIATION

3.1 Radiation

Radiation is a form of energy transfer as a stream of particles or electromagnetic waves. Other methods of energy transfer are conduction or convection.

3.2 Electromagnetic Radiation

Electromagnetic radiation or energy (EMR or EME) is a wave consisting of time-varying electric and magnetic field components that travel or radiate through space. EMR travels at a constant speed of ~3×10^8 metres per second (speed of light). EMR is classified according to its frequency or wavelength.

3.3 Extremely Low Frequency

Extremely low frequency (ELF) radiation refers to the electromagnetic radiation at the lower end of the electromagnetic spectrum that has extremely low frequencies and energies (< 2000 Hz) such as power line radiation (50 - 60 Hz). It cannot transfer significant amounts of energy to human tissue because it is low energy and doesn't match the vibration frequencies of molecules in the human body.

3.4 Very Low Frequency

Very low frequency (VLF) radiation refers to the electromagnetic radiation that has frequencies ranging from 2 - 100 kHz such as emissions from PC screens.

3.5 Radiofrequency Radiation

Radiofrequency (RF) radiation is the commonly used term for describing emissions with frequencies ranging from 100 kHz - 300 GHz. A subset of this bandwidth is called the microwave (MW) region and represents frequencies from 1 - 300 GHz. Typically this describes the region where mobile phone communication systems, radio and TV stations operate. MW radiation, like infra-red radiation, has frequencies that are close to (or match) the natural frequency of vibration of many of the molecules making up the human body and it is therefore potentially biologically active.

All of these types of radiation are classified as non-ionising radiation. This means they are unable to break molecular bonds inside cells. It is for this reason that they are currently not recognised as being able to initiate the development of a cancerous growth.

4 HEALTH EFFECTS

For frequencies up to 100 kHz the main interaction of the electric and magnetic fields with tissue is the induction of currents. Exposure to frequencies above 100 kHz could result in the induction of currents and absorption of sufficient energy to cause significant temperature rises (UNEP/WHO/ICNIRP, 1998).

The health effects for both bands can be divided into two main areas, recognised and uncertain.

4.1 Recognised Health Effects

Exposure up to frequencies of 100 kHz

Because the wavelengths for these frequencies are greater than three kilometres it is more than likely that the measurements performed to establish field strengths will be conducted in the near field. There is no fixed relationship between the electric and magnetic fields within the near field. For this reason the effects of the magnetic and electric fields will be considered separately.

Electric Fields

The human body is completely penetrated by the electric field because the wavelengths are quite long in comparison to the dimensions of the body. However, the internal organs will be shielded from these fields because the human body can be a conductor. Therefore the main effects of electric fields are due to surface charges and small skin currents. The biological effects due to induced currents by electric fields are summarised in Table 1 (UNEP/WHO/IRPA, 1987).

Table 1 Biological Effects Due to Electric Fields of Frequency less than 100 kHz

Current Density	Biological Effect
Below 1 mA/m^2	No known effects. The background current densities in most body organs are in this range.
1 to 10 mA/m^2	Subtle biological effects such as changes in calcium metabolism or suppression of melatonin production (controls the day/night rhythm). The background current densities of the heart and brain are in this region.
10 and 100 mA/m^2	Clearly demonstrated effects, such as changes in protein and DNA syntheses and in enzyme activity, evident visual and possible nervous effects. The healing process of fractured bones can be accelerated or brought to a standstill.

100 and 1000 mA/m^2	Clearly demonstrated effects, such as changes in protein and DNA syntheses and in enzyme activity, evident visual and possible nervous effects. The healing process of fractured bones can be accelerated or brought to a standstill.
above 1000 mA/m^2	Extra systoles and ventricular fibrillation (heart dysfunction) can occur (acute health hazards).

Magnetic Fields
Establishing the internal field current strengths based on the information about the external flux densities is difficult. It is possible to calculate magnetic flux densities that would produce potentially hazardous current densities in tissues. The biological effects due to induced current densities generated by magnetic flux densities from whole body exposure to sinusoidal homogeneous fields are summarised in Table 2 (UNEP/WHO/IRPA, 1987).

Table 2 Biological Effects due to Magnetic Fields of Frequency less than 100 kHz

Magnetic Flux	Current Density	Biological Effect
0.5 – 5 mT	1 to 10 mA/m^2	minor biological effects have been reported
5 – 50 mT	10 to 100 mA/m^2	there are some well established effects, including visual and nervous system effects
50 – 500 mT	100 to 1000 mA/m^2	stimulation of excitable tissue is observed and there are possible health risks
Above 500 mT	above 1000 mA/m^2	extra systoles and ventricular fibrillation can occur (acute health hazards)

Exposure to EMR with Frequencies from 100 kHz up to 300GHz

Table 3 Biological Effects due to EMR with Frequencies from 100 kHz up to 300GHz

Biological Effects	Description and Frequency Range
Stimulation of nerve and muscle	For frequencies of 100 kHz up to 10 MHz, induced current density can excite muscles and nerves. Examples are acute changes in the central nervous system excitability and reversal of the visually evoked potential. The current density threshold level for these two effects is approximately 100 mA/m^2
Whole body and excessive localised tissue heating	For frequencies of 100 kHz up to 10 GHz increases in the core body temperature and excessive localised tissue heating of more than one or two degrees Celsius over prolonged periods can cause adverse health effects. These effects include heat exhaustion - headache, nausea, dizziness and heat stroke. Laboratory studies have established that the threshold specific absorption rate (SAR) for irreversible thermal damage of the most sensitive tissues is 4 Wkg^{-1} under normal environmental conditions
Surface heating of the body	For frequencies of 10 GHz up to 300 GHz the penetration depth past the skin layer is very small. The energy is absorbed at skin depth and surface heating occurs. This process is similar to surface tissue being heated by an infra-red lamp. The power density threshold for excessive heating of skin tissue and in tissue near the body surface is 500 Wm^{-2}.

4.2 Uncertain Health Effects

Exposure up to 100 kHz
There are many investigations and studies being performed worldwide in an attempt to establish the health effects of low level exposure to these electromagnetic fields. The investigations can be separated into seven main areas: carcinogenicity in animals; carcinogenicity in adults; carcinogenicity in children; non-cancer health effects in animals; non-cancer health effects in humans; environmental exposure; laboratory studies; in vitro and mechanistic studies (NAS, 1997).

The most important and definitely the most topical health effect arising from the exposure to ELF and VLF electromagnetic fields is the possible development of cancer.

Exposure to EMR with Frequencies from 100 kHz up to 300 GHz
There are many investigations and studies being performed worldwide in an attempt to establish the biological and health effects of low level exposure to RF electromagnetic fields. The investigations can be separated into eleven main areas: cellular and molecular biology; biochemical changes; reproduction, growth and development; effects on the nervous system; behavioural effects; neuroendocrine effects; cardiovascular effects; effects on hematopoiesis and haematology; effects on immune response; auditory response, ocular effects (Michaelson and Elson, 1996).

Again the most important and definitely the most topical health effect arising from the exposure to RF electromagnetic fields is the possible development of cancer. Currently, the results of the residential and occupational epidemiological studies are the ones of most interest.

4.3 Indirect Effects of Electromagnetic Fields

Unearthed metal objects exposed to electromagnetic fields up to the 300 GHz frequency range can acquire a charge and have a different electric potential. When the charged item is grounded by a person touching or brushing the unearthed metal object there is a flow of electrical charge. This flow of electric current may result in stimulation of muscles and/or peripheral nerves. With increasing levels of current this may be manifested as perception, pain from electric shock and/or burn, inability to release the object, difficulty in breathing and at very high currents cardiac ventricular fibrillation (Tenforde and Kaune, 1987).

5. MEASUREMENTS

5.1 Measurement Equipment

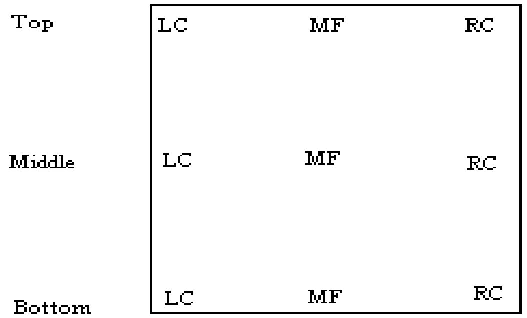
ELF	50/60Hz	Holaday Hi-3604 ELF / Power Frequency EMF Survey Meter
VLF	2 - 300 kHz	Holaday Hi-3603 VDT/VLF Radiation Survey Meter
RF	100 kHz – 2.06 GHz	Protek RF Field Strength Analyser

5.2 Measurement Methodology

Inverter Measurement Methodology for the ELF and VLF Range
There are a variety of inverters that are currently commercially available. They vary in design and operating size. Therefore, the manufacturer of the inverter should not be the most significant factor that affects the strength of the EMR emitted from these devices. But rather properties such topology, component selection, mechanical design and the level of screening incorporated into their design will control emission levels.

Since the actual design of the inverters may vary significantly from manufacturer to manufacturer, the location of the maximum and minimum EMR levels cannot be easily predicted. Hence, measurements were taken at nine locations across the surface of the front of the inverter (Figure 2) to establish the location of both the minimum and maximum EMR values for each distance from the inverter.

Figure 2 Measurement Locations on Inverters for ELF and VLF Range



The LCT refers to left-hand corner at the top, LCM refers to left side middle of face and LCB refers to left-hand corner at the bottom.

Measurements were taken at each of the nine positions for distances of 10, 20, 40, 80, and 160cm out from the outer surface of the inverter cabinet. The meter was aligned in each of the three axis to determine the axis with the maximum reading. This axis was then used for all further measurements of that particular inverter. This maximum axis was verified at other positions during the measurement.

This measurement represents the root mean square (rms) value of the power radiating through the detector. This value does not represent the true maximum value of the field strength but probably underestimates the true value to some degree. However, because of the squared relationship between field strength and distance from the inverter this underestimation is not significant enough to be considered an issue the further out the measurements are taken.

Measurement Methodology for the RF Range (0.150 – 2000 MHz)

The two pieces of equipment selected for these measurements were the diesel generator (Generator 1) and the 20 kVA inverter located in ACRELab at Murdoch University. The bandwidth chosen for the RF measurements is quite wide. It would not be practical to measure the spectrum in one scan. For this reason the RF band was broken into 19 different sections (Table 4). To establish if there were any significant RF emissions from the selected equipment, a background baseline was measured when the equipment was not operating. Measurement scans of the RF bandwidth were then completed when the equipment was operational.

Table 4 Measurement Sections for the RF Band (0.150 – 2000 MHz)

Name	Start (MHz)	Stop (MHz)	Step (kHz)	Attenuation (dB)
AM	0.150	1.71	10	-10
MHZ 1	1	20.78	120	-10
MHZ 2	20.08	39.16	120	-10
MHZ 3	39.16	58.24	120	-10
MHZ 4	58.24	77.32	120	-10
MHZ 5	77.32	96.4	120	-10
MHZ 6	96.4	115.48	120	-10
MHZ 7	115	274	1000	-10
MHZ 8	274	433	1000	-10
MHZ 9	433	592	1000	-10
MHZ 10	592	751	1000	-10
MHZ 11	751	910	1000	-10
MHZ 12	910	1069	1000	-10
GHZ 1	1069	1228	1000	-10
GHZ 2	1228	1387	1000	-10
GHZ 3	1387	1546	1000	-10
GHZ 4	1546	1705	1000	-10
GHZ 5	1705	1864	1000	-10
GHZ 6	1864	2000	1000	-10

Because of the possibility of spurious results occurring during measurements the bandwidth was scanned four separate times for each of the operational and non-operational situations for the generator and inverter. These multiple measurements allowed for signal averaging, reducing the impact of anomalous measurements. To eliminate the issue of transient features data smoothing was carried out using the data smoothing tool available on the EasyPlot program

The RF measurements when the equipment was operating and the background levels were then plotted using EasyPlot. The difference between the two measurements was also plotted.

Boundary lines of +3dB above the base line and -3dB below the base line were plotted on the graphs as well. These boundary lines represent the $\pm$ 3dB instrument accuracy for the RF measurements.
The 19 scans as per Table 2 were then combined to produce a series of scans.

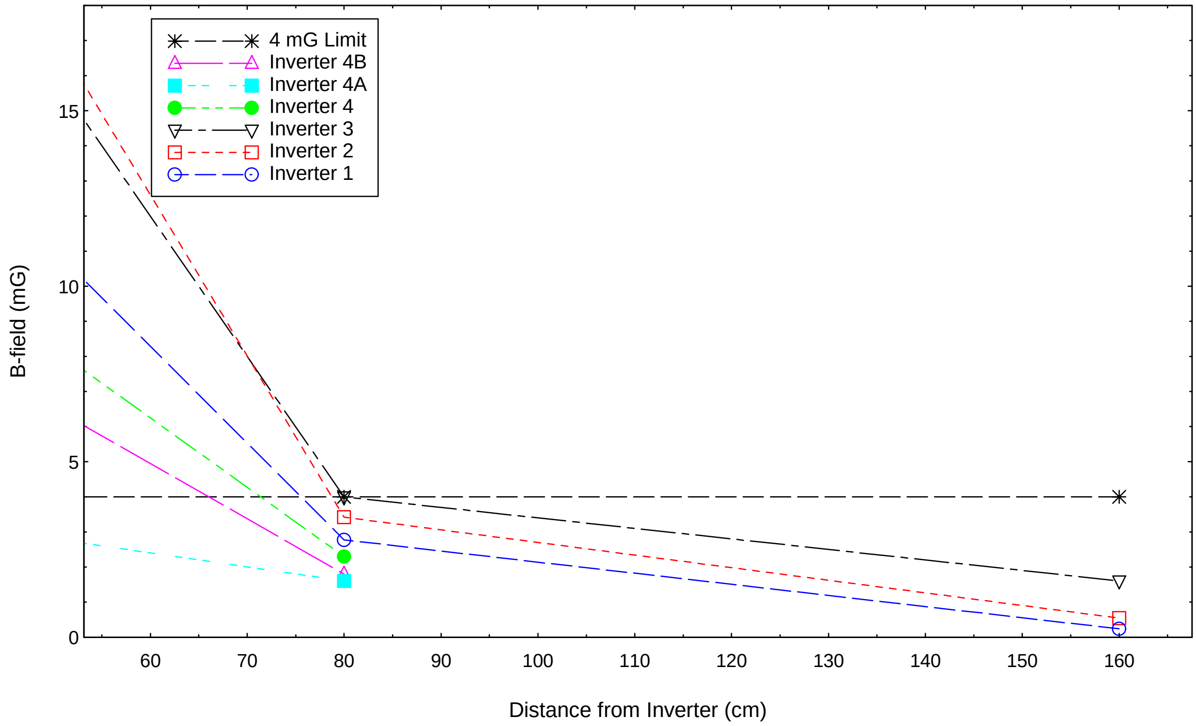
6 RESULTS

6.1 Inverters

ELF and VLF

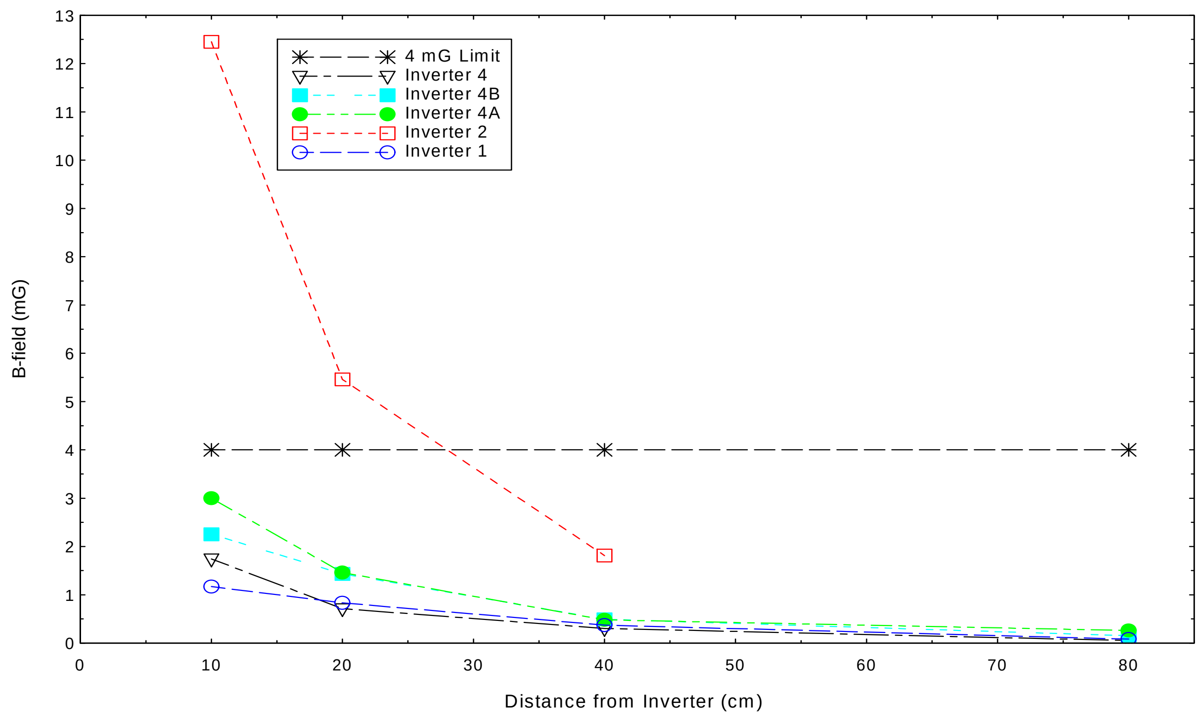
The maximum ELF B-field levels measured for all the inverters ranged from 42 up to 327 mG. The strength of the B-fields from all of these inverters dropped below 4 mG at a distance of approximately 80cm from the inverters (Figure 3).

Figure 3 Maximum ELF B-Field for Various Inverters



The maximum ELF E-field level measured for all the inverters was well below the 5kVm^{-1} maximum specified by the current Australian Standards (NHMRC, 1989).

Figure 4 Maximum VLF B-Field Levels for Various Inverters



The maximum VLF H-field level measured for all the inverters was 996mA/m, which is well below the recommended ICNIRP limit of 2.43 to 5 A/m for the 3 to 300 kHz band (UNEP/WHO/ICNIRP, 1998).

The maximum VLF E-field level measured for all the inverters was 0.96 V/m, which is well below the recommended ICNIRP limit of 87 Vm^{-1} for the 3 to 300 kHz bandwidth (UNEP/WHO/ICNIRP, 1998).

RF Levels
There were some measurable RF EMR emissions, in the 0.15 to 77.5 MHz band above background from the inverter, when it was operating. There were no significant RF EMR emissions measured above background in the 77.5 to 2000 MHz band.

6.2 Generators

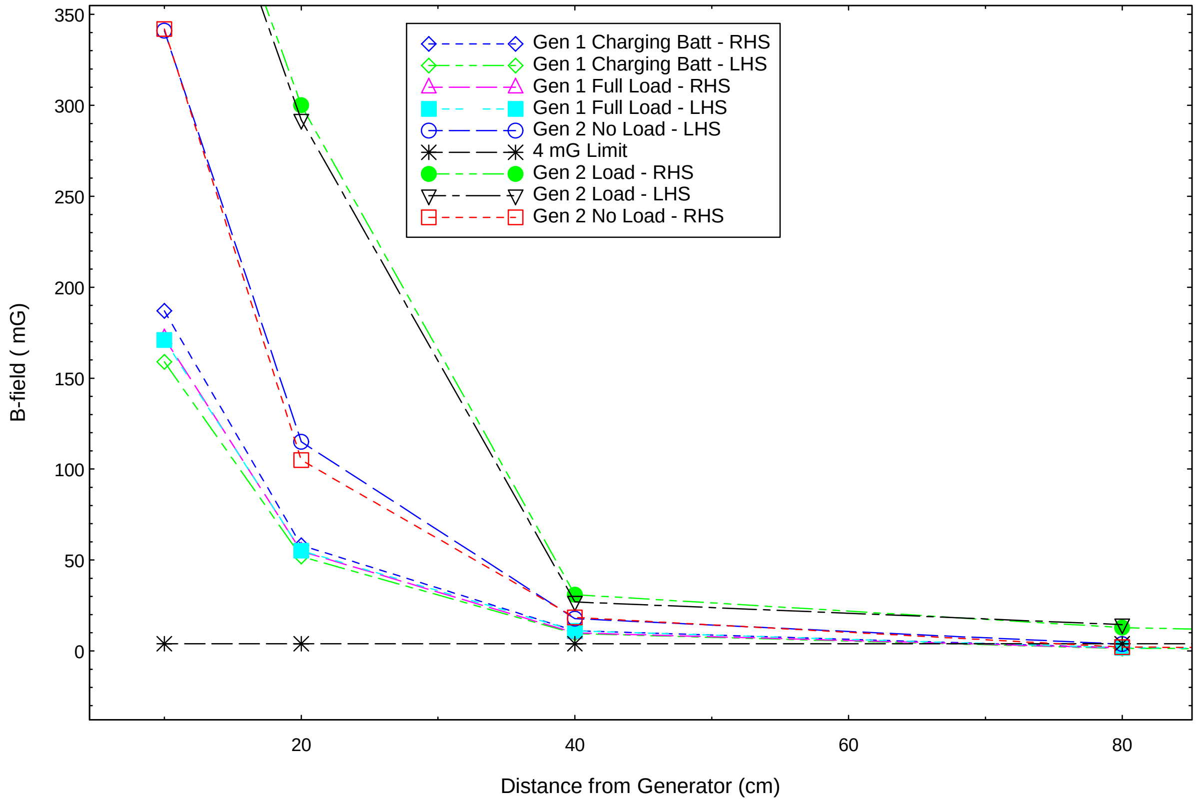
ELF and VLF
The maximum ELF B-field levels measured for all the generators measured ranged from 42 up to 327 mG. The strength of the B-fields from these inverters all dropped below 4 mG at a distance of approximately 80cm from the generators (Figure 5).

The maximum ELF E-field level measured was 7 V/m on the LHS at 10cm. This is well below the 5kVm^{-1} limit specified in the Australian Standards.

The maximum VLF H-field level measured was 35 mA/m on the LHS at 10cm. This is below the recommended ICNIRP limit of 2.43 to 5 A/m for the 3 to 300 kHz bandwidth.

The maximum VLF E-field level measured was 0.12 V/m at 10cm on the LHS. This is well below the 87 Vm^{-1} ICNIRP limit.

Figure 5 Generator ELF B-Field Strength Vs Distance



RF Levels
There were no significant RF EMR levels measured above background from the generators when they were operating. This result is not surprising because the diesel generator is commercially produced and would be required to adhere to electromagnetic compatibility (EMC) requirements.

6.3 Battery Bank

The maximum ELF B-field level measured was 9.24 mG at the middle – RC location at 10cm. The measured B-field for all locations dropped below the 4 mG mark at a distance of 40cm from the outer surface of the cabinet.

The maximum E-field measured was 26.6 V/m at the middle – RC location at a distance 40cm.

7 CONCLUSIONS

- Some RAPS equipment does emit EMR at levels likely to cause concern (B>4mG).
- However provided these devices are situated at least 1.6 metres from regularly occupied areas there should be no cause for concern.
- The major sources of EMR emissions are generators, inverters and battery banks.
- The main area of concern is ELF magnetic fields emitted by this equipment
- Some inverters also produce detectable RF emissions

8 RECOMMENDATIONS

Until research determines whether there are health hazards associated with chronic exposure to low level EMR in the ELF, VLF and RF bands a precautionary approach is advisable.

Simple steps like the appropriate placement of the various components of RAPS systems ie at distances greater than 160cm for inverters and generators from regularly occupied areas are recommended.

The elevated levels of RF EMR emitted by RAPS inverters in the 0.15 to 77.5 MHz bandwidth should be investigated further. In particular, the reduction of these elevated levels may be achieved using technical solutions of minimal cost. This is justified because there is a possibility of health hazards being associated with long term exposure to low level RF EMR.

As the technology of RAPS systems develops, the levels of EMR from new generations of RAPS system components should be checked.

EMR limits and testing procedures for inverters and generators should therefore be included in the standards that are being developed for RAPS systems.

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