**Why batteries used in Underground Safety Refuge Chambers fail prematurely**

In February 2012 we were approached to source batteries for use in underground refuge facilities.
We were provided with a photo of the sample (see below) and was told that this sort of problem was common in all refuges. At first glance it looked like the batteries had been overcharged but without visiting site to inspect the facilities there was no concrete reason to suspect this, as the prevailing opinion was that high operating temperatures was the probable cause the batteries where failing.
We began by looking at alternative battery types eventually settling on the EnduroGel from Power Charge.
This decision was made on the basis of its higher tolerance of temperature, its “Catalyst” technology, longer design life and because it came highly recommended.
We supplied the Enduro’s for a couple of years without any feedback and assumed the change had been positive for the mine and was were surprised when in early 2015 we received a call from the mine querying the quality of the Enduros because of their high premature failure rates.
The Enduro's had suffered the same fate as their predecessors but at a faster rate and we became suspicious of the refuges charging systems.
It was only after we began supplying another mine with batteries that we realised there was a serious problem with how the electrical system had been set up in the Refuge Chambers. Recently we have had the opportunity to investigate.


Destroyed Battery


Power Charge EnduroGel

In this report a number of recommendations are made although at the time of writing this report there is no guarantee that the problem of premature battery failure will be remedied.
These are recommendations based on the findings of the limited study we have conducted.
Implementing some or all of the recommendations will reduce the *probability* of failure and should enhance the refuges operational efficiency. It is only by implementing the changes and monitoring the batteries over a period of two years that concrete evidence the changes made, will have led to success.

In the end all the manufactures of the various batteries state that depending on the type and operating environment, their batteries have an eight to fifteen year *design* life. Therefore it is reasonable to expect that with correct installation and operation at least half of that life be realised.

We found that the *primary* cause of premature failure was inconsistent charging due to:
a). the chargers used being unsuitable for purpose and
b). the configuration of how the battery banks are wired which, depending on the configuration, caused over charge in some batteries and undercharge in others leading to swelling or loss of capacity and premature failure.

*The more concerning aspect of this research is the realisation that should the refuges be used in an emergency there is a strong possibility that they may not perform reliably for the thirty six hour period required.*

The purpose behind this study is to find measures and make recommendations that will ensure that the refuges will perform as expected.

**Case Study** - MinaArc 1367 Safety Refuge

The alarm was raised with this refuge when a routine check picked up that the installed two way radio was not operational. When the problem was investigated it was found that the battery banks were in a serious state decline.

The batteries (16 x RITAR RA12-150) were all in an overly discharged condition with cell numbers 10,12,14,16 (Refer diagram below) completely destroyed.
Temperature of batteries was 30.1 Deg C
The charger installed was a Magellan 24Siii035. A 35 amp float charger set at 27.2V
The estimated age of the battery bank is 25-26 Months as of January 2016

In this instance 16 batteries were being charged at the top of a string of two paralleled banks.
However, at the bottom of bank 2, two long paralleling cables were connected to cells 12 and 16 joined cells 4 and 8 in bank 1 (see fig 1) essentially forming a single 24V bank.
It is unlikely that these paralleling cables were fitted by the manufacturer and may have been added later.
It is also questionable whether this particular charger would have contributed to premature failure.

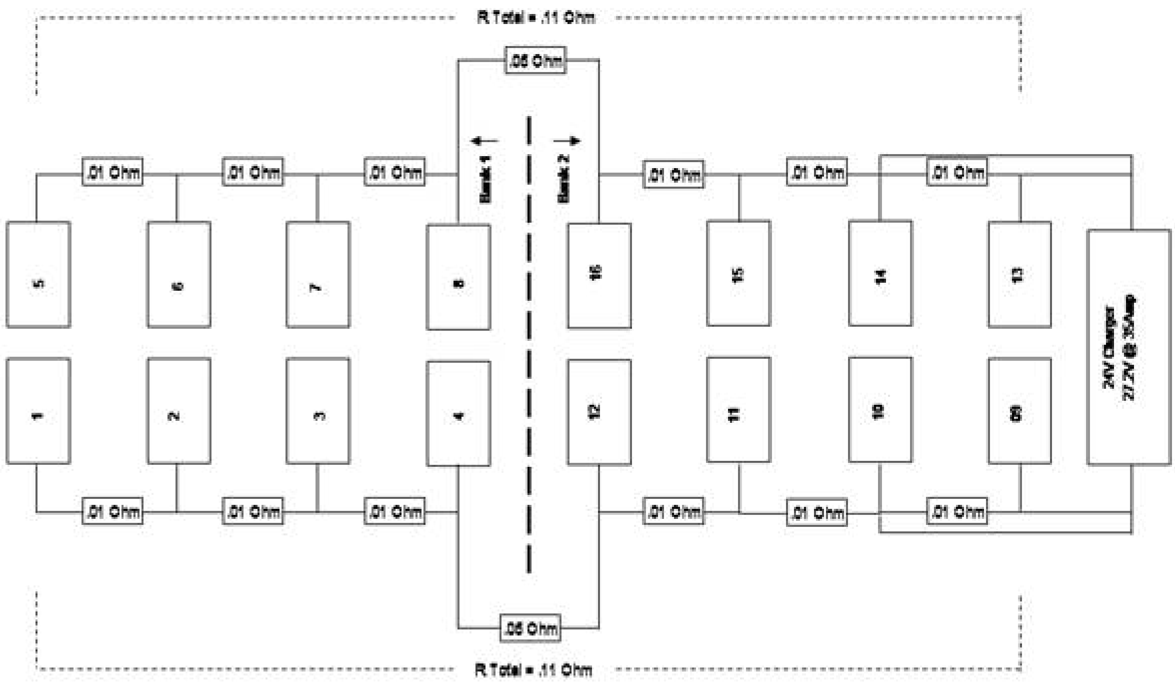



Fig 1

The interconnecting cables are essentially resistors albeit of a very low value.
As a consequence of this resistance the batteries in 1 would never have charged at the same rate as the others in bank 2 and therefore would never have received their proper share of charge current.
The voltage drop across the paralleling cables raised the voltage across bank two caused it to become overcharged and as a consequence cells 12 + 16 and 11 + 14 failed, suffering major swelling.
Over time probably within the later half of their first year, the batteries in bank one would have begun to deteriorate with sulphation and with their internal resistance rising this exacerbated the plight of those batteries in bank 2.

The battery charger had also failed with its SCR module becoming open circuited causing the entire bank to be over discharged

Twelve of batteries were recovered from the MineArc 12man 1367 refuge.
Battery type are Ritar – RA12-150.
Initial inspection showed their physical condition to be quite good with no swelling evident
Their individual voltages (no load) were between 5.3 and 5.7V
These batteries had been in this condition for about three weeks that we know of.

Out of the remaining batteries, four were chosen from bank 1. The top two sets in the parallel string battery Numbers 1&5, 2&6. See Fig 2

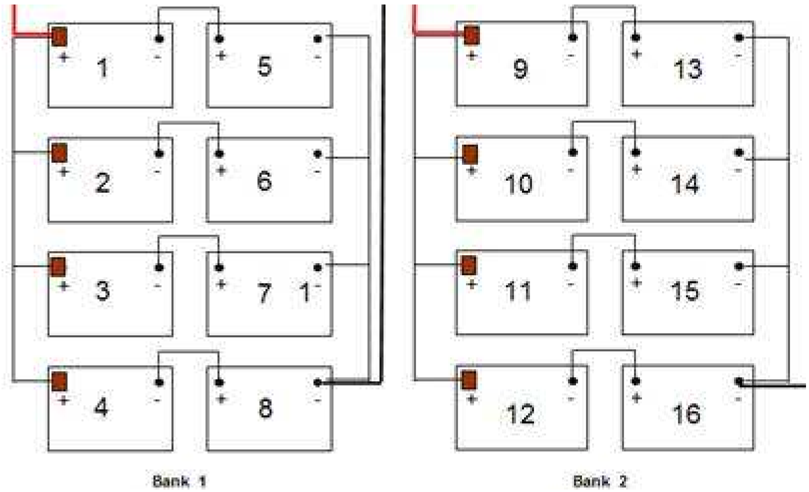



Fig 2

The following tests were carried out:

**Method:**

**Each battery** (1&5, 2&6) was individually placed on charge over 24 hours as follows:

13 hours Bulk charge to 14.5 volts @ 15 Amps
5 hours Absorption 14.2 volts @ 10 amps gradually reducing to 4 amps
8 hours Float 13.8 volts @ 3 amps gradually reducing to 600 mA
and finally 300-400mA when fully charged.

The batteries were then left for 1 day without charge and their individual voltages measured without load. All were between 13.07 and 13.06 volts.
All were left another 3 days re-measured with the same result.
Impedances were perfect @ between 3.5-3.7 MΩ

A 2 amp load was placed across each for 10 minutes (.3AH) and Voltage measured

Battery #1`=12.78V
Battery #2 =12.78V
Battery #5 =12.77V
Battery #6 =12.78V

Measured after 20mins recovery no load

Battery #1 =13.04V
Battery #2 =13.04V
Battery #5 =12.99V
Battery #6 =13.03V

The four remaining batteries from bank 1 Battery Numbers 3&7, 4&8 and those from bank 2 9&13, 10&14 where similarly charged using the above method. Battery Numbers 3&7, 4&8 responded identically to 1&5, 2&6 and all eight batteries were recovered and deemed fit for service. However, those from bank two although they started the cycling process with promising results never fully recovered with regards to internal impedances ranging from 10 – 30 MΩ and capacity under the test load of 30 amps fell quickly away after a few minutes. (See end of report)

**Observations**

1). Charging batteries at the 15A rate above took on average just on 24 hours per battery (approx 220 AH). (13 hrs @ 15A = 195AH + 5hrs @ 5A = 25AH + 8hrs @1.5A reducing to 600mA = <> 5) = 225AH after which each battery displayed nearly identical characteristics in impedance, charge time, voltage and float charge current. The large amount of charge required was due to their very low discharge state.

2). If the original charger had been used to float charge the same at @4 amp rate that time would probably be doubled.
It would take approx 55 hours – per battery or 220 hours (8 days) per bank (8 x 55Hr)

3). A close eye needs to be kept on the float voltage. It needs to be set for each battery brand and type.
There is a natural current required by a battery in relation to preventing self discharge,
In this case it was around 50 mA@ 13.45V. This was required to maintain full charge at 2.24 VPC
The point at which negligible current is drawn is – 2.17VPC (13.07 Volts)

4). It appears essential that an equalising charge needs to be placed across the battery (or bank of batteries) at regular intervals and indeed is stated on the manufacturers spec sheet

**Four batteries** (1&5, 2&6) wired in parallel and placed on float charge for 48 hours @ 13.8V, float current dropped from an initial 5 amps to .8A. (200mA per battery)

A 15 amp load was placed on the bank for three hours removing 45AH capacity as follows:

| | |
|---|---|
| 8:33am | – 15.2A @ 13.05 |
| 8:34am | – 15.2A @ 12.80 |
| 9:33am | – 15.4A @ 12.74 |
| 10:31am | – 15.4A @ 12.72 |
| 11:30am | – 15.5A @ 12.71 |

The bank was placed back on the charger for 24 hours (bulk and absorbsion stages unobserved).
Float voltage measured at the end of charging was 13.8V @ .8A (200mA per Battery)
Left on float further 24 hrs current dropped to .3A (75mA per Battery).
Float voltage reduced to 13.5 Volts – initially no current drawn
Measured after 10 minutes – current = .18A (45mA per Battery)
Float voltage reduced further to 13.2V – initially no current drawn rising to .18A (45 mA per Battery)

A load drawing 30 Amps was placed across the bank for nine hours – removing 270 AH capacity as follows

| | |
|---|---|
| 1:38pm | – 30A @ 13.38V |
| 1:39pm | – 30A @ 12.63V |
| 4:00pm | – 30A @ 12.53V |
| 8:30pm | – 29.3A@ 12.29V |
| 10:20pm | – 29.3A@ 12.19V |

The load was removed and the bank immediately placed back onto charge @ 15 A with charging completed within 19 hrs going to float @ 6.30-700pm – Float Current then 1.5A. Batteries left on float for further 12 hours float current reducing to 50mA or 12.5mA per battery. Impedances re-measured

Battery #1`=3.46 MΩ
Battery #2 =3.19 MΩ
Battery #5 =3.40 MΩ
Battery #6 =3.13 MΩ

The batteries where allowed to stand for further 12 hours and measurements taken.

| | |
|---|---|
| Battery #1`=13.15V | (not measured – undergoing further testing) |
| Battery #2 =13.14V | Battery #2 =3.74 MΩ |
| Battery #5 =13.15V | Battery #5 =3.41 MΩ |
| Battery #6 =13.13V` | Battery #6 =3.69 MΩ |

The same tests were carried out on Batteries 3&7, 4&8 with similar results.

**Single Battery Load Test:**

A fully charged battery which had been charged and left for 3 days was used for this test.

| | | |
|---|---|---|
| 1). | Starting voltage no load | 13.13V |
| 2). | Apply load @30 Amps | 12.50V |
| 3) | After 60 Seconds | 12.30V |
| 4). | After 120 Seconds | 12.30V |
| 5) | After 5 Minutes | 12.40V |
| 6). | After 30 Minutes | 12.36V |
| 7). | After 60 Minutes | 12.22V |

Power Charge ENDUROGEL 12V 170Ah results of two batteries tested.

Battery 1- Impedance: 3.47 MΩ

| | | |
|---|---|---|
| 1). | Starting voltage no load | 13.64V |
| 2). | Apply load @30 Amps | 12.70V |
| 3) | After 60 Seconds | -------V |
| 4). | After 120 Seconds | 13.37V |
| 5) | After 5 Minutes | 13.43V |
| 6). | After 30 Minutes | 13.46V |
| 7). | After 60 Minutes | 13.46V |

Battery 2 – impedance: 3.58 MΩ

| | | |
|---|---|---|
| 1). | Starting voltage no load | 13.48V |
| 2). | Apply load @30 Amps | 12.54V |
| 3) | After 60 Seconds | 13.06V |
| 4). | After 120 Seconds | 13.08V |
| 5) | After 5 Minutes | 13.14V |
| 6). | After 30 Minutes | 13.17V |
| 7). | After 60 Minutes | 13.17V |

**Final Results:**

At the end of testing all eight batteries were placed on a full charge cycle and left for 24 hours re-measured under a 1 amp resistive load and deemed fit for service.

Battery #1`= 3.68MΩ
Battery #2 = 3.96MΩ
Battery #5 = 3.56MΩ
Battery #6 = 3.87MΩ
Battery #3`= 3.93MΩ
Battery #4 = 3.58MΩ
Battery #7 = 3.39MΩ
Battery #8 = 3.46MΩ

Battery #1`= 13.04V
Battery #2 = 13.02V
Battery #5 = 13.00V
Battery #6 = 13.03V
Battery #3`= 13.02V
Battery #4 = 13.01V
Battery #7 = 13.03V
Battery #8 = 13.08V

Bank 2 batteries 9&13, 10&14 were unrecoverable

Battery #9 `= 18.8MΩ
Battery #10 = too high to measure
Battery #11 = 12.8MΩ
Battery #13 = 12.7MΩ

Battery #9 `= 12.90V
Battery #10 = wont accept charge
Battery #11 = 12.83V
Battery #13 = 12.73V

The refuge has had the paralleling cable removed see fig 3 below and has been fitted with a new Victron seven step charger with temperature compensation.

The condition of the batteries will be monitored and recorded each month.

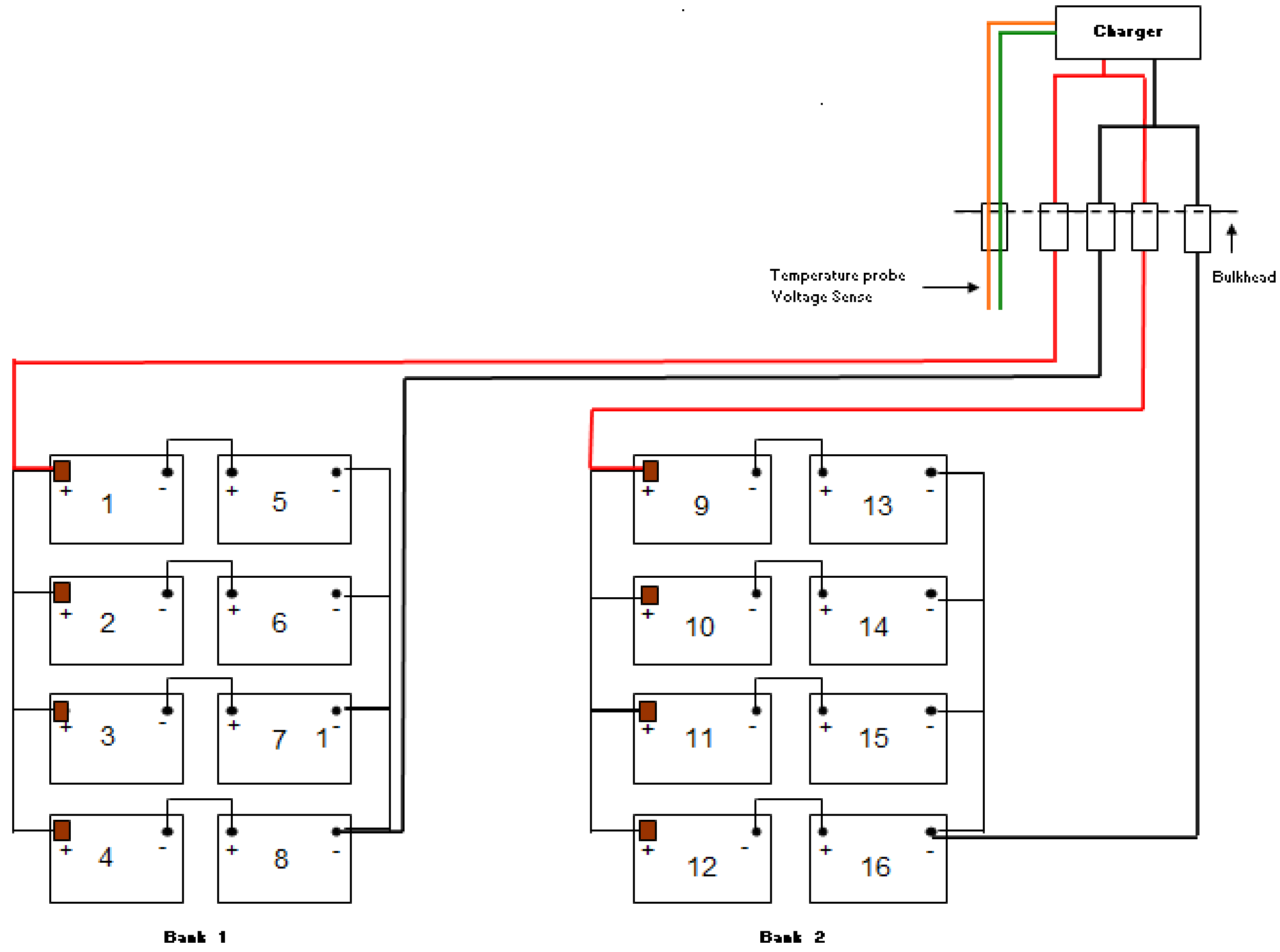



Fig 3

**<u>Case Study</u>** – Strata 12 man Refuge Chamber

During routine testing it was found that the batteries in this chamber failed under load – before the batteries were replaced we looked at its wiring configuration – see fig 5
Unfortunately we don't know how old the original batteries are but most of them had swelled.
The charger used here is an AMTEX 1K-110FTSA 108-125V, 9 amp. The charger was set for 108Vor 2.25Vpc.

The individual battery voltages had been audited for two months prior recording voltage and impedances see fig 4 of particular concern is that the batteries in this refuge failed well before December

| Refuge 1694 | FirstPwr Battery # | Internal Resistance M.Ohm | Internal Resistance M.Ohm | Internal Resistance M.Ohm |
|---|---|---|---|---|
| DATE | | 01/12/2015 | 01/01/2016 | 01/02/2016 |
| Temp | | 24.2C | 20.C | .C |
| | A1 | 10.40 | 12.40 | 13.80 |
| | A2 | 10.00 | 12.30 | 14.30 |
| | A3 | 82.80 | 141.30 | 184.20 |
| | A4 | 158.00 | 200.90 | 281.40 |
| | A5 | 17.60 | 62.40 | 19.10 |
| | A6 | 33.40 | 36.30 | 29.20 |
| | A7 | 27.70 | 28.50 | 12.70 |
| | A8 | 23.00 | 23.80 | 12.00 |
| Z Δ mΩ | | 148.00 | 188.60 | 269.40 |
| | B1 | 9.40 | 26.50 | 21.10 |
| | B2 | 10.00 | 41.30 | 42.10 |
| | B3 | 33.80 | 30.70 | 31.70 |
| | B4 | 11.50 | 14.20 | 25.80 |
| | B5 | 17.00 | 17.10 | 21.80 |
| | B6 | 40.00 | 44.10 | 33.20 |
| | B7 | 30.00 | 31.80 | 50.30 |
| | B8 | 19.00 | 22.00 | 25.40 |
| Z Δ mΩ | | 30.60 | 29.90 | 29.20 |

| | Battery No | Battery Voltage | Battery Voltage | Battery Voltage |
|---|---|---|---|---|
| DATE | | 01-12-15 | 01-01-16 | 01-02-16 |
| | A1 | 13.74 | 13.58 | 13.60 |
| | A2 | 13.61 | 13.49 | 13.52 |
| | A3 | 14.32 | 14.33 | 14.15 |
| | A4 | 12.00 | 11.90 | 12.25 |
| | A5 | 13.39 | 13.41 | 13.47 |
| | A6 | 13.80 | 13.54 | 13.38 |
| | A7 | 14.80 | 13.35 | 13.51 |
| | A8 | 13.51 | 13.45 | 13.65 |
| | Bank V | 109.17 | 107.05 | 107.53 |
| Average | | 13.65 | 13.38 | 13.44 |
| Cel Δ V | | 2.80 | 2.43 | 1.90 |
| Vpc | | 2.27 | 2.23 | 2.24 |
| | B1 | 13.80 | 13.83 | 13.65 |
| | B2 | 13.70 | 13.24 | 13.38 |
| | B3 | 13.00 | 13.22 | 13.43 |
| | B4 | 13.60 | 13.55 | 13.48 |
| | B5 | 13.50 | 13.33 | 13.39 |
| | B6 | 13.90 | 13.50 | 13.35 |
| | B7 | 13.37 | 13.41 | 13.52 |
| | B8 | 13.40 | 13.42 | 13.43 |
| | Bank V | 108.27 | 107.50 | 107.63 |
| Average | | 13.53 | 13.44 | 13.45 |
| Cel Δ V | | 0.90 | 0.61 | 0.30 |

Fig 4

Auditing in this fashion had only just begun and personnel noted significant changes and minor swelling and decided to carry out a load test on each battery the results of which were alarming.

| DATE | | 01/12/2015 | 01/01/2016 | 01/02/2016 | |
|---|---|---|---|---|---|
| Z Δ mΩ | | 0.00 | | | |
| | Battery No | Battery Voltage | Battery Voltage | Battery Voltage | Battery Voltage |
| DATE | | 01-12-15 | 01-01-16 | 01-02-16 | load test |
| | A1 | 13.74 | 13.58 | 13.60 | 10.80 |
| | A2 | 13.61 | 13.49 | 13.52 | 11.00 |
| | A3 | 14.32 | 14.33 | 14.15 | 1.00 |
| | A4 | 12.00 | 11.90 | 12.25 | 7.00 |
| | A5 | 13.39 | 13.41 | 13.47 | 9.80 |
| | A6 | 13.80 | 13.54 | 13.38 | 6.60 |
| | A7 | 14.80 | 13.35 | 13.51 | 10.80 |
| | A8 | 13.51 | 13.45 | 13.65 | 11.21 |
| | Bank V | 109.17 | 107.05 | 107.53 | 68.21 |
| Average | | 13.65 | 13.38 | 13.44 | 8.53 |
| Cell Δ V | | 2.80 | 2.43 | 1.90 | 10.21 |
| Vpc | | 2.27 | 2.23 | 2.24 | 1.42 |
| | B1 | 13.80 | 13.83 | 13.65 | 10.20 |
| | B2 | 13.70 | 13.24 | 13.38 | 8.00 |
| | B3 | 13.00 | 13.22 | 13.43 | 9.20 |
| | B4 | 13.60 | 13.55 | 13.48 | 10.40 |
| | B5 | 13.50 | 13.33 | 13.39 | 10.20 |
| | B6 | 13.90 | 13.50 | 13.35 | 8.20 |
| | B7 | 13.37 | 13.41 | 13.52 | 13.49 |
| | B8 | 13.40 | 13.42 | 13.43 | 10.00 |
| | Bank V | 108.27 | 107.50 | 107.63 | 79.69 |
| Average | | 13.53 | 13.44 | 13.45 | 9.96 |
| Cell Δ V | | 0.90 | 0.61 | 0.30 | 5.49 |
| Vpc | | 2.26 | 2.24 | 2.24 | 1.66 |

This refuge had two banks wired for 100 volt operation. They were stored on two shelves similar to the example below

Between the top and bottom banks two long harnesses were used to interconnect each other to form the 100V string.

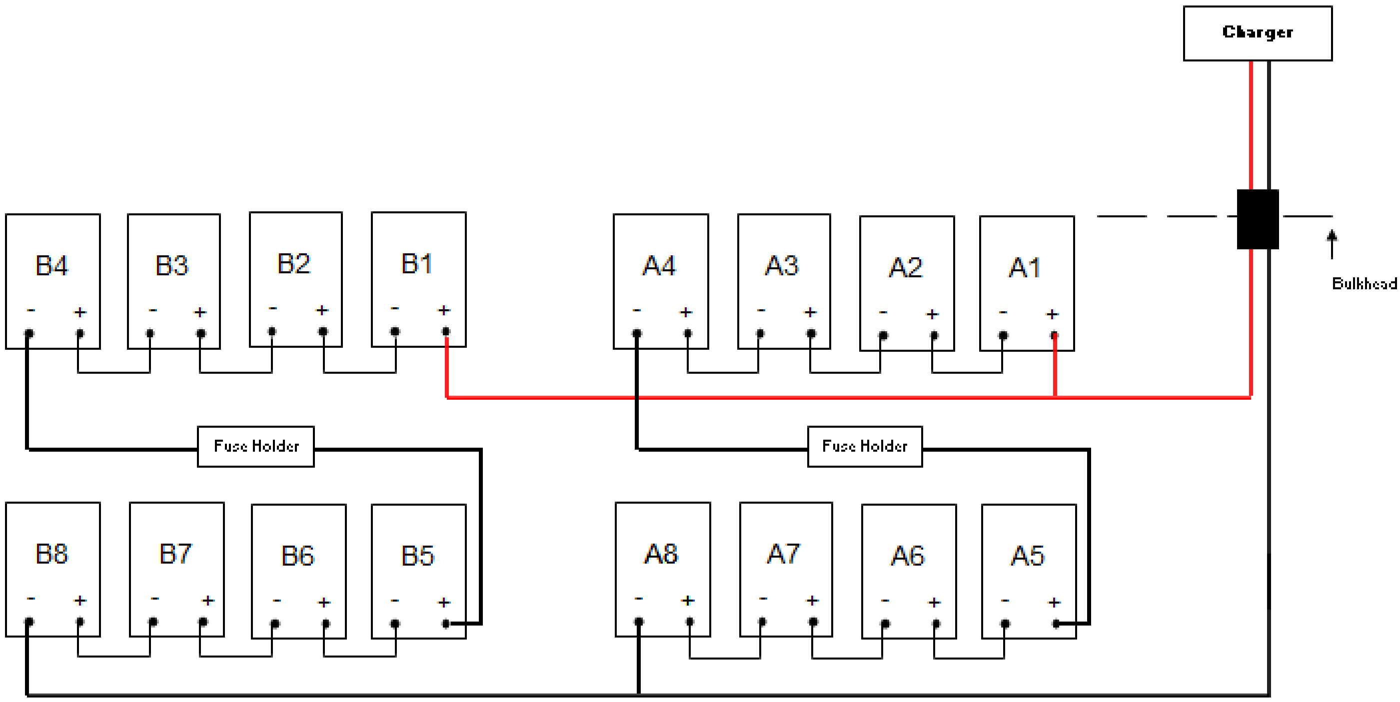



Fig 5

One striking thing to note is that without doing both impedance and load testing, it is very difficult to detect there is a potential problem. This is because although significantly different, individual battery voltages *seemed* ok especially in bank two where variances were quite small compared to bank one.
When the refuge was routinely checked the 240v inverter is run for around thirty minutes and this small load would not have been enough to raise an alarm that something was amiss.

Analysing the batteries, it was found that none could be recovered, all had very high impedance measurements and all had evidence of swelling – some more than others.
Temperatures varying between 20-26 degrees C is unlikely to be a contributor to the failure of these batteries as is the charging voltage which was set at 108 Volts.

Looking at the figures above (see fig 4) – it can be seen that in December, both bank voltages were higher than the following two months, note also that bank A is significantly higher than bank B, corresponding with it's higher impedances as well. I think this can be explained by how the banks are configured

Referring to fig 5 above.
Bank A is the first point at which the charge is placed having for all intents no resistance. As bank B access's its charge a voltage drop in the harness raises the voltage across Bank A eventually leading to overcharge and an undercharge on Bank B, similarly the long interconnecting cables introduced between each bank will have the same effect eg, A1 – A4 will receive more charge than A5 – A8

Note that A4 had a significantly higher impedance and lower voltage than A3 which had significantly lower impedance and higher voltage across it. A3 was also a different brand of battery.

Without knowing the complete history of these batteries it is extremely difficult to conclude that the harness alone is the cause of the failure.

This refuge has been reconfigured – and will be monitored for performance over a two year period.
When installing the new batteries – the float voltage was increased to110V for 24 hours before reducing it back to 107.5V. All the batteries with the exception of A6 equalised out and this will be closely monitored.

**Installation Date** 23/02/2016
**Battery Type** FirstPower 12V 150AH LFP12150FT

Bank 1 Float Current .01A
Bank 2 Float Current .01A
**Total Float Curren .02A**

Measured Float Voltage **A** 109.6V
Measured Float Voltage **B** 109.6V

**Charger Type**
AMTEX BCH1K-110ST

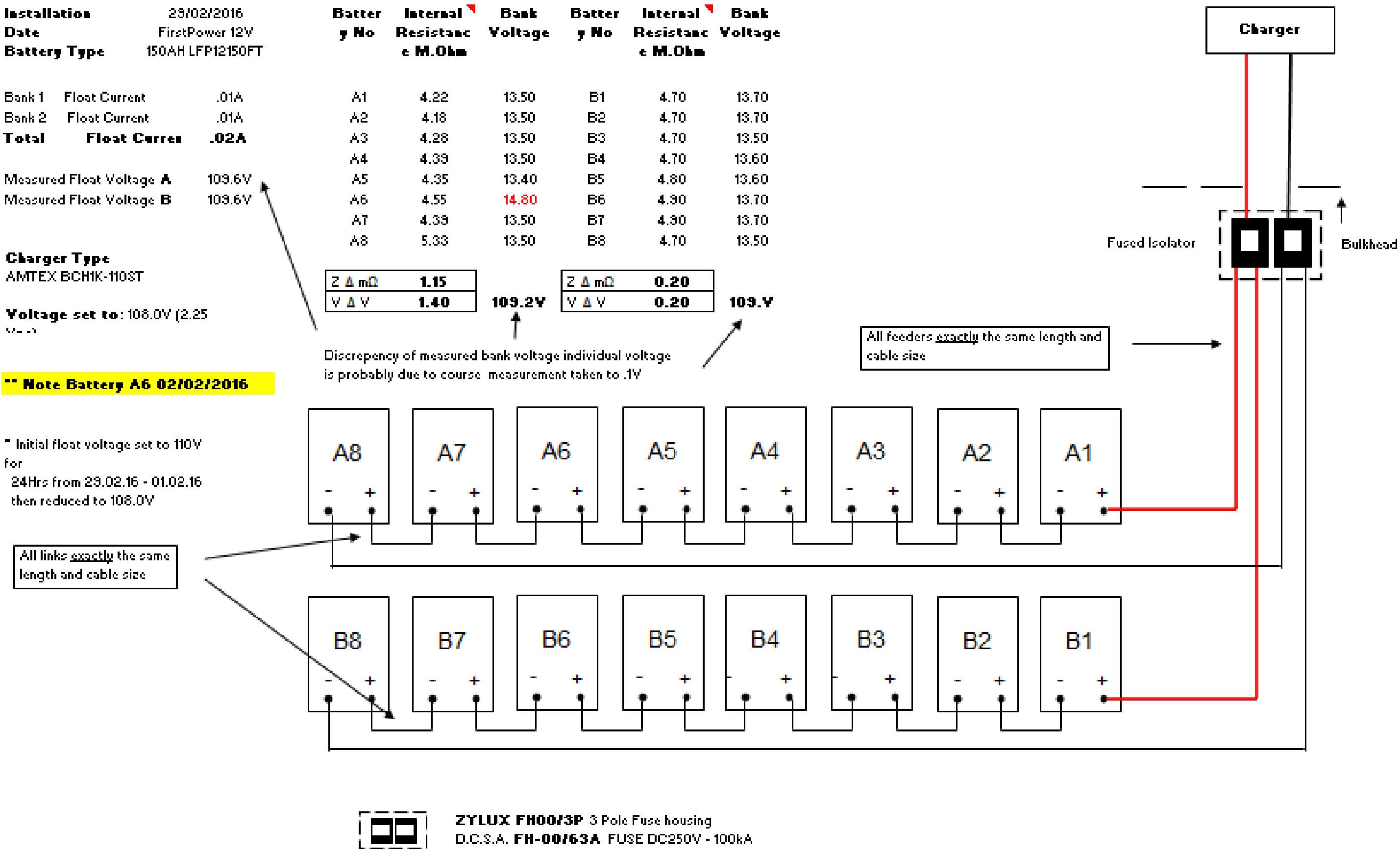
**Voltage set to:** 108.0V (2.25 V...)

**** Note Battery A6 02/02/2016**

* Initial float voltage set to 110V for 24Hrs from 23.02.16 - 01.02.16 then reduced to 108.0V

| Battery No | Internal Resistance M.Ohm | Bank Voltage | Battery No | Internal Resistance M.Ohm | Bank Voltage |
|---|---|---|---|---|---|
| A1 | 4.22 | 13.50 | B1 | 4.70 | 13.70 |
| A2 | 4.18 | 13.50 | B2 | 4.70 | 13.70 |
| A3 | 4.28 | 13.50 | B3 | 4.70 | 13.50 |
| A4 | 4.39 | 13.50 | B4 | 4.70 | 13.60 |
| A5 | 4.35 | 13.40 | B5 | 4.80 | 13.60 |
| A6 | 4.55 | 14.80 | B6 | 4.90 | 13.70 |
| A7 | 4.39 | 13.50 | B7 | 4.90 | 13.70 |
| A8 | 5.33 | 13.50 | B8 | 4.70 | 13.50 |
| Z Δ mΩ | 1.15 | | Z Δ mΩ | 0.20 | |
| V Δ V | 1.40 | 109.2V | V Δ V | 0.20 | 109.V |

Discrepency of measured bank voltage individual voltage is probably due to course measurement taken to .1V




**ZYLUX FH00/3P** 3 Pole Fuse housing
D.C.S.A. **FH-00/63A** FUSE DC250V - 100kA

**Conclusions:**

The information gathered, suggests that reduced life span being experienced when used in an underground refuge systems is not due to the battery per-se but due to the following:

1). Incorrect harnessing - causes over charge in some banks/batteries and undercharge in others leading to swelling and premature failure. This observation has been shown to be correct in our study cases particularly with the 1367 refuge .

2). With 100V charger systems, when used in conjunction with the existing harnesses significantly contributes to the reduced life due to incorrect charging and or poor maintenance of the battery.
The batteries can quickly (within the first few months of installation) loose capacity and are essentially “flat” even though they seem to test ok.

3). In our study, temperature appears not a significant factor in reduced life, operating temperatures vary from around 25 – 30 deg however it is recognised that as temperature increases the charging/float voltage/current needs to be adjusted accordingly – battery charging systems need to be temperature compensated esp. in hotter environments

4). When batteries are poorly charged– it does not follow that all the batteries in all the banks are destroyed, especially in paralleled 24 volt systems

5). Monitoring changes in a batteries internal resistance in conjunction with load testing will provide a signal that maintenance is required. A conclusion as to how often is not made however monthly recording of bank voltage, bank float current, individual battery voltage and impedances along with a three monthly load test seems appropriate. As can be seen from the example of the 1694 refuge trending is very pronounced.

6). The majority of charging systems on refuges utilising 100V battery systems are unsuitable for purpose, Their un-monitored use encourages sulphation of batteries which significantly reduces the batteries capacity and eventual failure.

7). AGM Batteries in float/standby need an equalising cycle at least every three-six months or as specified by the manufacturer and charged according to the manufactures procedure
Enduro Gel type batteries should be performed on an 'as needed' basis.
Ritar recommend every three months for theirs.

8). AGM style batteries appear the most suited to this application

The article below describes the process of swelling batteries and is reproduced for readers information:

Most of the time, *swelling* (emphasis added) happens to sealed lead-acid batteries of either AGM (Absorbed Glass Mat) or GEL (gelled electrolyte) construction.
These battery constructions are known as "recombinant" batteries, referring to the absorption of gasses generated by the chemical process of the battery.
In order to absorb these gasses, the positive and negative plates must be as close together as possible and are usually only held apart by the thickness of the separator. A consequence of the necessity of gas absorption, the pack of plates (the element) is inserted very tightly into the cell cavity, resulting in a lack of space for any other components
In the situation of a swollen battery, the cell plate components expanded, and the force exerted on the case caused it to swell and most likely split at numerous points.

The expansion of the cell element is as a result of internal heat, and can be as a result of either overcharging of the battery or from a drastic shorting of the battery terminals.
Either one of these situations will generate internal heat in the battery
Additionally, elemental lead natural has a high expansion rate when exposed to heat.
Since the cells of a battery of AGM or GEL construction are deliberately manufactured with no extra room, the result is the individual cell casings will split from expansion pressure, and deform from high heat, destroying the battery due to the massive damage to internal parts.

This usually does not happen to the battery alone; usually the battery was either shorted or overcharged.
The overcharging of the battery can be the result of a charger that is delivering too much current to the battery, or a charger of higher voltage than the battery was accidentally used-for example a 12V charger on a 6V battery.
Regardless of the cause, the result is almost always the same; swelling and the destruction of the battery

*Courtesy:* Universal Power Group

**Recommendations:**

1). Fully audit all Safety Refuges on site documenting battery harnessing (wiring configuration) and measuring; Float current, float voltage at both the charger and the first point of contact to the battery string, internal resistance of each battery, voltage across each battery, voltage across each bank, battery capacity under load. This will establish a base line.
2). In conjunction with (3). Replace the float charger with a type which is capable of applying an appropriate bulk, absorption, float and equalising charges and is temperature compensated. Its settings should be adjusted to the type of battery being charged.
3). Correct wiring harness if this is found to be defective or incorrectly configured and fit terminal type fuses (Bussmann MRBF series) on low voltage banks that are paralleled if none are currently installed. On 100V banks fit suitable fuses and isolators.
4). If holding batteries in store – ensure they are fully charged before placing into storage and note the date of acquisition.
5). Batteries held in store must receive a refresher charge every six months
6). When replacing batteries – ensure that ***all*** the batteries are fully charged
7). Do not mix battery types
8). Do not place a new battery in a string where the average impedance of that string is significantly higher than the replacement battery – this will cause an imbalance and will destroy other batteries
9). When replacing batteries – write the installation date onto the new batteries
10). Apply an equalising charge or a cycle charge at least every three months or as per manufacturers recommendations..
11). Maintain a monthly audit of internal resistance and voltage of each battery watching for increases over time which deviate widely from the manufactures specification, and measure the voltage across each battery in the string watching for excessive differences between each battery's individual voltages, especially those which appear higher than the chargers set float voltage. Compare the results against the base line. Note: Impedance tests are not accurate when testing batteries connected in parallel. Individual batteries must be disconnected to conduct the test (affects mainly 24V systems)
12). Ensure that the float current does not become elevated – if it does establish the reason. The average float current for a fully charged battery should be about 50mA or less and 200mA per 100V string (eight batteries).
13). Every three months carry out a test of battery capacity under load.
..

**Short term option:**

1). Maintain a monthly audit of internal resistance and voltage of each battery
2). Every three months carry out a load test
3). Every three – six months (or sooner if problems are detected) manually carry out an equalising charge on each bank.
4). Reconfigure battery wiring harnesses to appropriate standards and ensure each installation complies with the relevant Australian standards

**Long term option:**

1). Reconfigure large battery systems from high voltage 100V to a lower voltage – 48V or even 24V this will create smaller strings and larger paralleled banks – the advantages are;
  a). Lower cost of chargers which are more readily available
  b). Smaller strings are easier to equalise
  c). Battery storage on the refuges do not have to be changed
2). Reconfigure battery wiring harnesses to appropriate standards and ensure each installation complies with the relevant Australian standards

3). Install an appropriate battery charger which is designed to charge the lower voltage banks and ensure it is temperature compensated and compatible to the type of battery being charged
4). Ensure regular monitoring and carry out maintenance as required

**Acknowledgements:**

We would like to thank Barminco mining for the opportunity to examine the batteries removed from the MinaArc 1367 Safety Refuge, for arranging access to the refuge at Bluestone and for the help, advice and co-operation of the Electrical team.

Also

To MMG for access to their audit data and dead batteries.

**Amendments:**

| | |
|---|---|
| Document | Changes to grammar |
| Page 12 | **Short term option:** Point 4 added<br>**Long Term option:** Point 2 added and points 3 & 4 shifted |
| Page 8 | Case Study: Shairzal changed to Strata 12 man Refuge Chamber |