eclectic.engineering

michael hayes MIEAust CPEng NER RPEQ CEM

ABN 39 626 904 765

P O Box 265 Macarthur Square NSW 2560

Phone: 0419 476 664

e-mail: michael@eclectic.engineering

web: www.eclectic.engineering

Electrical Engineer

AEE Certified Energy Manager 91840

Licenced Electrical Contractor EC38250

CEC PV, SPS & Batt Design & Install

Battery DC cables to Inverters may need to be oversized by 25%

During a routine battery install of an Inverter Energy System (IES), an oscilloscope was used to show the DC current and surprisingly, it was nowhere near as flat as superficially expected. The waveform consisted of an elevated 2nd harmonic. The average value centred roughly on the midpoint of the sine wave as depicted in the simplified and re-constructed Fig. 1 below.

In understanding this waveform it was realised that most modern grid forming inverters incorporate an isolating transformer but little to no inductance on the battery port. This is evident, particularly on ELV batteries with results below based on 24 and 48V systems. At this voltage, capacitance is unable to adequately buffer the energy flowing out of the battery. Consider a resistive AC load with no grid connected and the consequence of this is that as the AC current crosses zero, there is very little current required from the battery. However, as the AC current reaches a peak (either positive or negative), battery (discharge!) current will peak. Obviously in the case of resistive loads little to no energy is returned to the battery in the absence of PV generation. To restate this, apart from the battery current being unidirectional (discharging) it also exhibits two peaks per AC cycle, so there is a dominant 100Hz component in battery current added to the average DC current.

The capacitance within the inverter will store some energy but little in comparison to that of an entire cycle.

The AC voltage and DC current (in this example for an average of 100A DC) for a resistive AC load will be very similar to that simulated in Fig. 1 below.

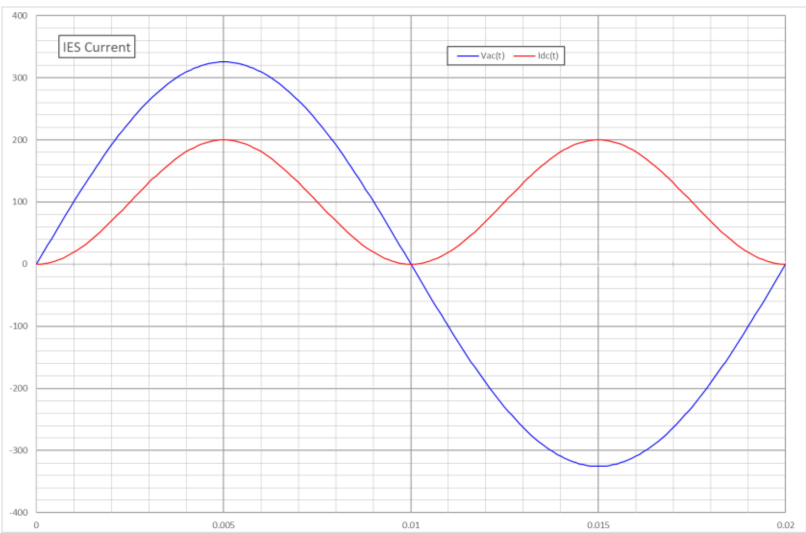


Figure 1

Simulation of the observed DC current waveform along with the AC voltage

This simplified waveform can be characterised as: $i(t) = A(1 - \cos(\omega t))$ where $\omega = 2\pi f$ and f=100Hz

To calculate the RMS value of this current the following equation is used, integrating over one cycle.

$$I_{rms} = \sqrt{\frac{1}{0.01}\int_0^{0.01} i^2(t) \cdot dt}$$

$$I_{rms} = \sqrt{\frac{1}{0.01}\int_0^{0.01} A^2(1 - \cos(2\pi * 100t))^2 \cdot dt}$$

In order to perform this integration, the following identities are used

$$cos\ 2\omega t = cos^2\ \omega t - sin^2\ \omega t$$

$$sin^2\ \omega t = 1 - cos^2\ \omega t$$

Then $cos\ 2\omega t = cos^2\ \omega t - 1 + cos^2\ \omega t$

$$cos^2\ \omega t = \frac{cos\ 2\omega t + 1}{2}$$

$$I_{rms} = A \cdot \sqrt{\frac{1}{0.01}\int_0^{0.01} (1 - 2\,cos(2\pi * 100\,t) + cos^2(2\pi * 100t) \cdot dt}$$

$$I_{rms} = A \cdot \sqrt{\frac{1}{0.01}\left[t - \frac{2\sin(2\pi * 100\mathrm{t})}{2\pi * 100} + \frac{\sin(4\pi * 100t)}{2 * 4\pi * 100} + \frac{t}{2}\right]_0^{0.01}}$$

$$I_{rms} = A\sqrt{\frac{1}{0.01}(0.01 - 0 + 0 + \frac{0.01}{2} - 0 + 0 - 0 - 0)}$$

$$I_{rms} = A\sqrt{\frac{3}{2}}$$

$$I_{rms} = A\sqrt{1 \cdot 5} = 1.2247 * A$$

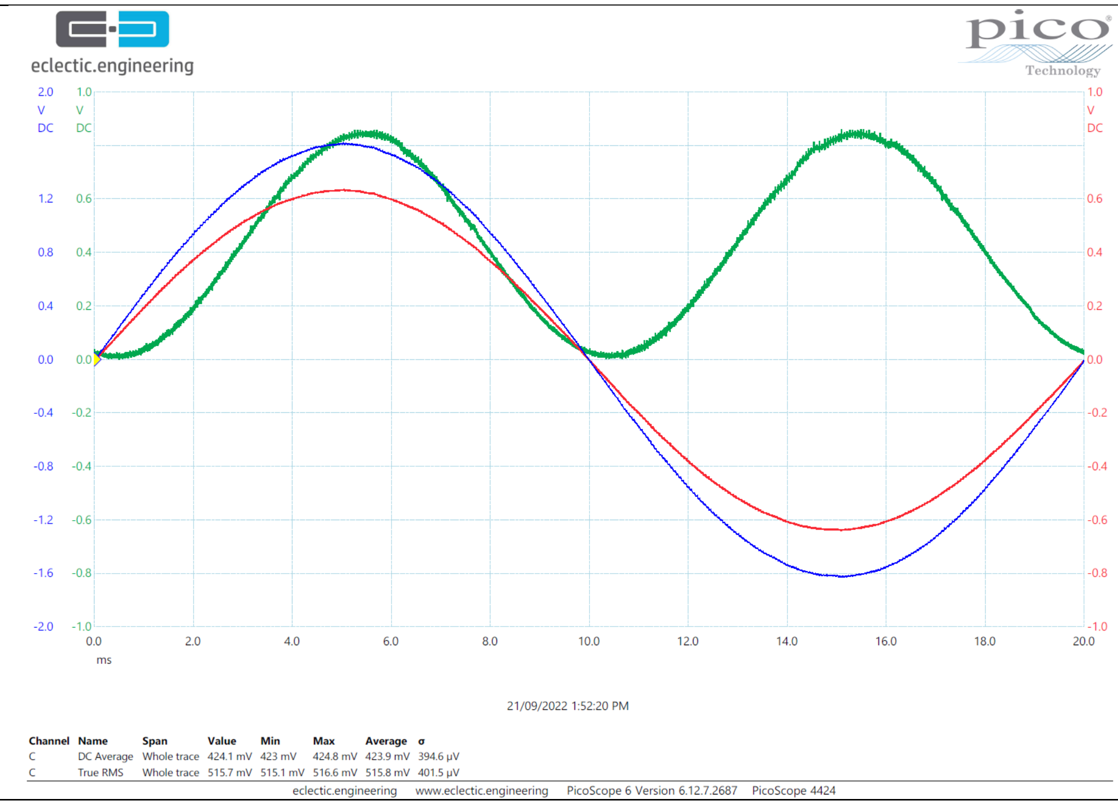
Thus the RMS value of Battery Current is 1.2247 times the average DC current

A first test was made using a Selectronics SPMC 240AU with both AC and DC current probes and an isolated voltage probe connected to a 4 channel PC based oscilloscope, Picoscope 4424 with the following results. Note the actual battery current is slightly phased shifted to the AC voltage, likely due to minimal capacitor storage and the minimum current is slightly more than zero.

Figure 2

Recorded waveforms of A Selectronics SPMC 240AU

AC Voltage (÷200)
AC Current (100mV/A)
DC Current (10mV/A)



The Average DC current as calculated by the Picoscope above is 423.9mV (÷10mV*1A) which is 42.4A and the RMS value is 515.8mV (÷10mV*1A)

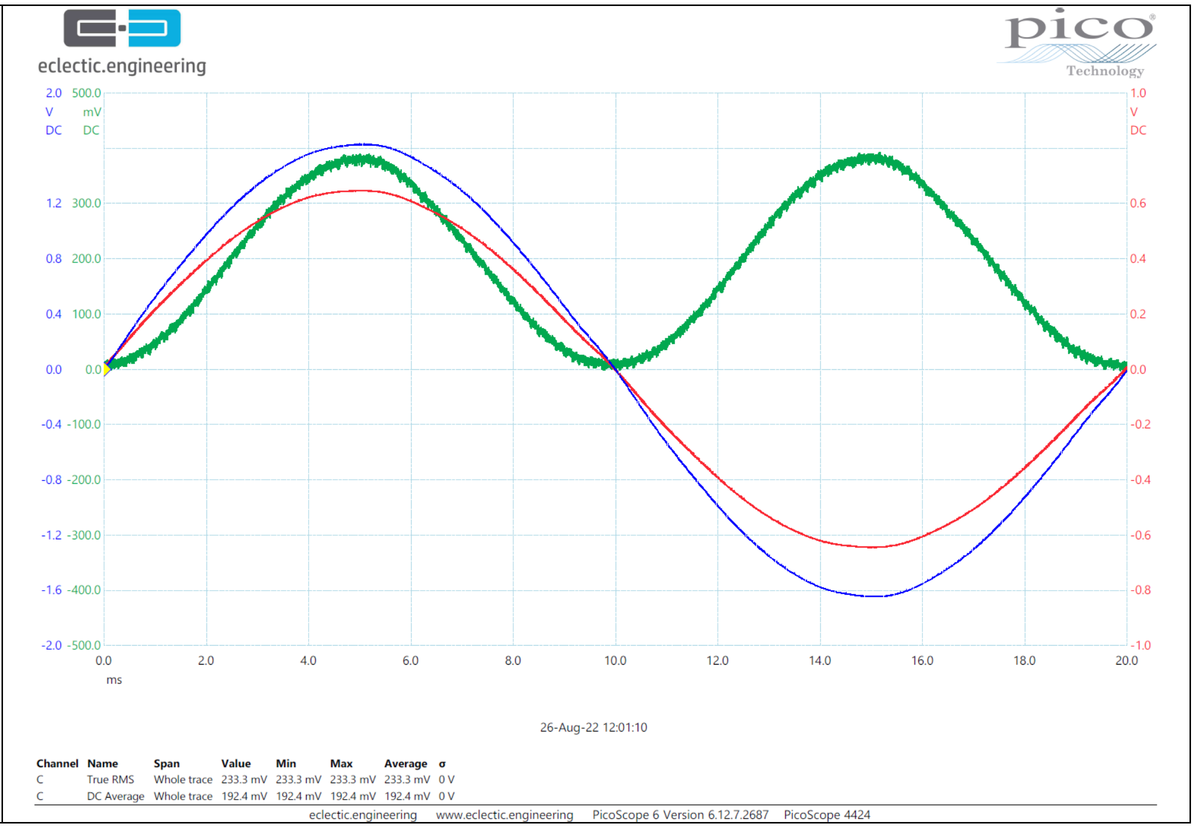
Thus, the Irms : Idc ratio is 515.8/423.9=1.217 or 99.4% of the above theoretical calculation of $\sqrt{1.5}$

Measurements were also performed on an SMA Sunny Island SI6.0H inverter fed with a 52V Lithium Ion Battery with results shown in Fig. 3

Figure 3

Recorded waveforms of an SMA SI6.0H

AC Voltage (÷200)
AC Current (100mV/A)
DC Current (10mV/A)



Here the Average DC current as calculated by the Picoscope above is 192.4mV (÷10mV*1A) which is 19.2A and the RMS value is 233.3mV (÷10mV*1A)

So the Irms : Idc ratio is 233.3/192.4=1.213 or 99.0% of $\sqrt{1.5}$

In practice, this means that once the average DC current is known, it should be multiplied by $\sqrt{1.5}$ or 1.2247 to get a value of effective heating due to that current on a cable or fuse. Conversely, the rated currents obtained from AS 3008 for cable type and installation conditions must be adjusted by dividing by $\sqrt{1.5}$

This means a raw current rating from AS3008 must be divided by 1.2247 to give a useful rating when used as a battery cable in a standard DVC A inverter energy system. To simplify this recommendation, Idc rms = Idc av * 1.25 which is similar to but of completely different origin to Isc * 1.25 calculations in PV Systems.

Michael Hayes

24 Oct 2022