**Simple Expanded Scale Voltmeter**
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This document describes the design and practical construction of a very simple expanded scale voltmeter. This was designed for a renewable energy system in the developing world, therefore had to be simple, easy to build and cheap. Previously a standard analogue voltmeter was used on such systems to give an indication of the system voltage. The scale for such meters was typically 0-50V and the system (typically a lead-acid battery) voltage could not be read accurately enough for system diagnostics. The need for a voltmeter that accurately displayed small changes around the system voltage was highlighted. A design for a 10 to 15V range voltmeter is shown here but, with a few calculations, any voltage range could be displayed. Advantages of this are that it is cheap and easy to construct. It is probably not the most accurate device you could build but it will give better indication of the system voltage and help with battery diagnostics.

Parts required:
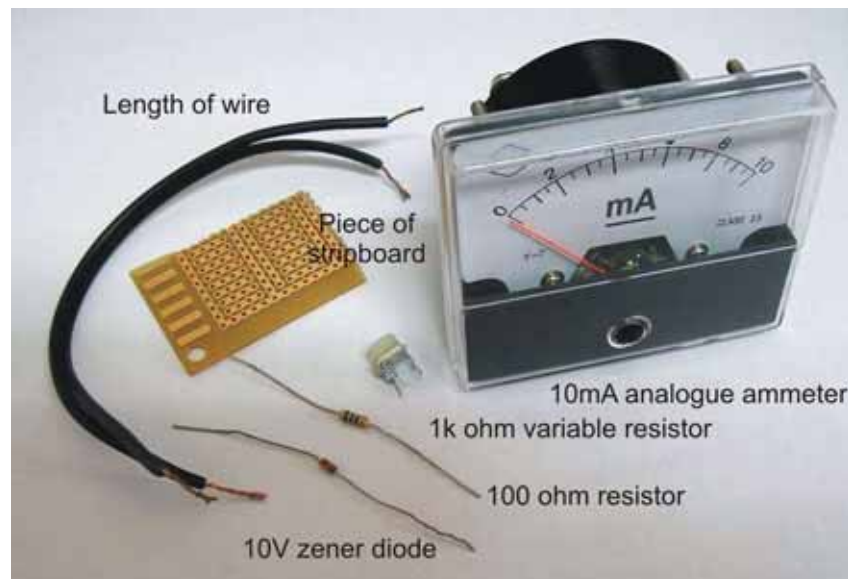
1 x Ammeter (low range is preferred, 10mA in this case)
1 x Resistor
1 x Variable resistor
1 x Zener diode (equal to the lowest voltage to mesure)
1 x Strip board (small piece)
Soldering Iron and solder
Cutter
Screwdriver
Access to a variable power supply
Access to a graphics package and printer would be an advantage

Circuit diagram
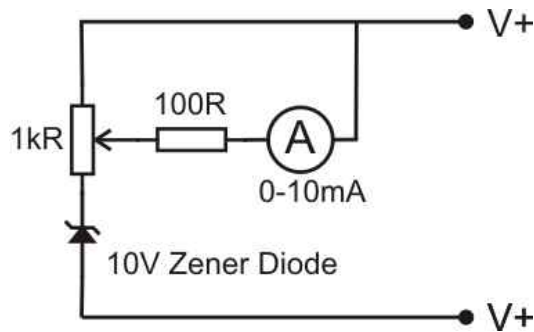
The basic idea is to drop some voltage across a zener diode. An ammeter is used to read the voltage by using a resistor (remember Ohms Law? V=IR). The lowest voltage that can be read will be equal to the rating of the zener diode (in this case 10V). The scale can then be chosen through the use of the correct resistor values and some calculation (see below). The variable resistor allows fine tuning of the scale, especially when the exact resistor values are unobtainable.

The voltage drop across the ammeter and the resistor and part of the variable resistor is designed to be equal to the highest voltage to be read (V_{high}) minus the rating of the zener diode (this is also the lowest voltage read, V_{low}).

The full scale defection rating of the ammeter can then be used to calculate the resistance value required. This can then be made from a value resistor that is close but lower than the resistance required. The variable resistor can then be used, along with an accurate volt meter to calibrate the device.

Calculations

Definitions:
Zener diode voltage $= V_{zener}$
Ammeter maximum current $= I_{max}$
Variable resistor $= R_{var}$
Fixed resistor $= R$
Lowest voltage to measure $= V_{low}$
Highest voltage to measure $= V_{high}$

1. Choose $V_{zener} = V_{low}$. This will depend upon the available zener diode ratings. Zener diodes could be used in series to give the correct value.
2. Voltage across ammeter and resistor network, $V_{net} = V_{high} - V_{zener}$.
3. Resistance in the path with the ammeter, R_{total}, is comprised of R plus the proportion of the variable resistor depending upon its position.
   Maximum resistance in ammeter path $R_{total\ max} = R_{var} + R$.
   Minimum resistance in ammeter path $R_{total\ min} = R$.
4. Apply ohms law (V = IR) to ensure V_{high} can be measured by the chosen resistor values. The maximum current flowing in this circuit will be equal to the maximum ammeter full scale deflection value I_{max}. The equation here is $V_{net} = I_{max}$ x R_{total}.
5. Using $V_{net} = V_{high} - V_{zener}$ in $V_{net} = I_{max}$ x R_{total} gives the equation:
$$\textbf{V}_{\textbf{high}} = (\textbf{I}_{\textbf{max}} \textbf{ x } \textbf{R}_{\textbf{total}}) + \textbf{V}_{\textbf{zener}}$$
6. The highest V_{high} is when resistance is highest ($V_{high\ max} = I_{max} (R_{var} + R) + V_{zener}$)

7. The lowest V_{high} is when the resistance is lowest ($V_{high\ max} = I_{max}\ (R) + V_{zener}$)
8. This will give the range of values through which the scale can be calibrated.

Let's put some numbers into that to show what I mean:

1. $V_{low} = 10V$, therefore V_{zener} must be 10V or the closest available value.
2. $V_{net} = 16V – 10V = 6V$ across the ammeter and resistors.
3. Max resistance = 1000 + 100 = 1100 ohm
   Min resistance = 100 ohm
4. $I_{max} = 10mA = 0.01A$
5. No calculations to do – have a cup of tea?
6. Highest $V_{high} = 0.01 \times 1100 + 10 = 21V$
7. Lowest $V_{high} = 0.01 \times 100 +10 = 11V$
8. Therefore with the values chosen here a voltmeter with a low reading of 10V and a high reading of 11V to 21V can be produced.

Obviously just adjust the values above to whatever you have to hand or whatever range you require.

For a 12V nominal lead-acid battery the battery voltage range of interest is from about 10V to 16V DC. This can be multiplied up for other system voltages (eg 48V system should read from 40V to 64V)

This voltmeter will draw slightly over 10mA to read the voltage. Relatively, this is a very small load (about the same as an LED), but it will be a constant load. A switch could be added but I would not recommend it as it good to ensure the battery voltage is always visible. For a renewable energy system with a large battery bank this load will be negligible.

Practical construction

Build the circuit on a small piece of strip board:
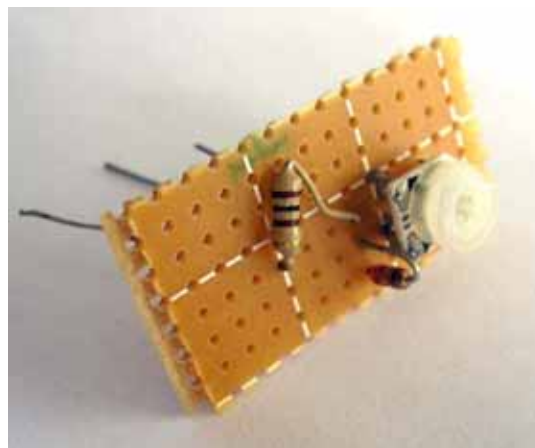
Open up the ammeter and carefully de-solder and remove the coil:

Drill a hole large enough for the variable resistor to turn. Glue the strip board in place so that the variable resistor is accessible, with a screwdriver, through the hole:

Create a new scale for the device. This can either be done by hand (paint onto the original scale or draw a new one on a piece of paper) or using some graphical design package and a printer. In this case Corel Draw was used.

No colour printer available – hence the black and white dial

Final device testing and calibration

The device then needs calibrating. Use an accurate voltmeter or Multimeter and a variable power supply to do this. Set the variable resistor to its highest value. Apply the lowest voltage (measure with voltmeter) and ensure that the dial reads 0mA or V_{low}. Then apply the highest voltage V_{high} (measure with voltmeter). Adjust the variable resistor until the meter needle reads the correct value. Test the unit to ensure that, within the required range, the meter reads correctly. There may be problems with the linearity.
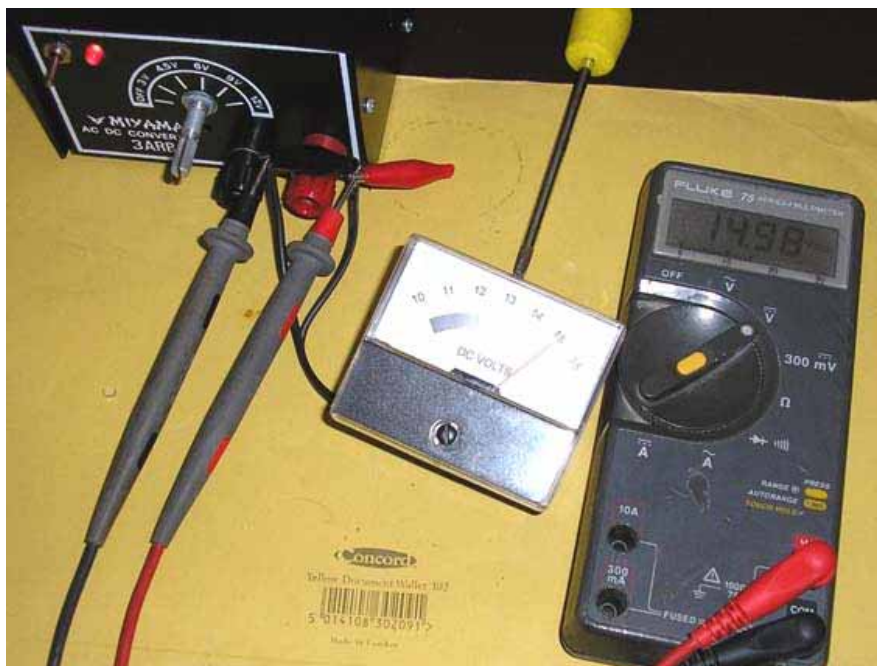
Adjust variable resistor until the dial value is the same as the calibrated Multimeter. Check the scale by running through the range of voltages.