FURTHER IMPROVEMENT OF ALUMINIUM REDUCTION CELL RESISTANCE SLOPE CALCULATION

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Plan of the Presentation

- Introduction
  - Cell voltage equations
  - Cell voltage vs dissolved alumina concentration curves
  - Slope of the cell voltage vs dissolved alumina concentration curves
  - Calculation of the cell pseudo-resistance and normalized cell voltage
- Smooting/fitting the cell normalized voltage or cell pseudo-resistance
  - First numerical scheme requiring the bare minimum computer resources
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Introduction

- Cell voltage noise filtration is the key to achieve cell operation with high current efficiency and very low anode effect frequency.

- During feeding cycles, the evolution of the cell resistance is mostly dictated by the evolution of the concentration of the dissolved alumina in the bath. It is fair to say that calculating the slope of that cell resistance can now be considered as an exact science

- Especially during the underfeeding regime from the lean side of the cell voltage vs alumina concentration curve, the gradual increase of the slope of the cell voltage has been well characterized and the added bubble and MHD driven cell voltage noise has been very well characterized as well.

- Hence finding the optimal numerical algorithm to filter out that noise and calculating the current noise free cell resistance slope is a strait forward proposal. In the past the limited C.P.U. power of cell controller may have prevented the usage of such an algorithm, but this is no longer a limitation.

Cell voltage equations

$$R_{bath}\ (\Omega\ cm) = 1\ /\ \exp(1.9105 + 0.1620*CR - 17.38E\text{-}3*C_{Al_2O_3} - 3.955E\text{-}3*C_{CaF_2} - 9.227E\text{-}3*C_{MgF_2} + 21.55E\text{-}3*C_{LiF} - 1745.7/(273 + T_{liquids})) \quad (1)$$

$$V_{bubble}\ (V) = CD_{cat} * R_{bath} * \left(\frac{(\delta - t_A)}{(1 - 0.02 * C_{Al_2O_3})^{1.5}} \right) + CD * R_{bath} * \frac{t_A}{\left(1 - \frac{1.26}{(1 + 0.75 * C_{Al_2O_3})} \right)} \quad (2)$$

$$V_{bath}\ (V) = (ACD - \delta) * CD_{cat} * R_{bath} + V_{bubble} \quad (3)$$

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Cell voltage equations

$$\Delta G^\circ = 986483 - 321.88 T_{\text{liquids}} \quad (4)$$

$$|E_0|\ (V) = \frac{\Delta G^\circ}{6 * 96487} + \frac{8.3144 * (273 + T_{liquids})}{6 * 96487} * \ln\left(\left(\frac{C^{sat}_{Al_2O_3}}{C_{Al_2O_3}}\right)^{2.77}\right) \quad (5)$$

$$|\eta_{cc}|\ (V) = \frac{8.3144 * (273 + T_{liquids})}{1.5 * 96487} * (1.375 - 0.125 * CR) * \ln\left(\frac{CD_{cat}}{0.257}\right) \quad (6)$$

Cell voltage equations

$$CD_{cri}\,(A/cm^2) = \left(5.5 + 0.018 * \left(T_{liquids} - 1050\right)\right) * \frac{\left(\left(C_{Al_2O_3}\right)^{1/2} - 0.4\right)}{\left(L_{anode} * W_{anode} * 1e4\right)^{0.1}} \qquad (7)$$

$$|\eta_{aa}|\,(V) = \frac{8.3144 * \left(273 + T_{liquids}\right)}{2 * 96487} * \ln\left(\frac{CD_{cri}}{\left(CD_{cri} - CD\right)}\right) \qquad (8)$$

$$|\eta_{ac}|\,(V) = \frac{8.3144 * \left(273 + T_{liquids}\right)}{1.08 * 96487} * \ln\left(\frac{CD}{0.0029 * C_{AL_2O_3}^{\;0.56}}\right) \qquad (9)$$

$$V_{elec}\,(V) = |E_0| + |\eta_{cc}| + |\eta_{aa}| + |\eta_{ac}| \qquad (10)$$

$$V_{cell}\,(V) = V_{ext} + V_{anode} + V_{cathode} + V_{bath} + V_{elec} \qquad (11)$$

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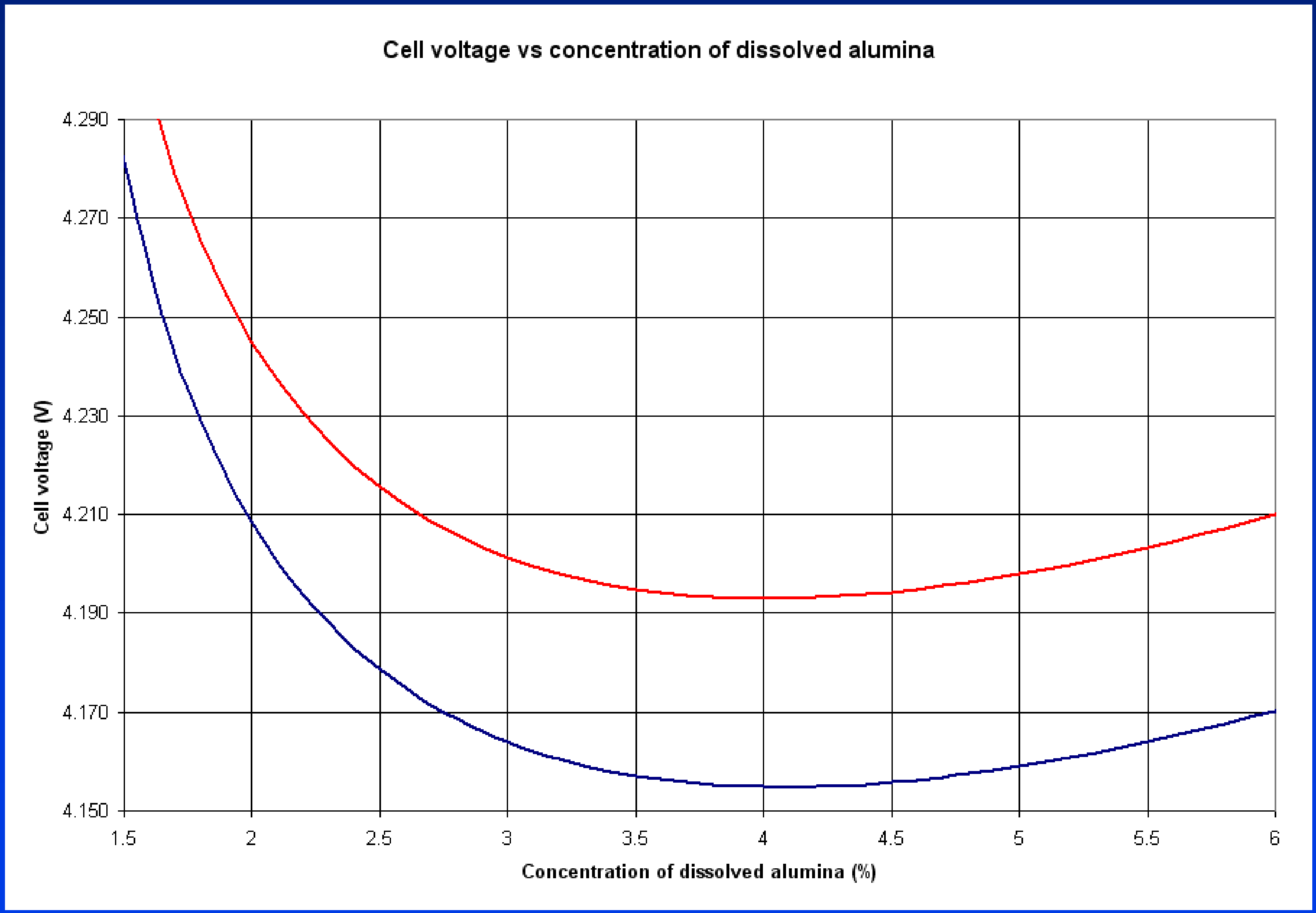
Cell voltage vs concentration of dissolved alumina for 2 values of the ACD



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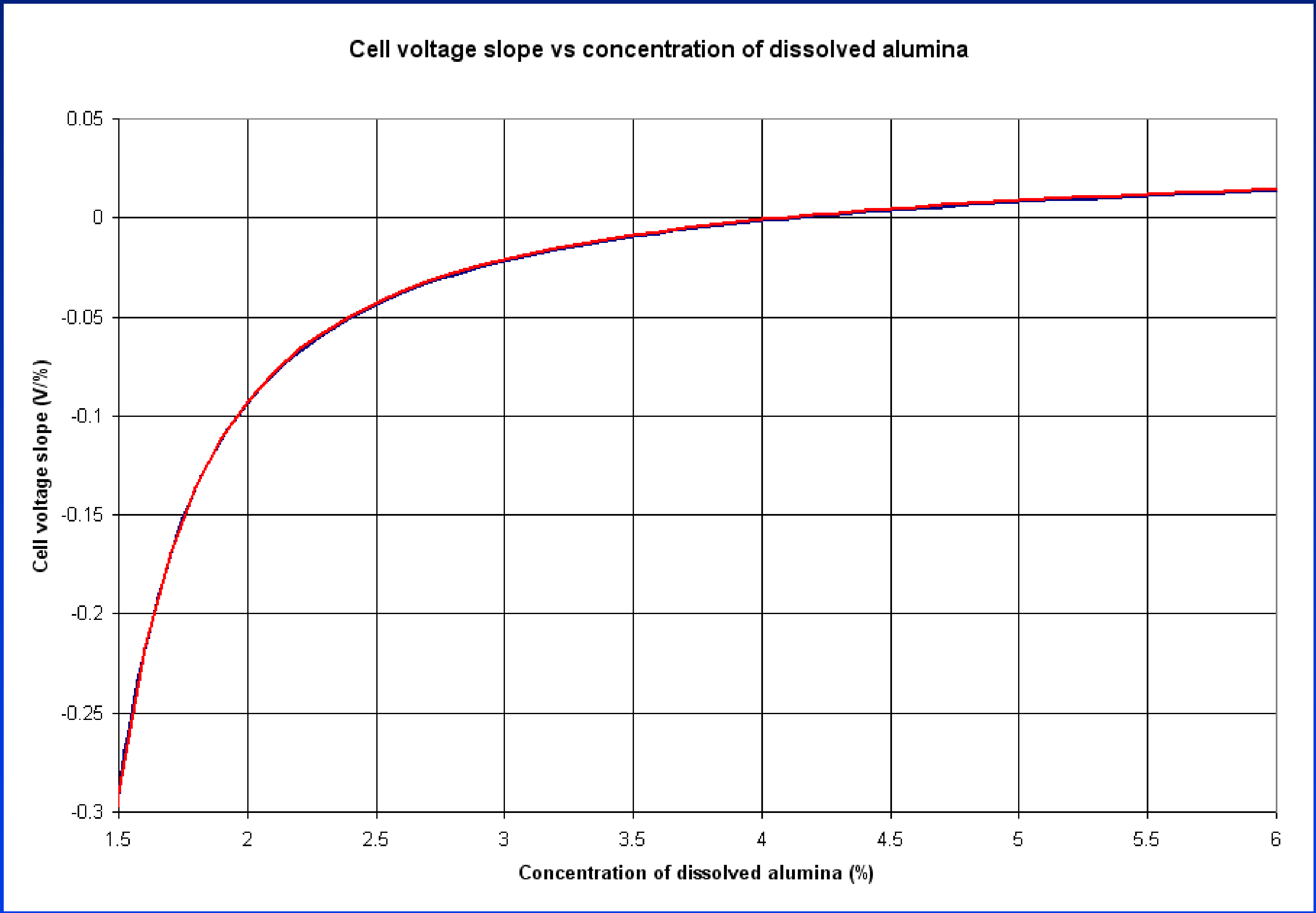
Cell voltage slope vs concentration of dissolved alumina for 2 values of the ACD



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The key to modern alumina feeding control logics

- Assuming that during the underfeeding regime the rate of decrease of the concentration of dissolved alumina is only due to the difference between the alumina consumption rate and the alumina feeding rate, there a direct relationship between the slope (or first derivative vs time) of the cell voltage and the actual concentration of dissolved alumina in the cell.

- The key to modern alumina feeding control logics and their associated very good operational results of 95-96% current efficiency and 0.05 or less anode effect per pot per day is the controller ability to calculate the cell pseudo resistance or cell normalized voltage slope despite the noise in the amperage and voltage signals and keep operating the cell on the lean side of the slope in order to avoid muck formation.

Calculation of the cell pseudo-resistance and normalized cell voltage

Because the cell amperage is fluctuating, the cell voltage is not directly used in control logic algorithms. The normalized cell voltage or the cell pseudo resistance is used instead. The definition of the cell pseudo resistance and the cell normalized voltage are presented below:

$$\Omega_{cell} = (V_{cell} - BEMF) / I \qquad (12)$$

$$V_{cellnorrm} = (V_{cell} - BEMF) / I * I_{nom} + BEMF \qquad (13)$$

Where:

BEMF is the extrapolated voltage at zero amperage usually set to 1.65 (V)

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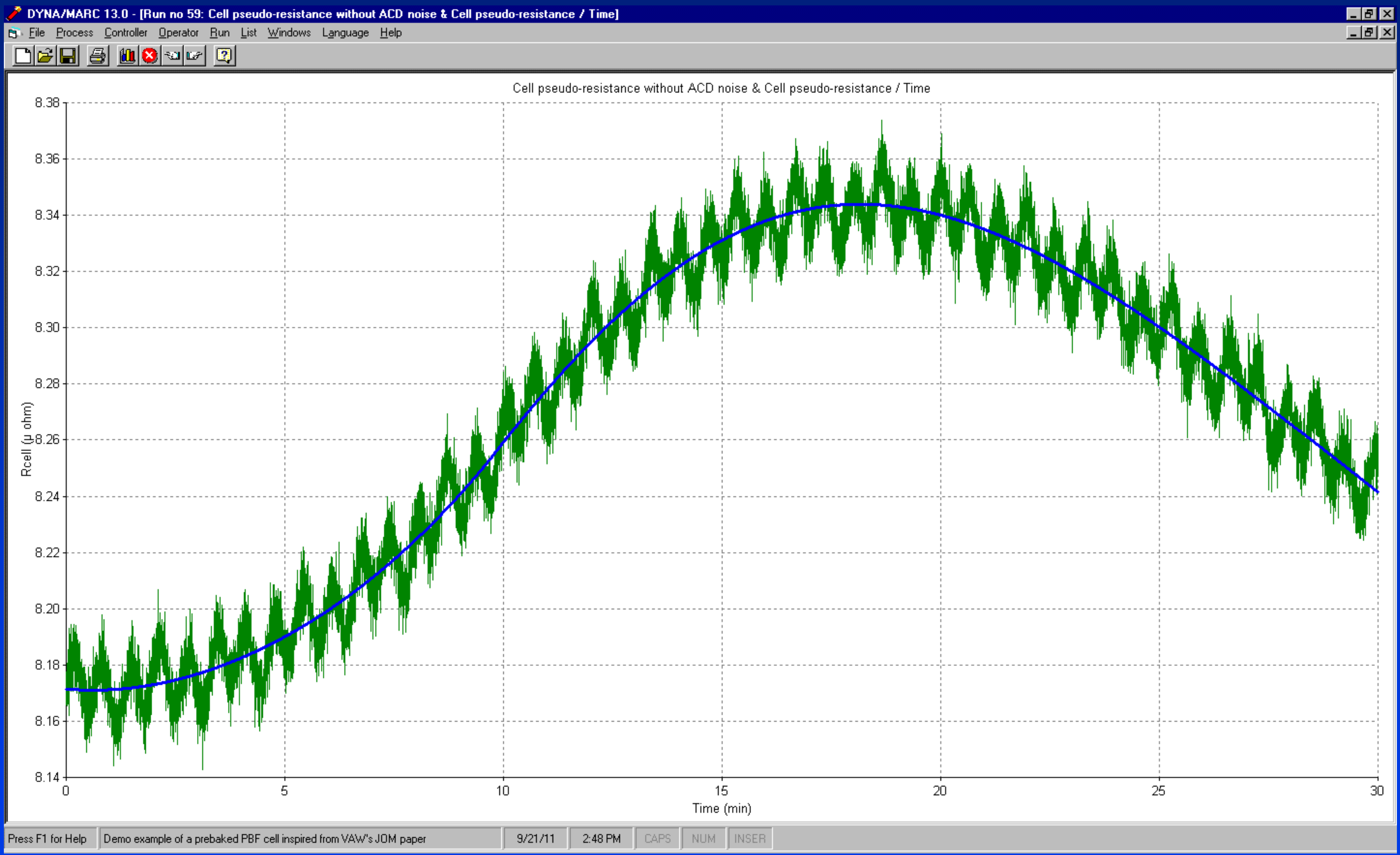
Evolution of the cell pseudo resistance with and without noise



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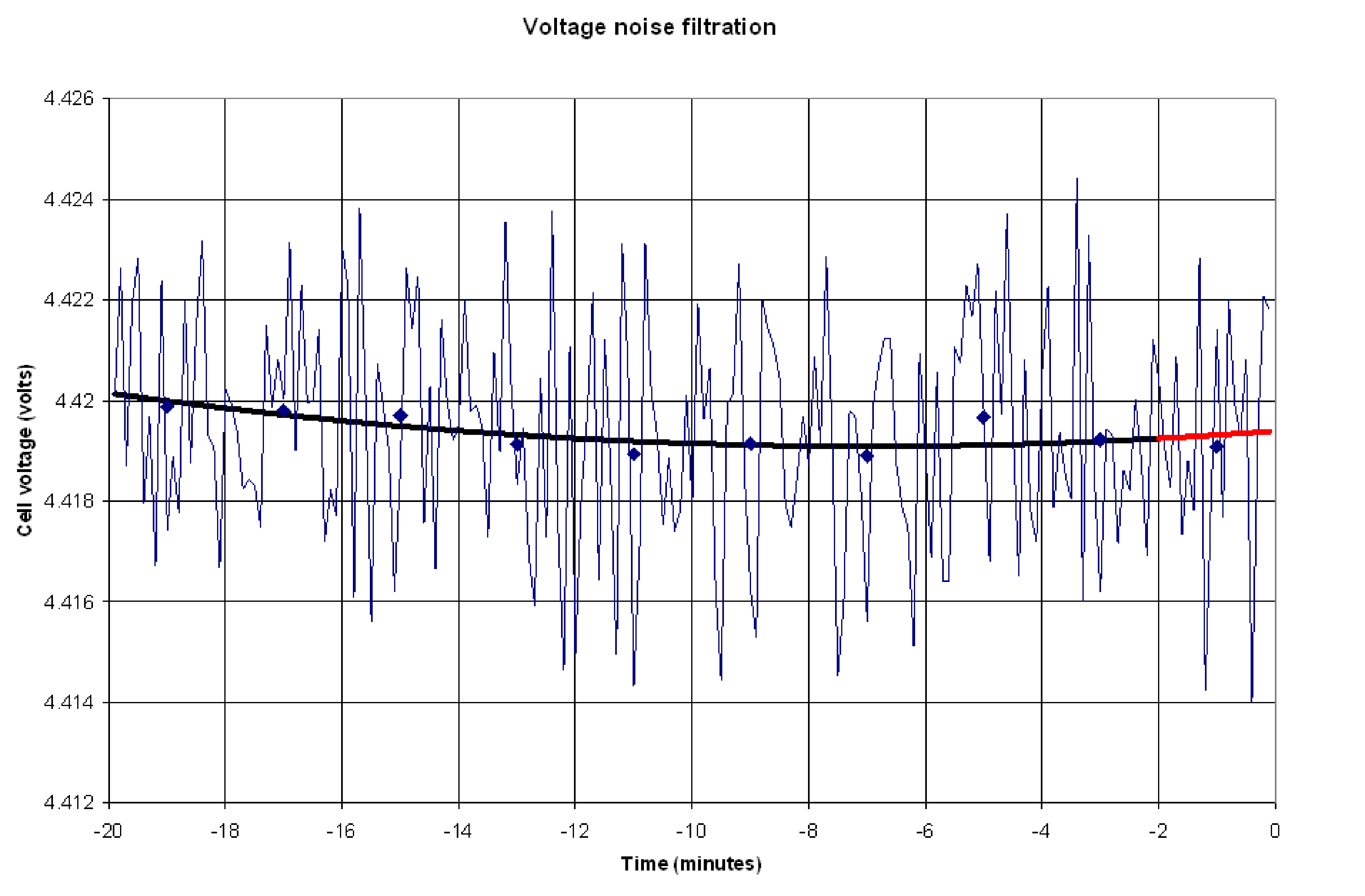
First numerical scheme requiring the bare minimum computer resources

- The first numerical scheme that will be presented here has already been presented in a previous publication; it requires the bare minimum computer resources typical of the type of numerical scheme developed about 25 to 30 year ago.

- The cell voltage is sampled every 6 seconds or at a frequency of 0.16667 Hz and averaged every 2 minutes. At each of those 2 minutes cycles, the last ten 2 minutes averaged value datapoints are fitted using quadratic root mean square (RMS). The slope of the fitted parabola at time zero is compared against the trigger slope value to decide if it is time to shift from underfeeding to overfeeding mode .

First numerical scheme requiring the bare minimum computer resources



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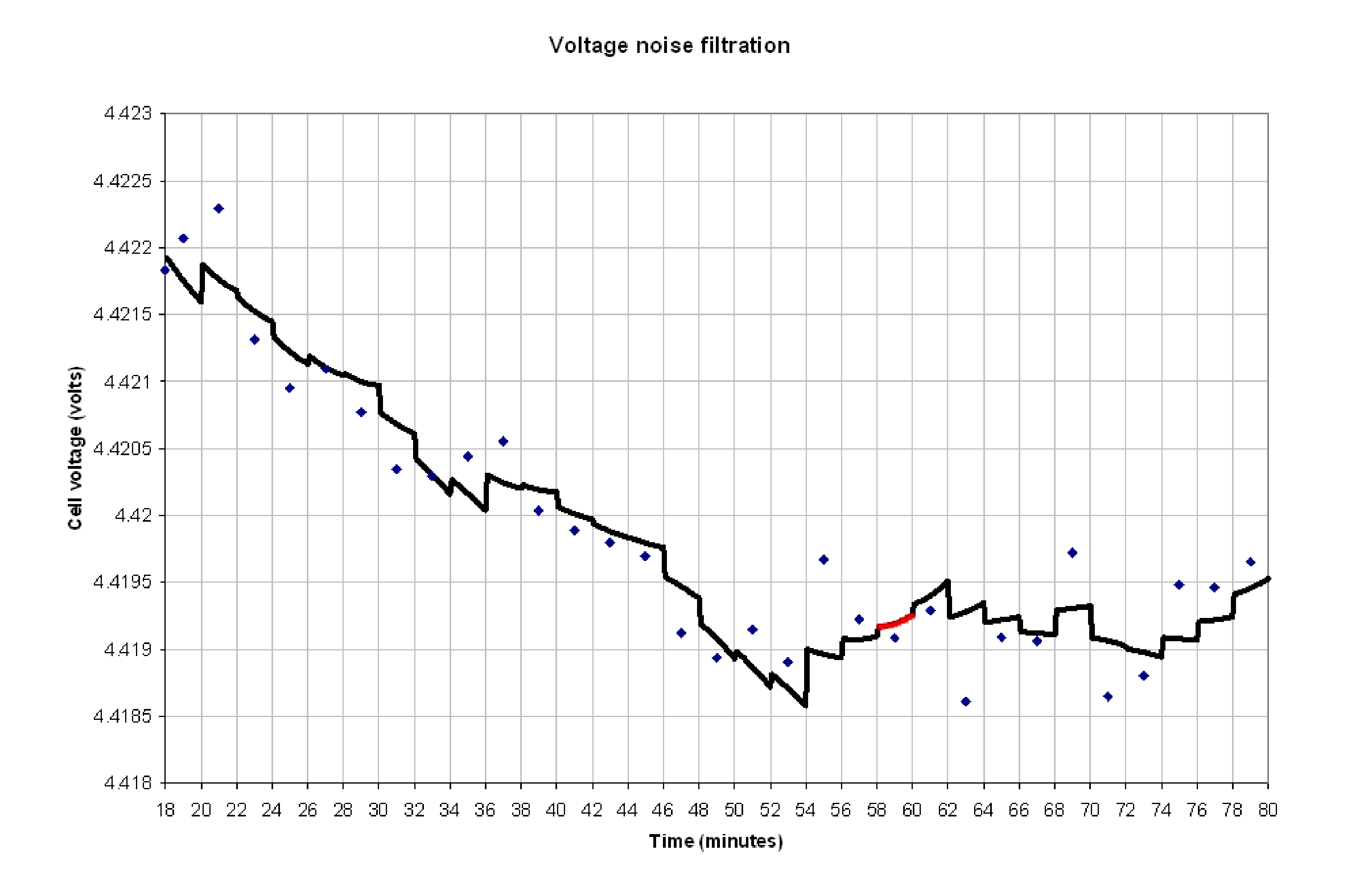
First numerical scheme requiring the bare minimum computer resources



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First numerical scheme requiring the bare minimum computer resources

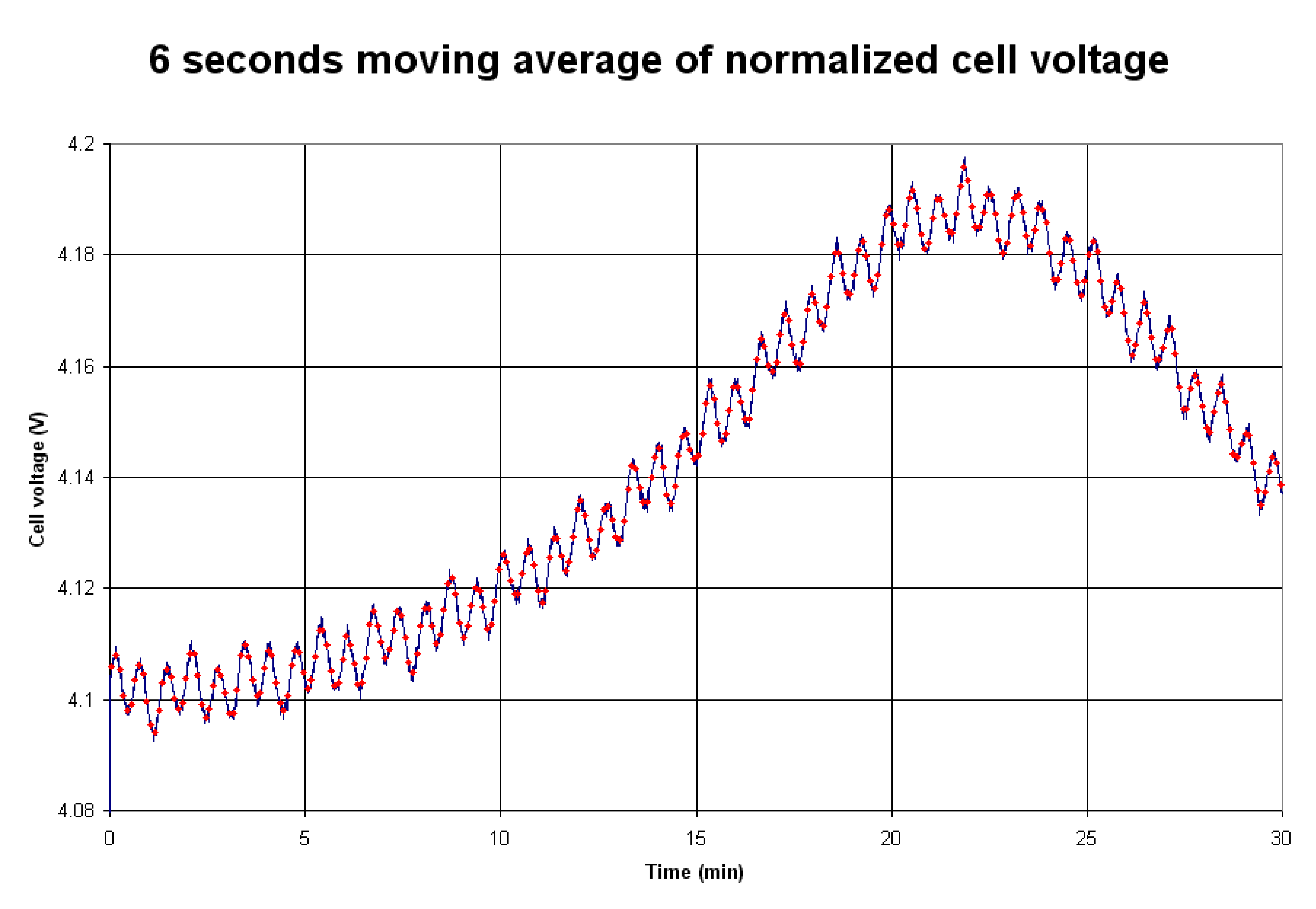
- The last figure presents the successive addition of the red curve sections of the previous to last figure. The red curve section of the previous to last figure is also the red section of the previous figure.
- As previously discussed, the calculated slope is still very noisy, the slope calculated using linear RMS instead of quadratic RMS with the same 10 datapoints is less noisy but it represents the best fit of the slope 10 minutes in the past.
- Clearly those schemes are not good enough, they lead to either many escaped anode effects if the trigger slope is set to high or too many false positives leading to slugging problems if the trigger slope is set to low.
- Many old smelters are still using that type of numerical scheme today.

Second numerical scheme requiring more computer resources

- Gradually as years passed, it became possible to use numerical scheme requiring more computer resources. The second set of numerical schemes presented was presented at the COM in 2011.

- The cell voltage is sampled at a frequency of 10 Hz and averaged every 5 seconds. At each of those 5 seconds cycles, the last one hundred and twenty (120) 5 seconds averaged value datapoints are fitted using quadratic RMS.

Second numerical scheme requiring more computer resources



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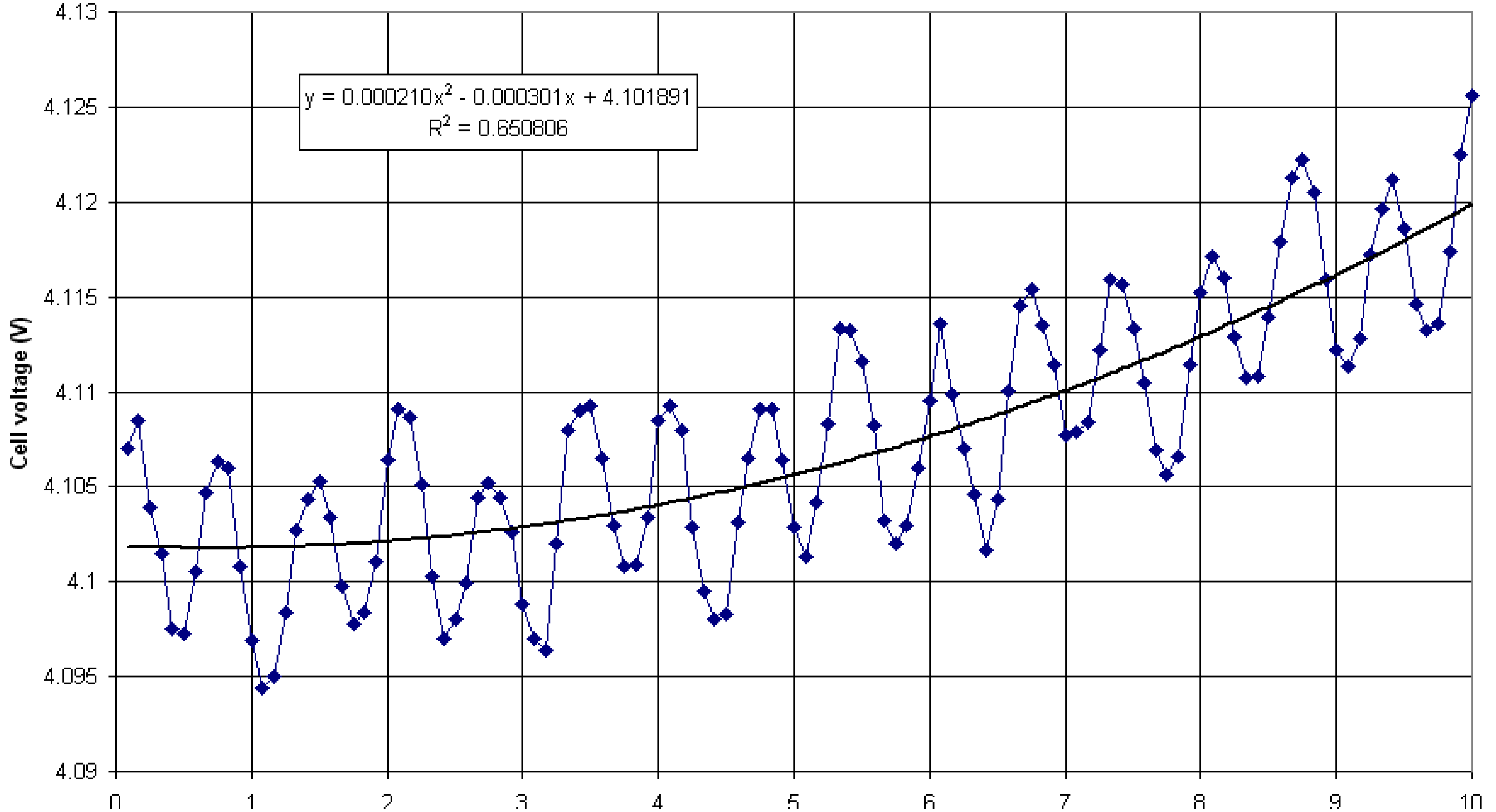
Second numerical scheme requiring more computer resources

Quadratic root mean square fit of normalized cell voltage

Prediction of the current noise free normalized cell voltage: 0.00021*100-0.000301*10+4.1019 = 4.1199 V



Prediction of the current noise free slope of the normalized cell voltage: 2*0.00021*10-0.000301 = 0.0039 V/min

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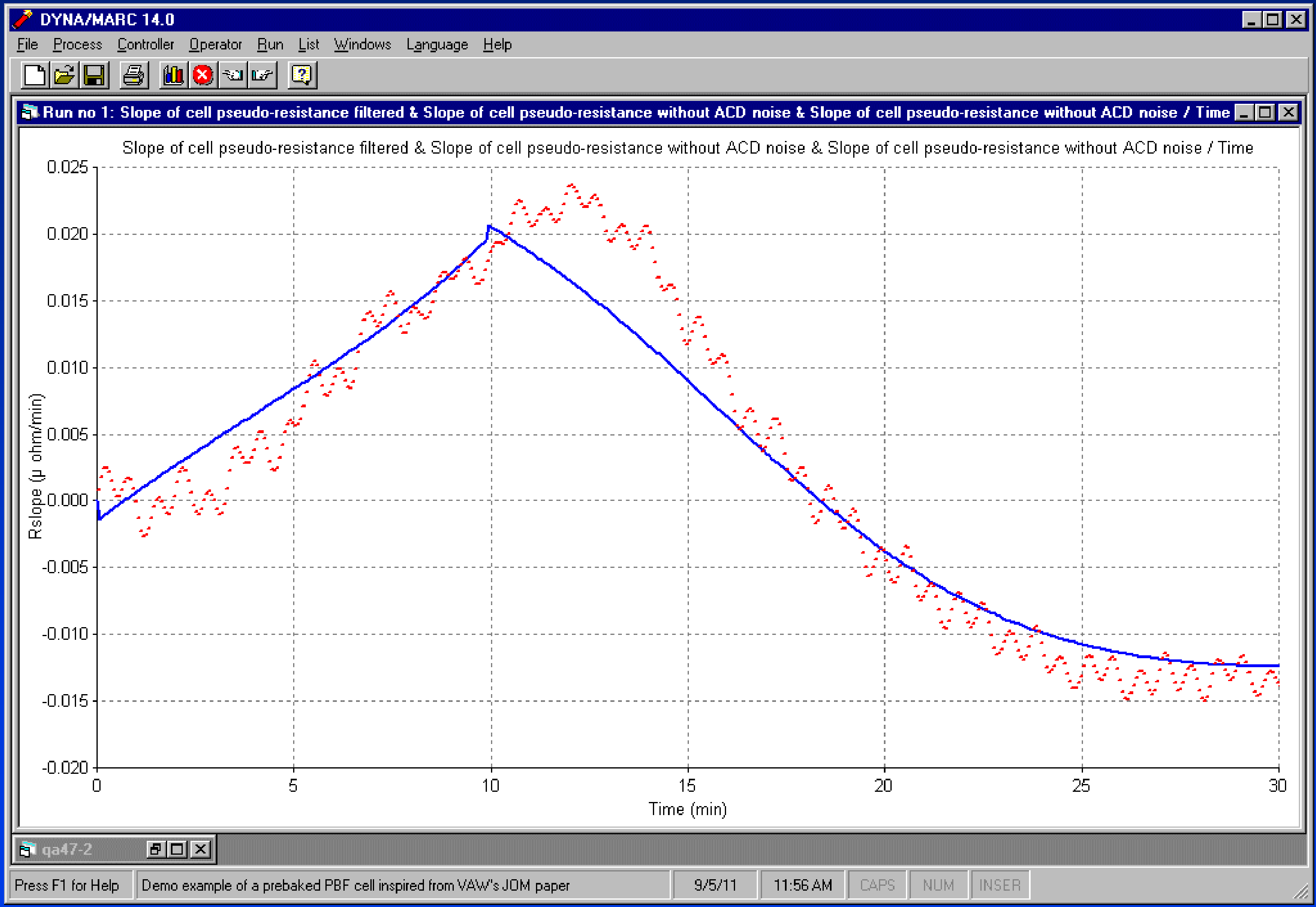
Second numerical scheme requiring more computer resources



Second numerical scheme requiring more computer resources

- **Performing a 120 datapoints quadratic RMS fit every 5 seconds is obviously far more demanding on the cell controller CPU than performing a 10 datapoints quadratic RMS fit every 2 minutes but, as presented in the previous figure, there is almost no noise left in the slope estimate.**

- **Yet some noise is still present so it is possible to do a better job.**

Optimum noise filtration numerical scheme

- **Clearly these days, considering the very low cost of hardware and the industry desire to continue to reduce anode effect frequency, there should be no hardware related limitations when selecting the noise filtration numerical scheme and hence, the one selected should be the one the producing the optimal results.**
- **The optimal filtration numerical scheme would be one that produces a filtered slope with no visible noise.**

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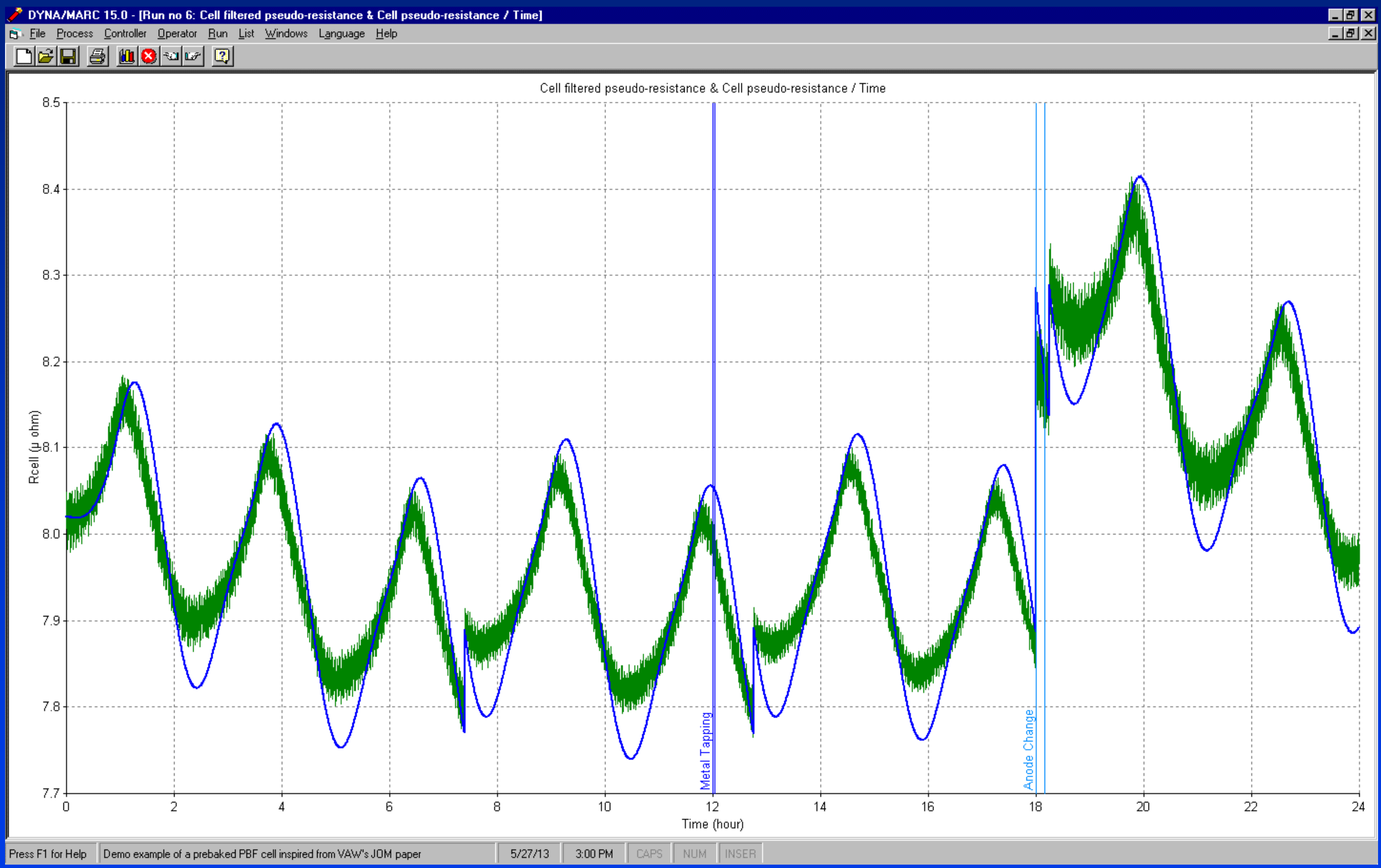
Optimum noise filtration numerical scheme

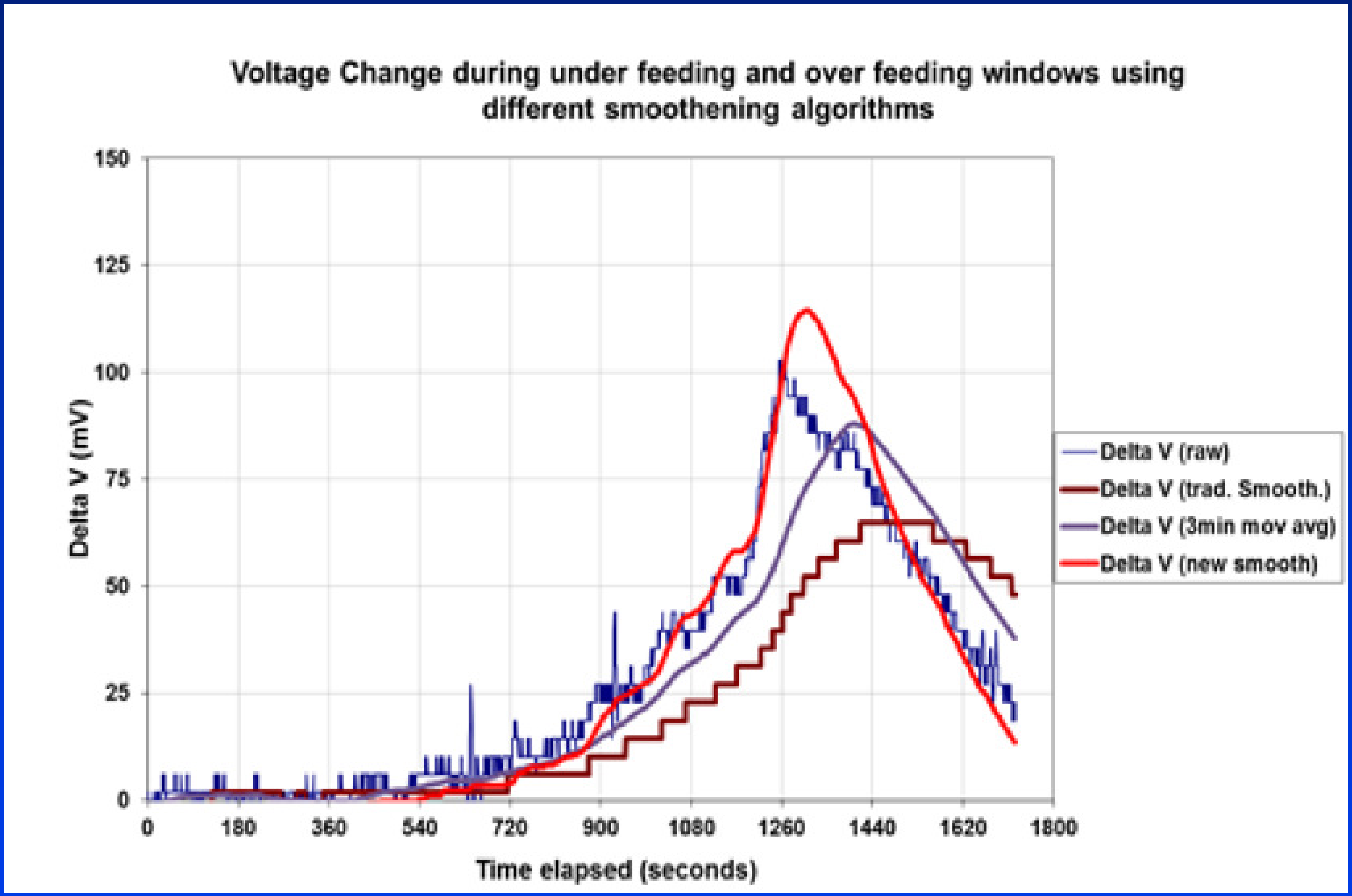


Optimum noise filtration numerical scheme

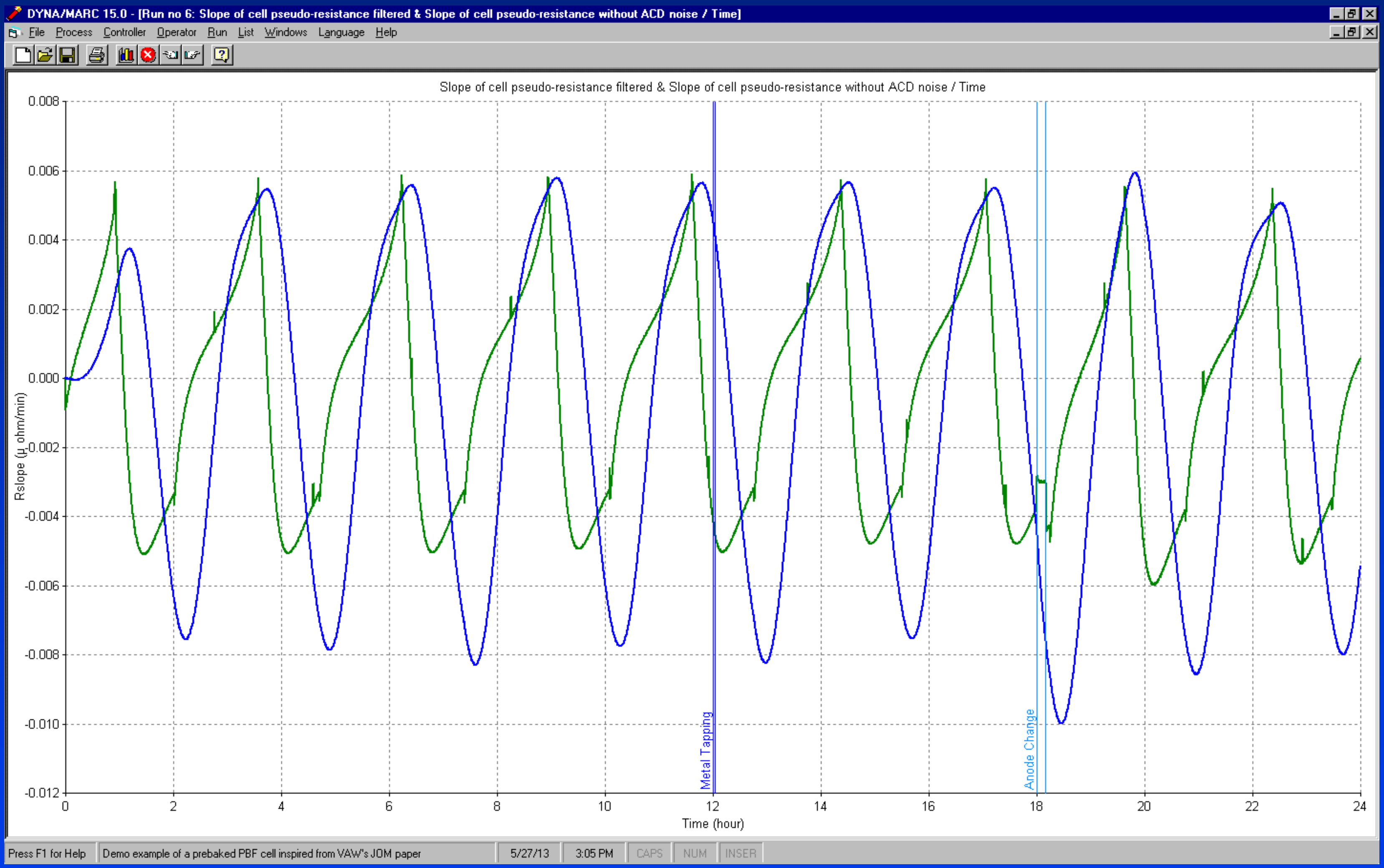
- The blue curve of the previous graph do overshoot the green curve each time the feeding regime is changed which again is typical of quadratic RMS fit. As for the first two noise filtration numerical scheme, this third “optimal” one consists of sampling the cell voltage at a given frequency, averaging the sampled value to generate datapoints and fitting a given number of those datapoints using quadratic RMS.

- Those results are even better than the those presented by Dubal (see next figure) who is reporting the lowest anode effect frequency of the industry.

Dubal noise filtration numerical scheme



Optimum noise filtration numerical scheme



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Optimum noise filtration numerical scheme

- As desired, the filtered pseudo resistance slope evolution curve is 100% noise free and is not lagging the noise free curve toward the end of underfeeding. The fit is obviously not perfect but can be considered optimum as it is fulfilling all the requirements for cell control needs.

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Conclusions

- Cell voltage noise filtration is the key to achieve cell operation with high current efficiency and very low anode effect frequency.
- During the underfeeding regime from the lean side of the cell voltage vs alumina concentration curve, the gradual increase of the slope of the cell voltage has been well characterized and the added bubble and MHD driven cell voltage noise has been very well characterized as well.
- It follows that in those circumstances calculating the slope of that noisy cell resistance can now be considered as an exact science. Hence finding the optimal numerical algorithm to filter out that noise and calculating the current noise free cell resistance slope was a straightforward proposal.
- That optimal numerical algorithm requires more computer resources than those currently used in the industry but considering the very low cost of hardware and the industry desire to continue to reduce anode effect frequency, there clearly should be no hardware related limitations when selecting the noise filtration numerical scheme.