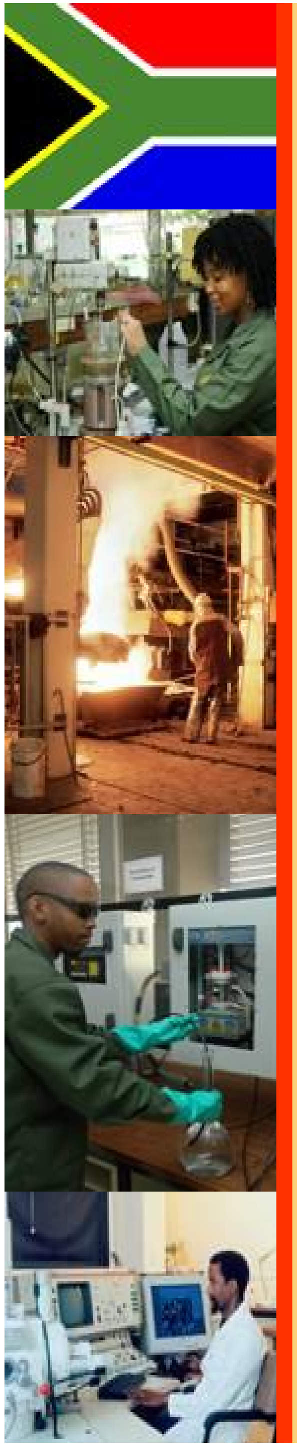

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The Effectiveness of Resistance vs. Current Control of Submerged-arc Furnace Electrode Penetration in Selected Scenarios

4 June 2009

Chris Hockaday
Head: Furnace Control, Measurement and Control Division

Introduction

- Background of submerged-arc furnaces
  - Circuit
  - Electrode considerations
- Control of submerged-arc furnaces
  - Various methods
- Reasons for this study
  - May be circumstances where one is preferable to the other
  - Evaluate this from all angles, not just power input

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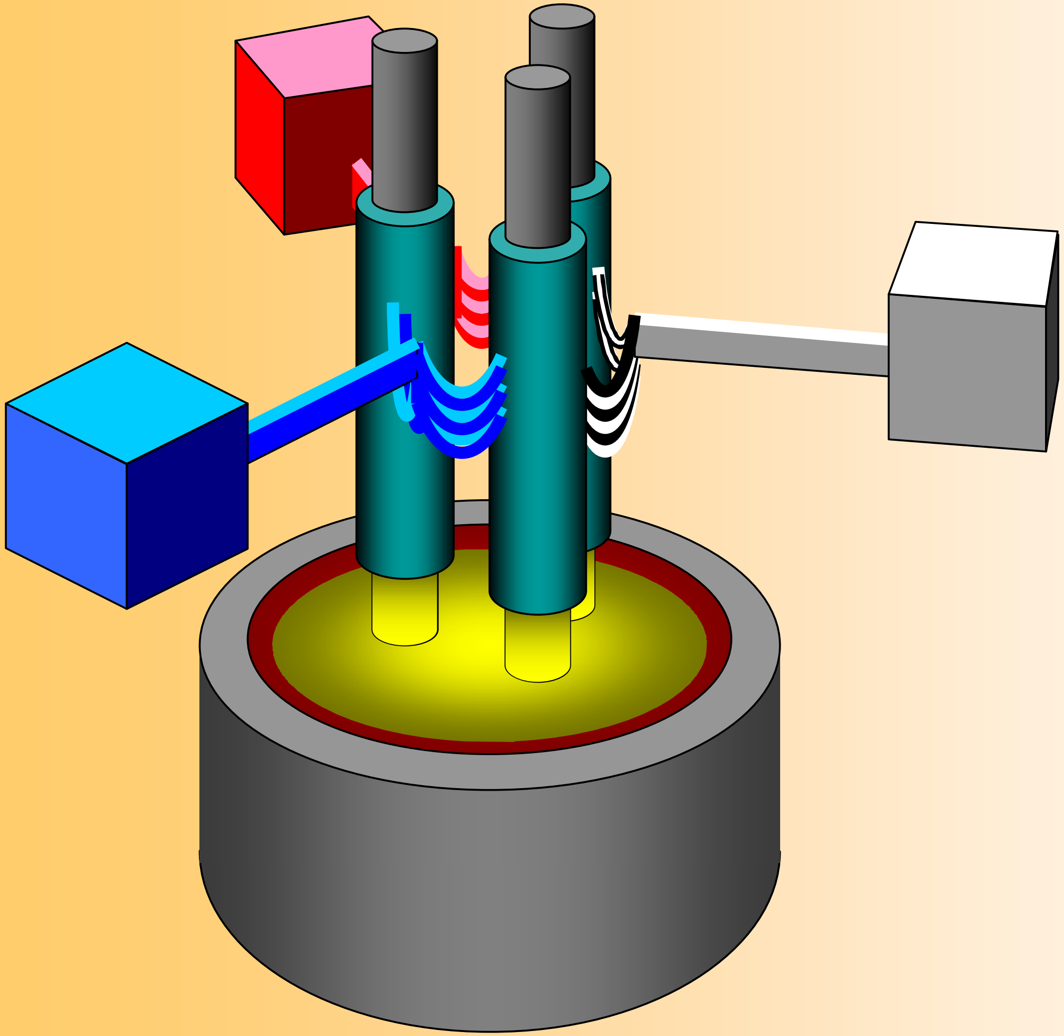
Submerged-arc Furnace



- Power supplied by three transformers
- Søderberg self-baking electrodes
- Electrodes interconnected via molten metal bath

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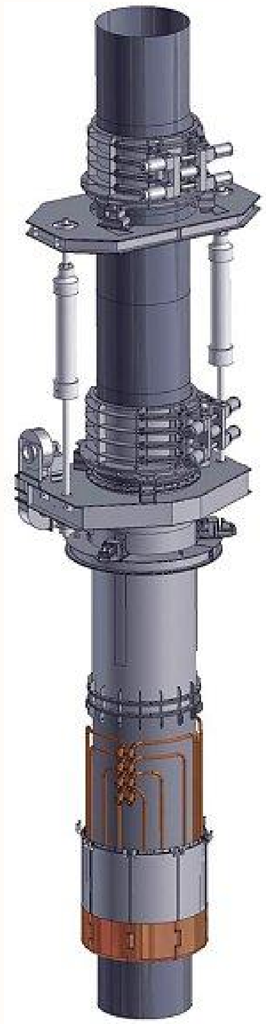
Søderberg Electrodes

- Self baking
  - Steel casings
  - Paste blocks
    - Melted and baked solid by heat from the electrode's own current
    - Baking rate depends on $(\text{electrode current})^2$
- Slipping
  - Compensates for erosion of electrodes
  - Over/under slipping results in long/short electrodes
  - Slip rate needs to be matched with baking rate otherwise risk of breakage



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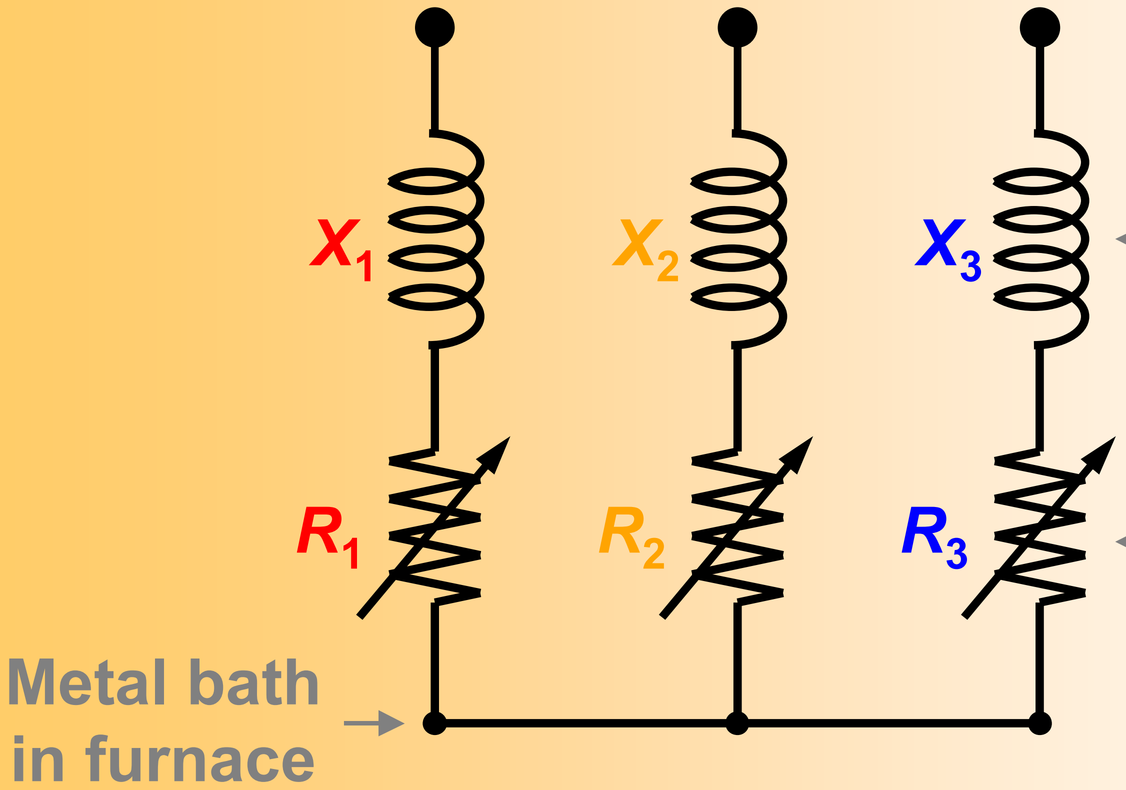
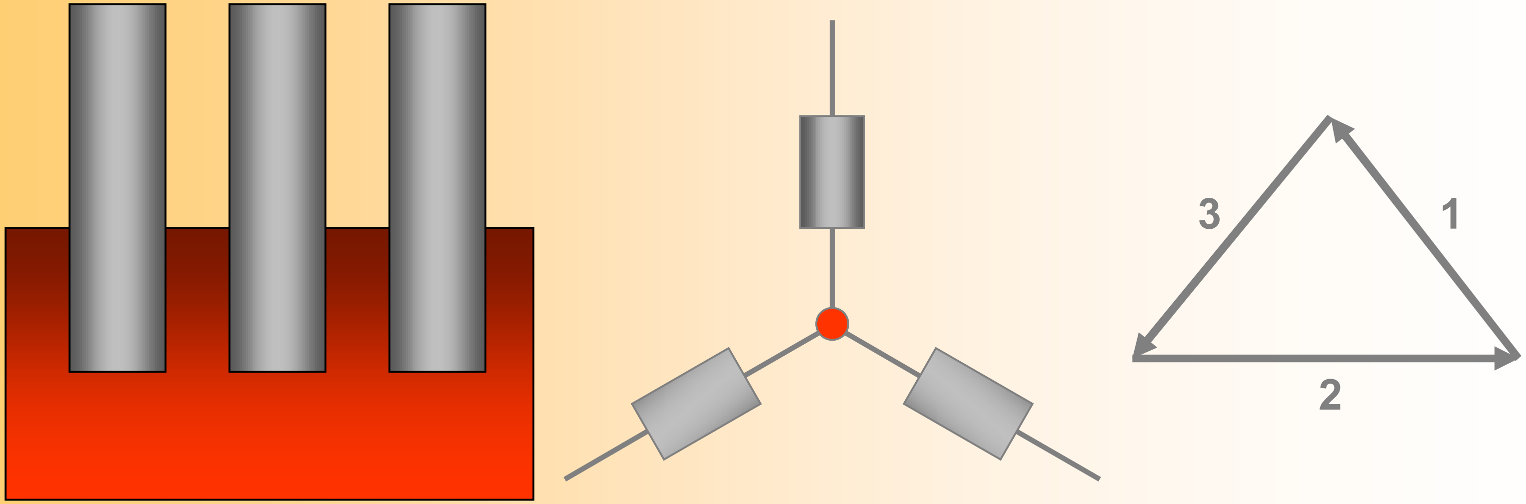
Basic Circuit of Submerged-arc Furnaces

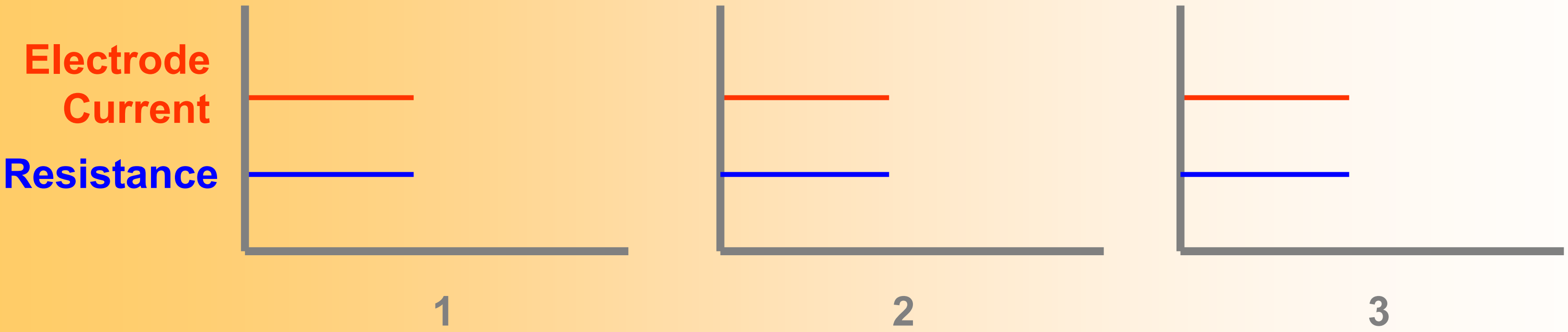


Reactances (~fixed - furnace geometry)

Resistances (variable by raising or lowering electrodes)

The Interaction Effect





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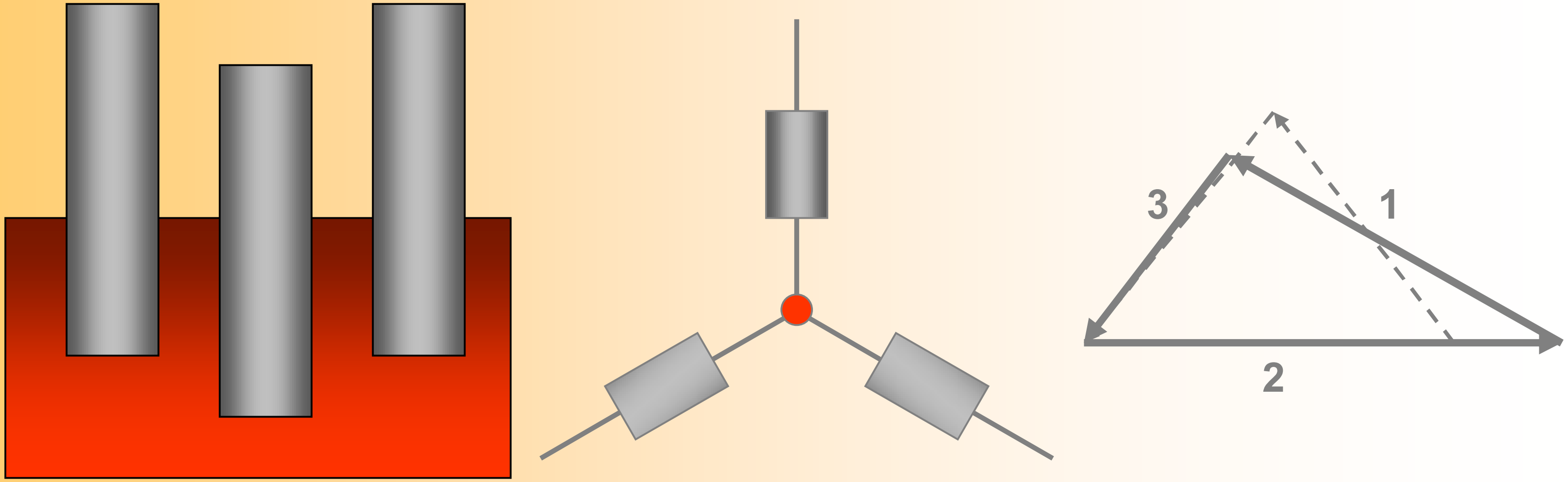
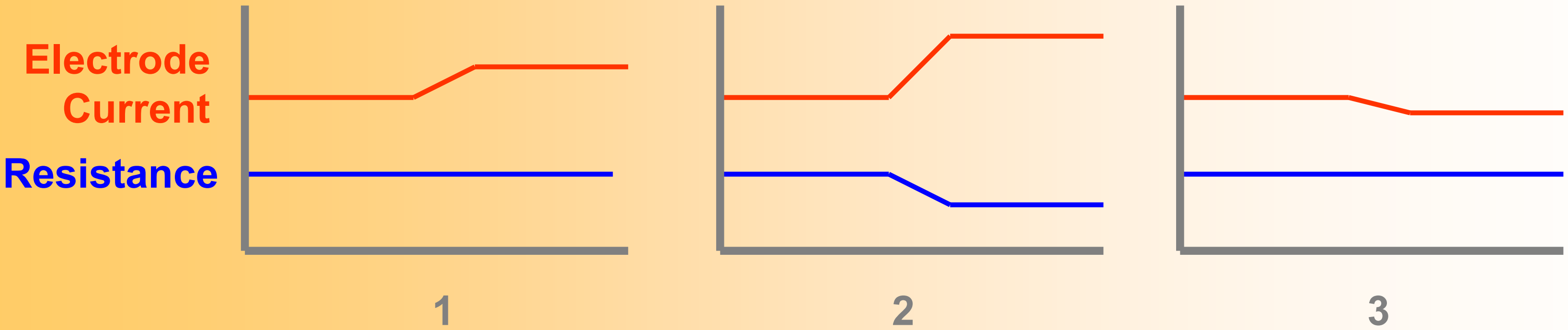
The Interaction Effect (2)





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Control of Electrode Penetration

- Traditionally current control
  - Availability of measurements
  - Suffers from interaction effect
  - Variable penetration at different loads

- Impedance/Resistance control
  - Less sensitive to interaction effect
  - Difficult to measure reliably due to
    - Hearth connection
    - Induced errors in measurements due to magnetic fields

- Calculated resistance control
  - No hearth connection required
  - Can be calculated from primary side which can be measured more accurately

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Purpose of This Study

- Resistance control generally accepted as superior to current control
- But: in upset/unstable conditions some furnace operators attempt to balance furnace:
  - current control
  - manual operation (invariably using current as a reference)
- Is this course of action justified under certain circumstances?
  - Consider from all aspects

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Aspects Considered

- Overall power input
  - Production
- Power distribution
  - Electrode consumption, build-ups, efficiency
- Hoist position
  - Efficiency
- Current asymmetry
  - Energy supply penalties
- Sum of squares error in current
  - Affects baking rate → maximum slip rate

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Scenarios Considered

- All Electrodes Free (FR) ↕↕↕
  - Analogous to having all electrodes near their correct, ideal lengths.
  - All electrodes operate within the limits of travel
- One Electrode On Bottom Stops (BS) ↕↕⤓
  - Analogous to a short electrode on an industrial furnace
  - Electrode lowered to the bottom of its travel range in order to achieve the setpoint for resistance or current.
- One Electrode On Top Stops (TS) ↕↕⤒
  - Analogous to a long electrode on an industrial furnace
  - Electrode lifted to the top of its travel range in order to achieve the setpoint for resistance or current.

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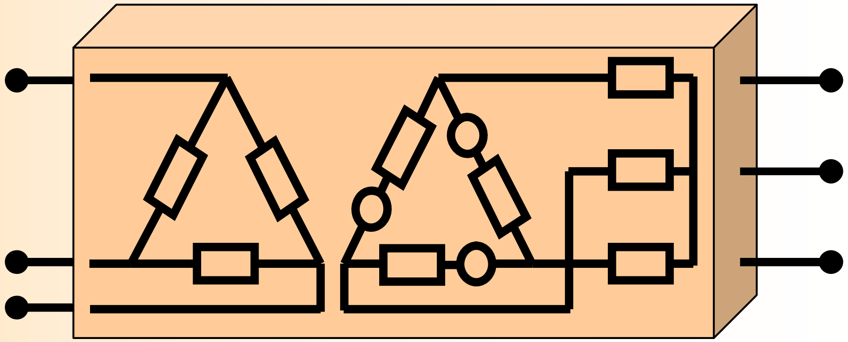
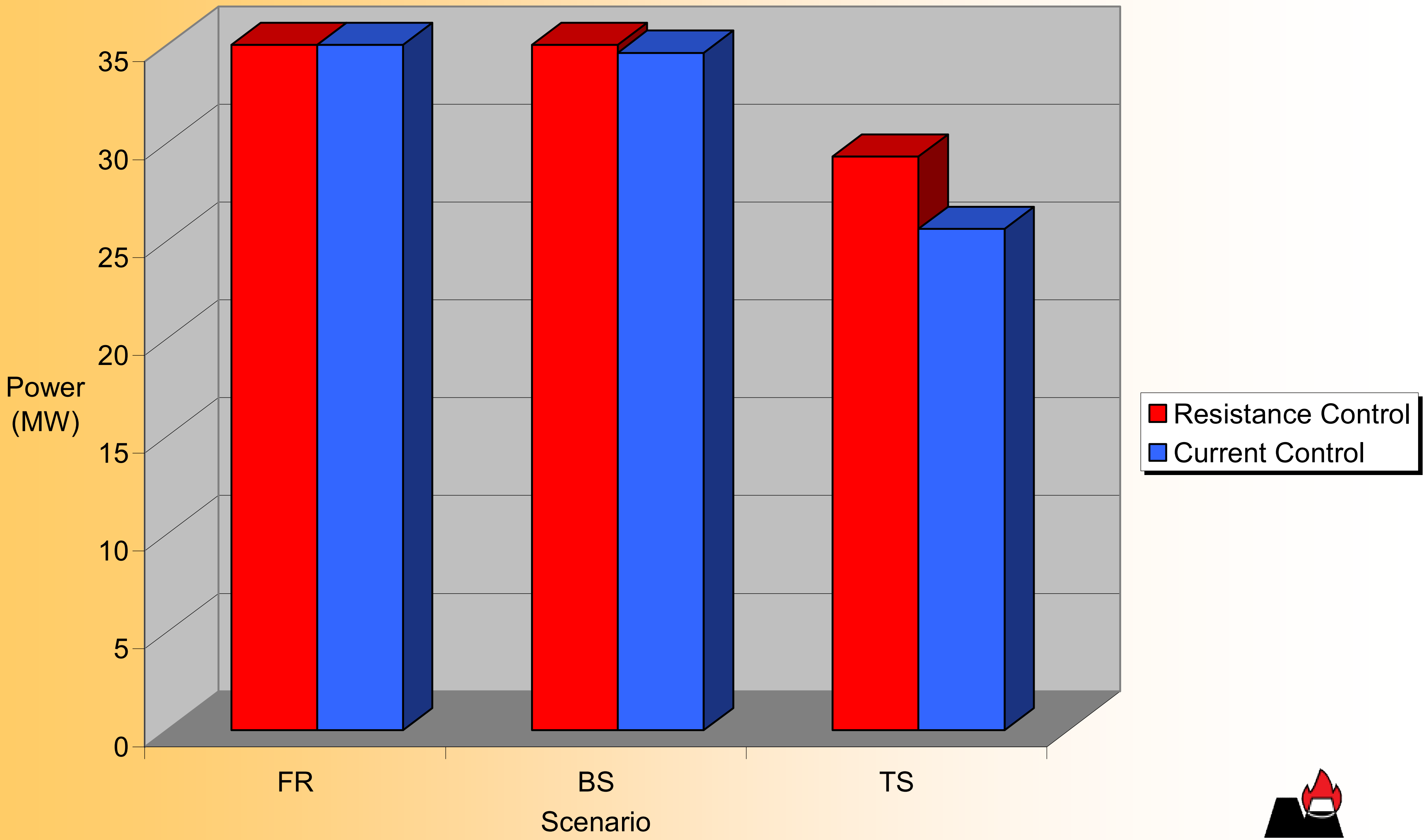
Test Platform

- Mintek Submerged-arc Furnace Simulator
  - Models entire electrical circuit
  - Disturbances simulated by adjusting metal bath level
    - Effectively alters tip-bath resistance/distance
    - Configurable rate and range
    - Configurable per electrode
  - Eliminates any effects caused by metallurgical conditions
    - Allows evaluation of electrical behaviour

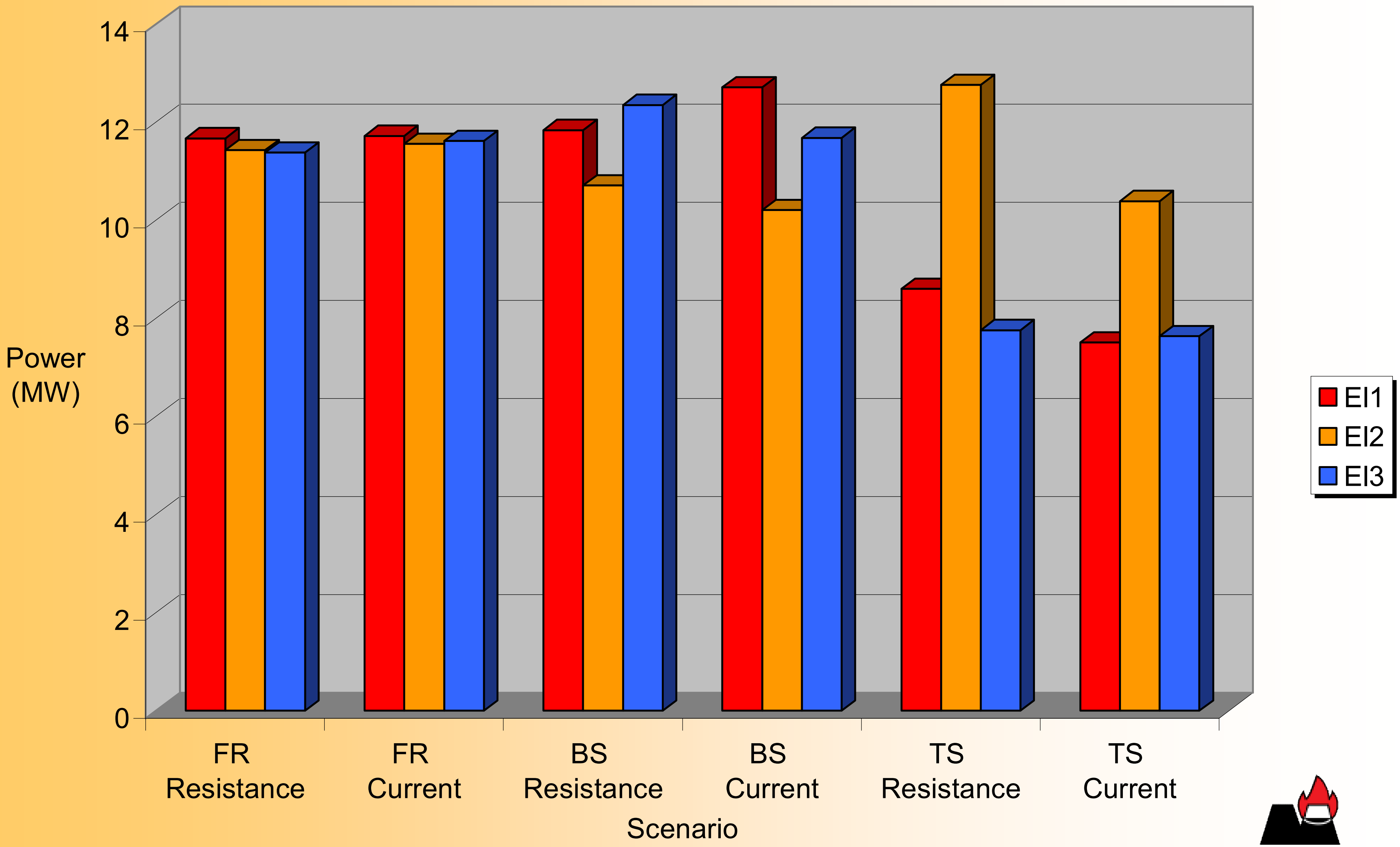
- Simulation parameters
  - Furnace
    - 48 MVA Furnace
    - 88 kA electrode current limits
    - **Power factor ~ 0.85**
  - Control
    - 35 MW Power setpoint
    - 2.0 mΩ resistance setpoint
  - Conditions
    - Slow rate of change – tapping cycle
    - Rapid rate – burden collapse etc.
    - Disturbances simulated on electrode 3



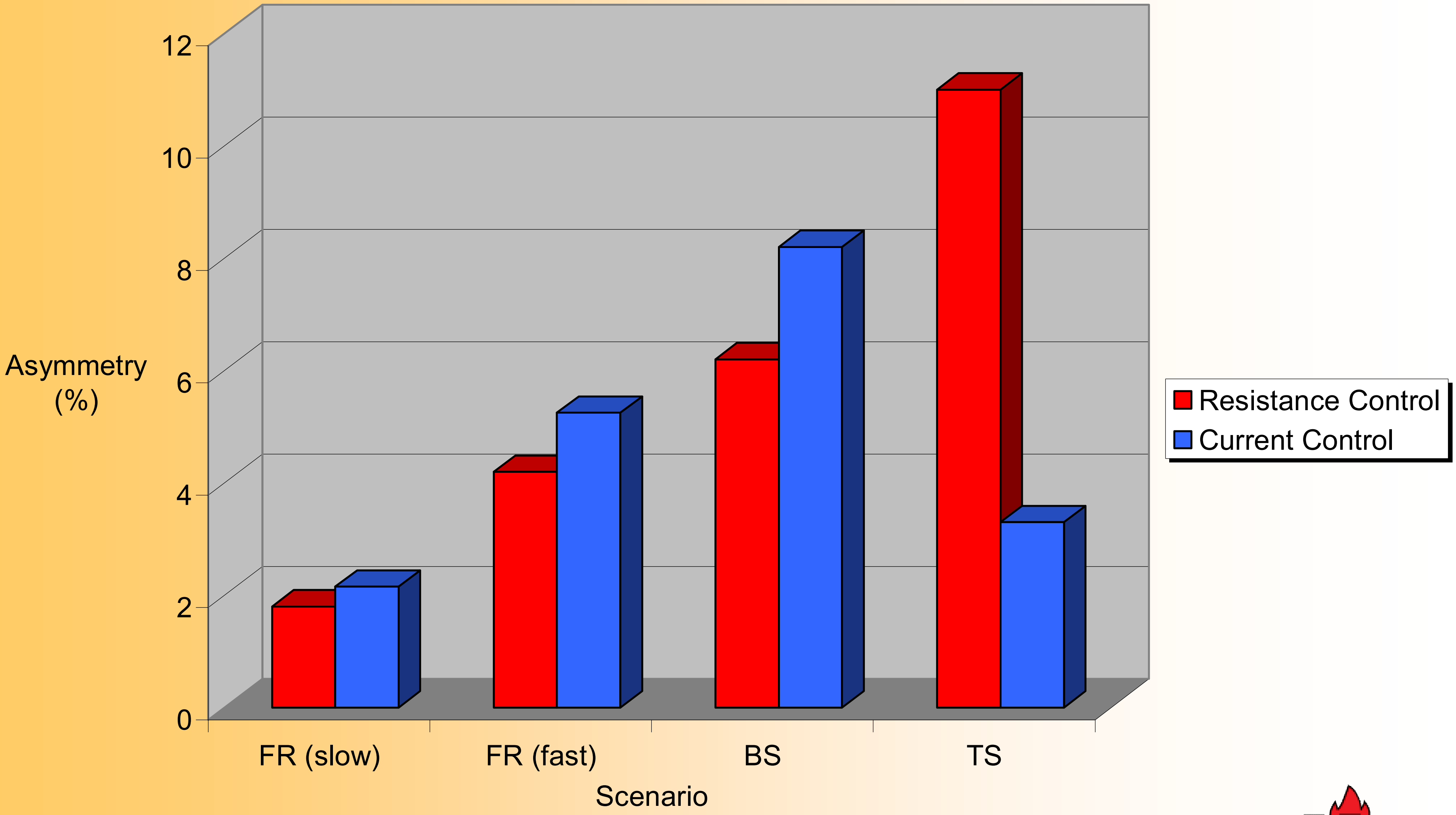
Results – Total Power Input



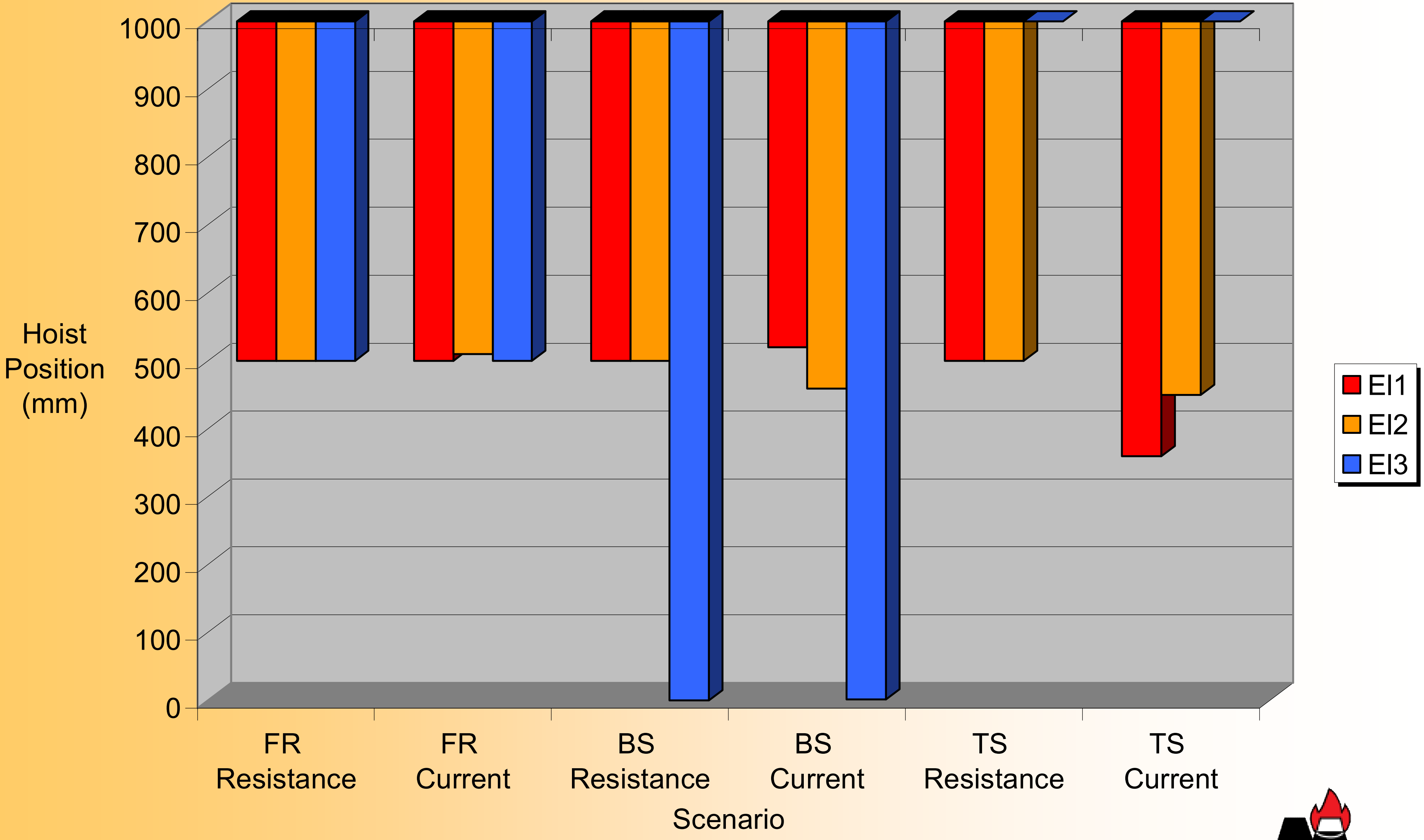
Results – Electrode Power Distribution



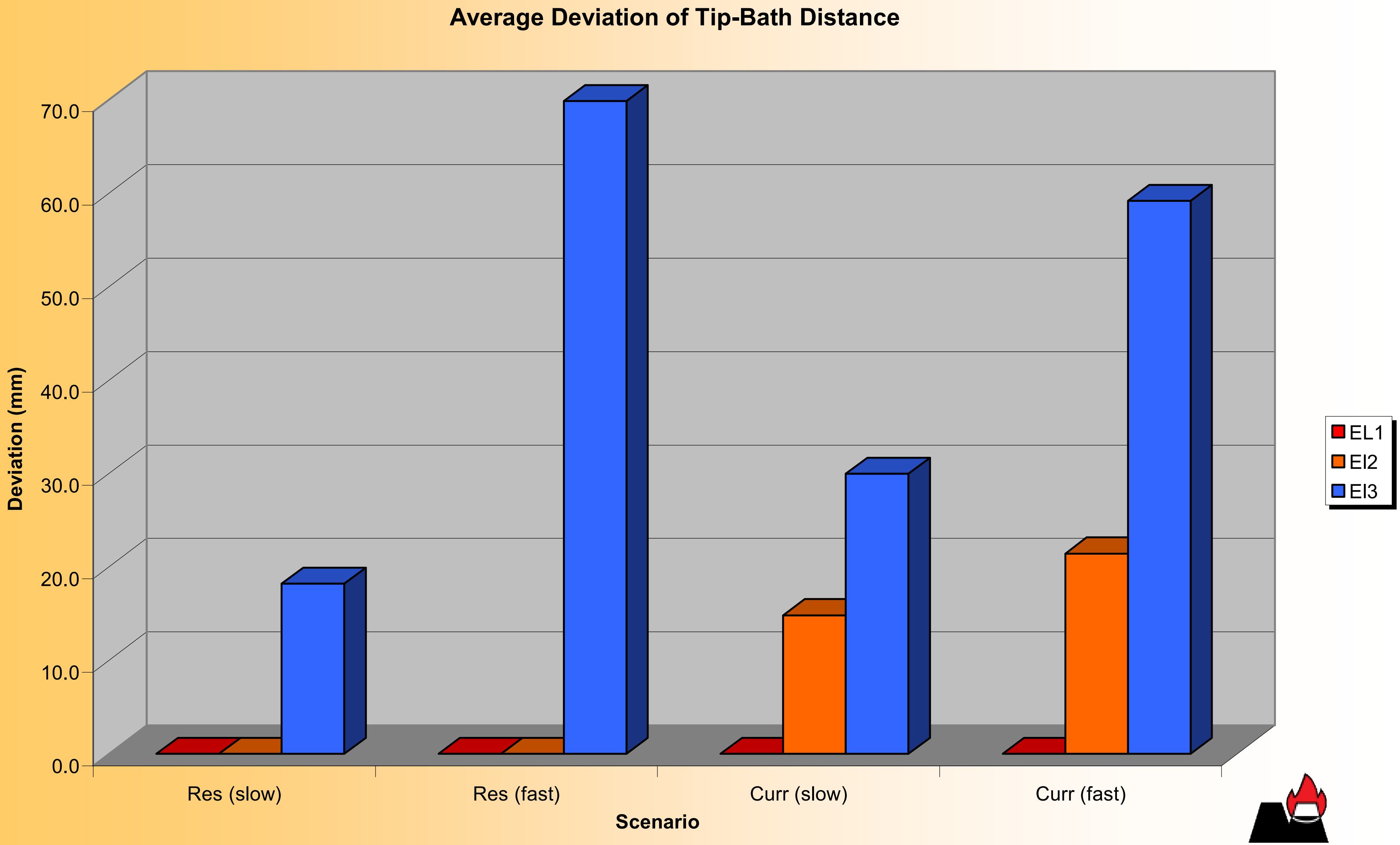
Results - Asymmetry



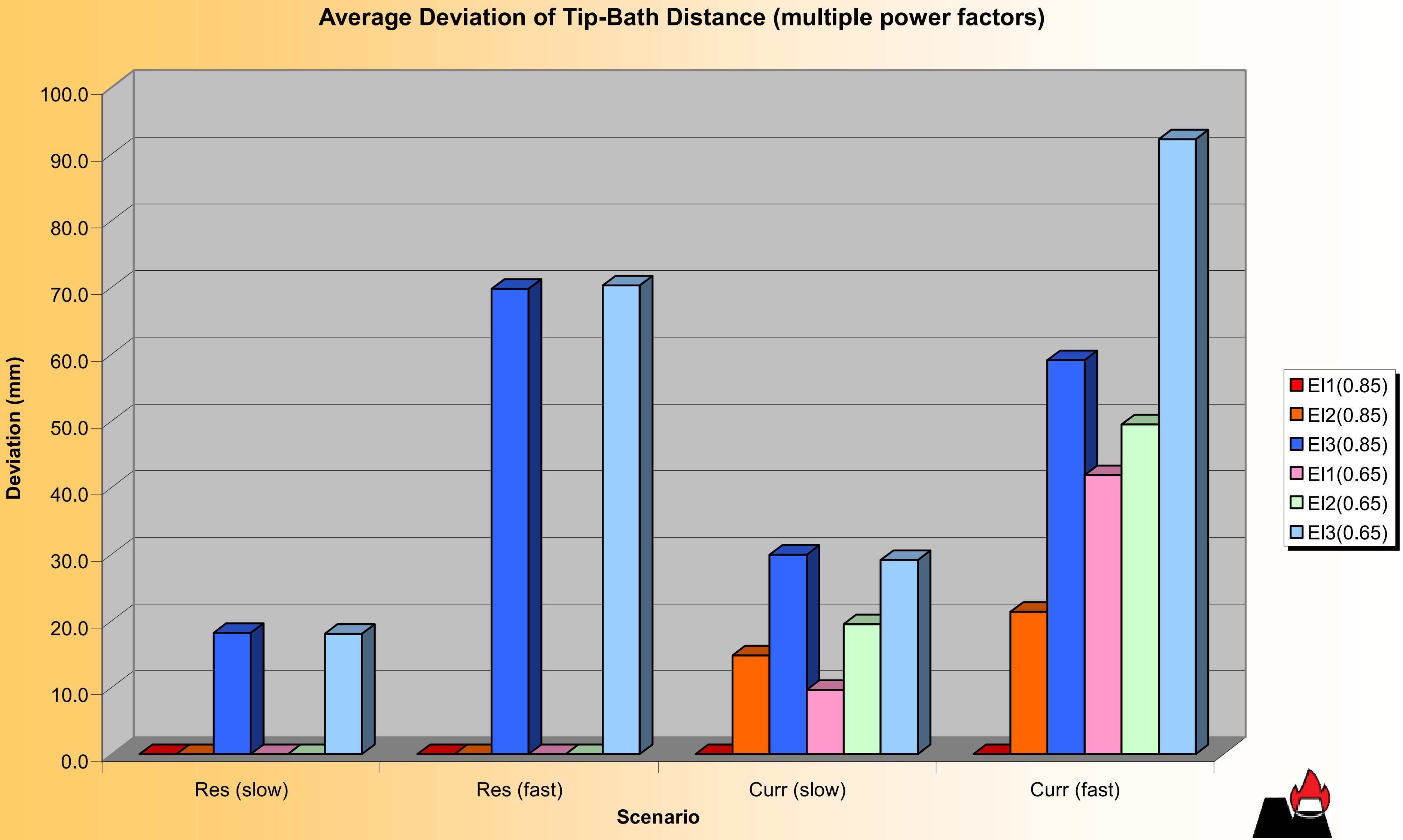
Results – Hoist Position



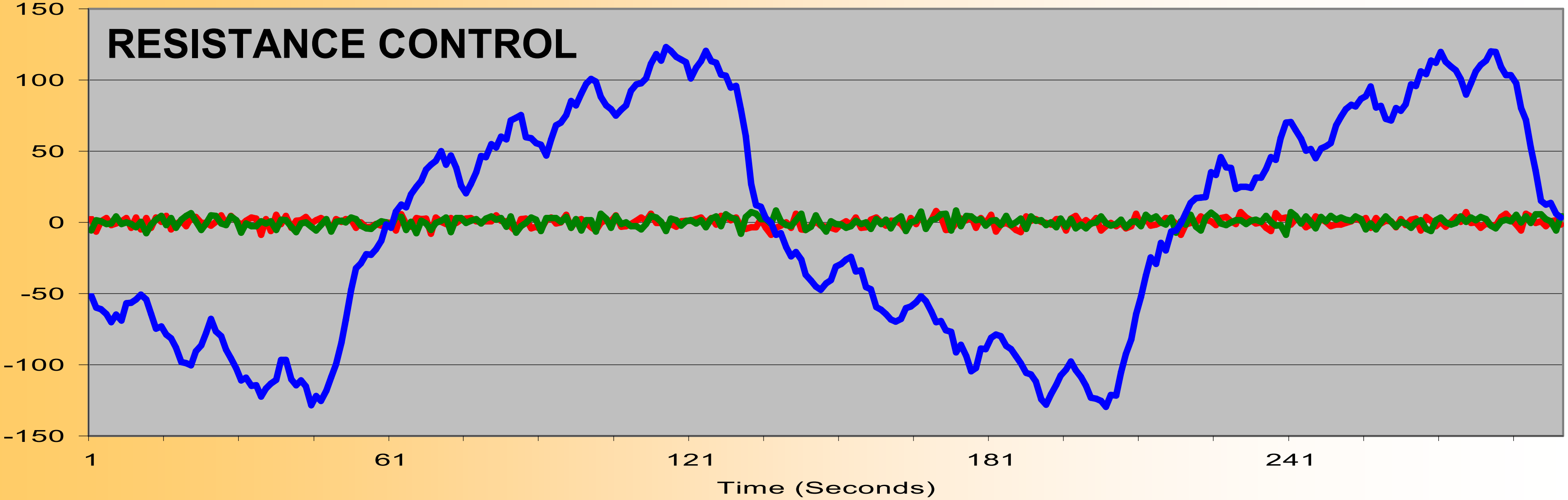
Electrode Penetration – Free Travel

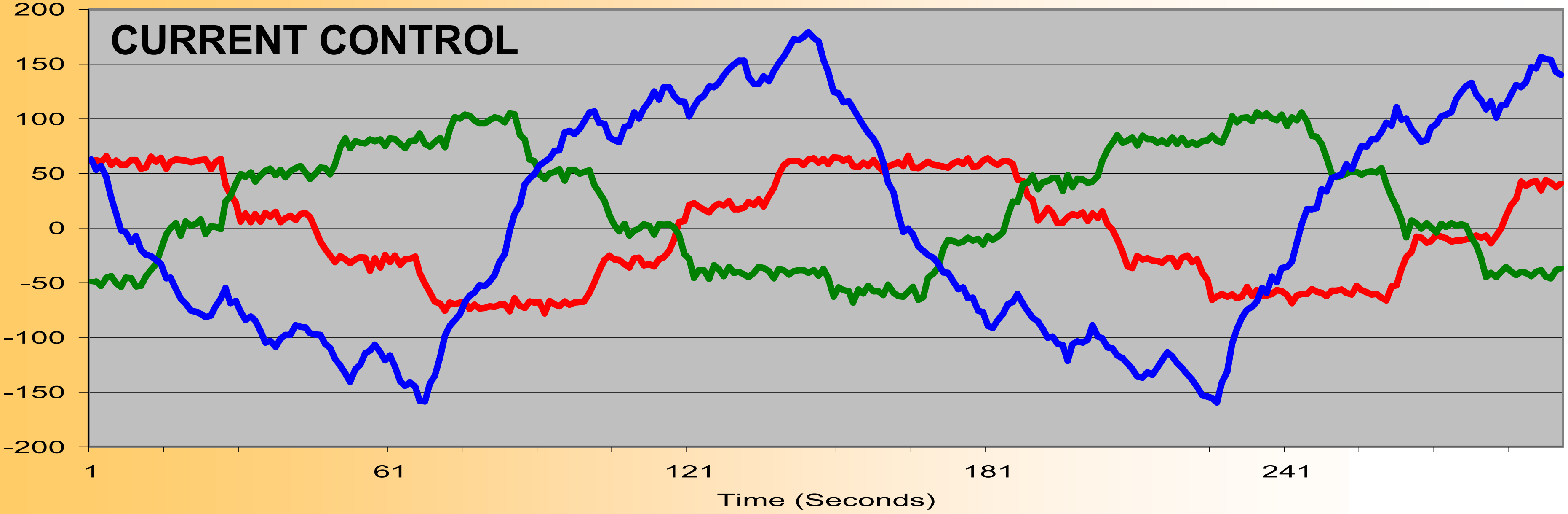


Electrode Penetration – Free Travel (2)

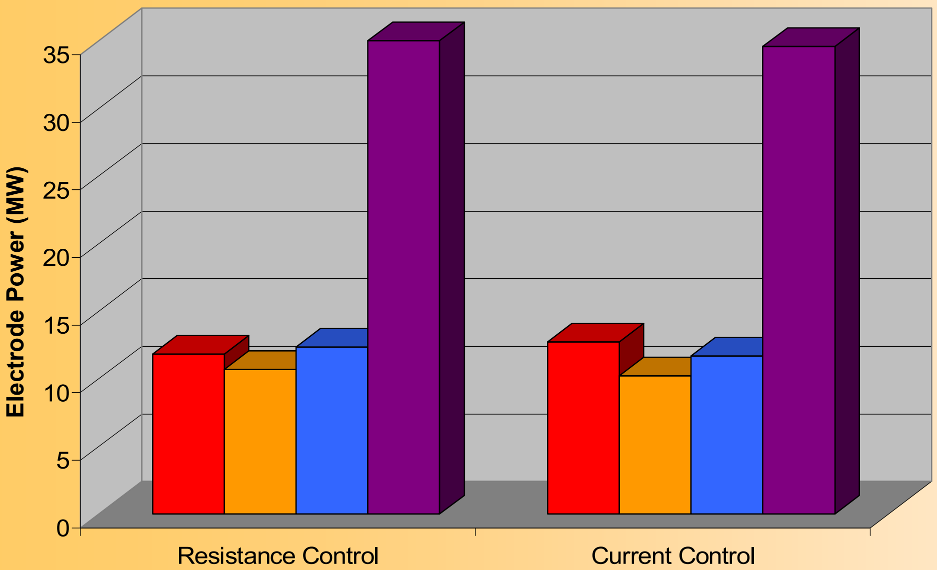


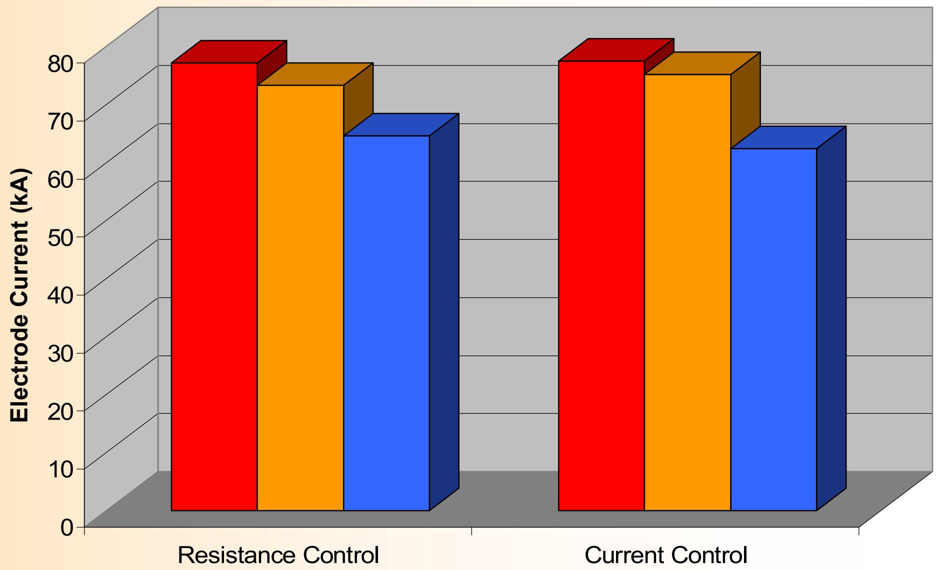
Electrode Penetration – Free Travel (3)

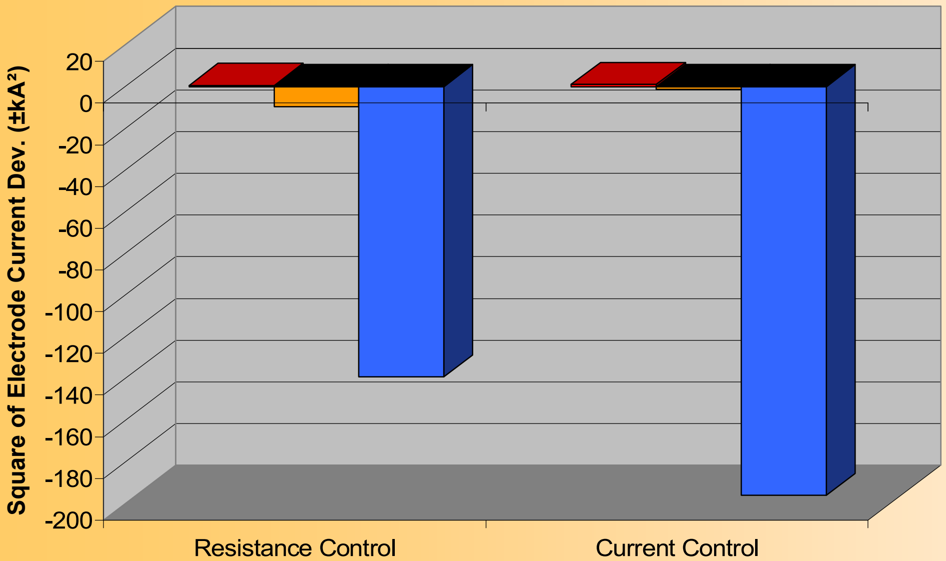


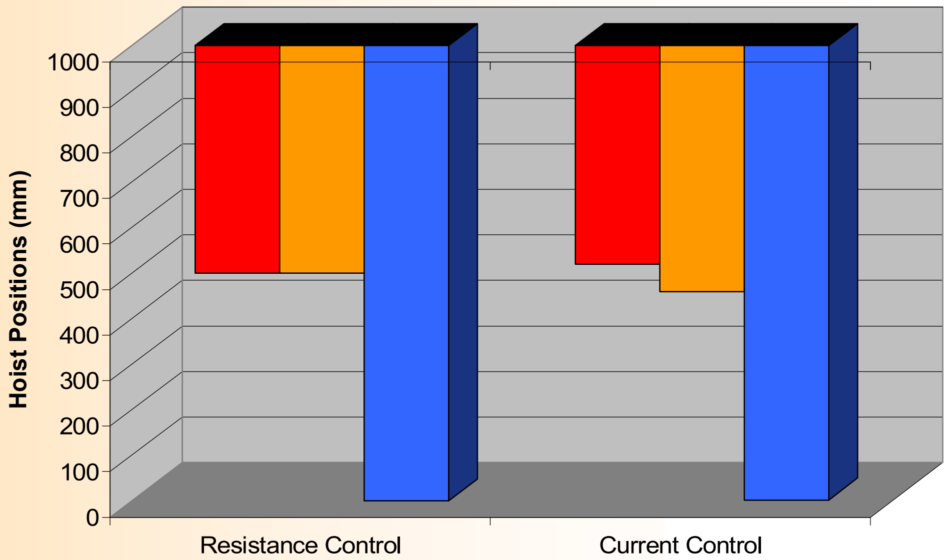


Summary – Bottom Stops

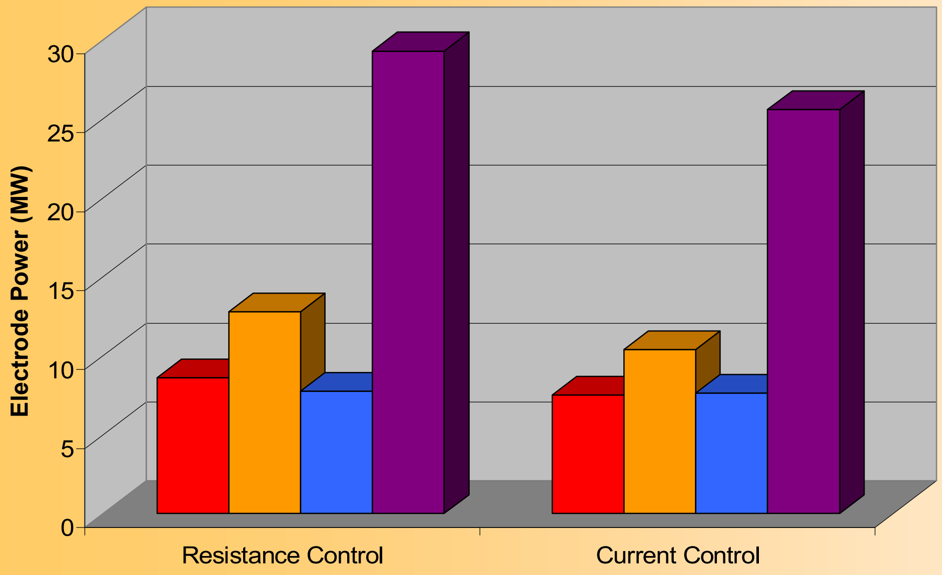


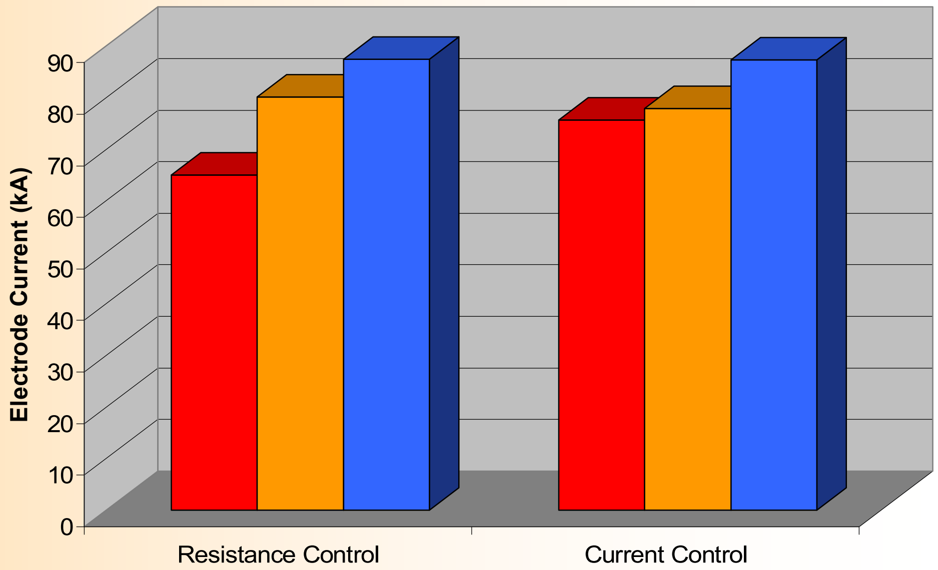


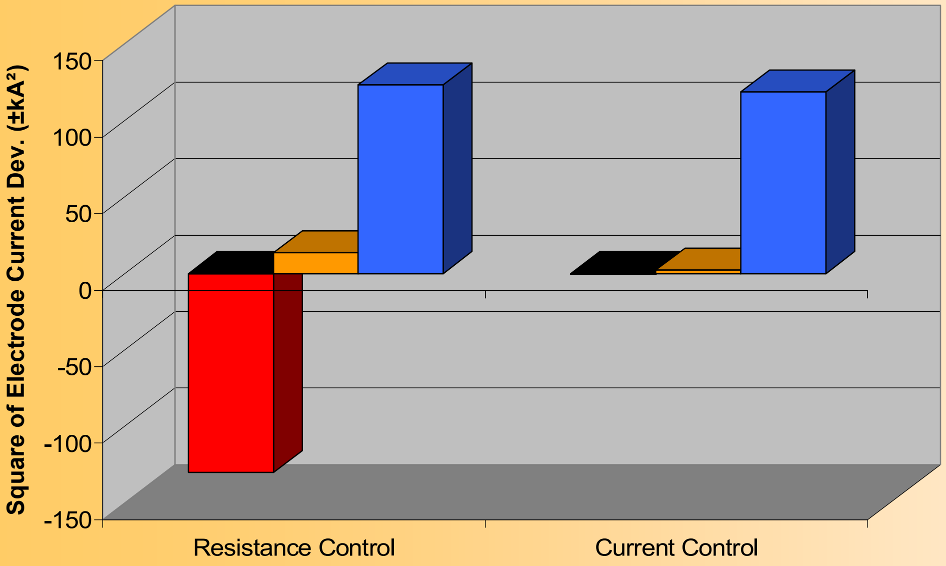


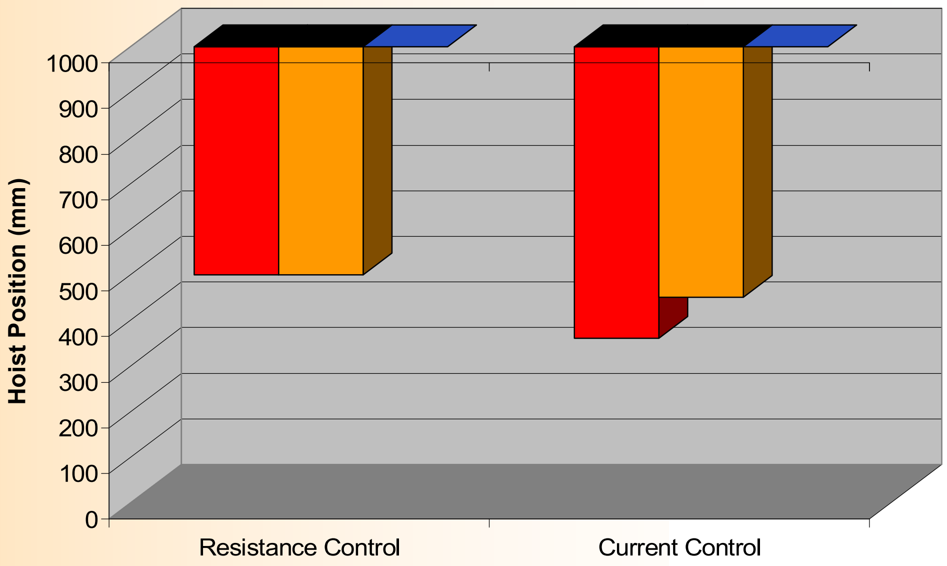


Summary – Top Stops

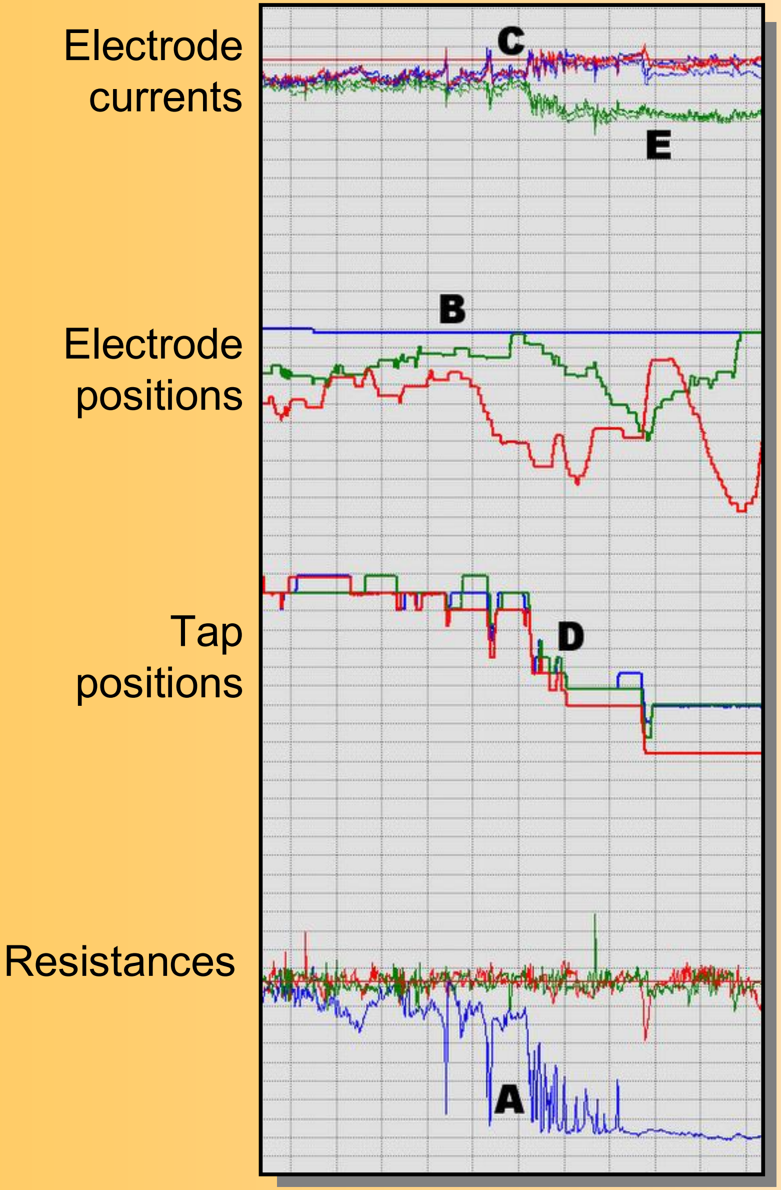








Top Stops – Real World Example



Explanation:

A. Resistance 3 drops
B. Electrode 3 already at top stops
C. Current 3 (and 1) exceeds limits
D. Controller taps down to reduce currents
E. Current 2 drops

If under current control:

F. El 2 would be pushed in to restore current;
G. El 3's current would increase further!
H. Further tap down actions required yielding lower power

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Summary

	Resistance Control	Current Control
Free Travel ↕↕↕	Similar to current control in stable conditions, high pf	More unbalanced/more electrode movement in upset conditions (interaction effect)
Bottom Stops ↕↕⤓	Balanced power, avoids chronic imbalance	MW on shallow electrode – low efficiency Chronic imbalance
Top Stops ↕↕⤒	Better MW	Lower power Better penetration, symmetry & I^2 -> better baking

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Options/Conclusions

- Better to use resistance control under all scenarios, including top stops, unless baking of electrodes is a major issue

- With a flexible control platform one could monitor electrode conditions, slipping, baking zone etc and intelligently adapt control method

- Little justification, however, since power input is typically the main objective from a production perspective

Thank you

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