When You Trust Your Data, Entirely New Capabilities are Possible

Utilizing HELM™
for Advanced Grid Management and Planning

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FERC
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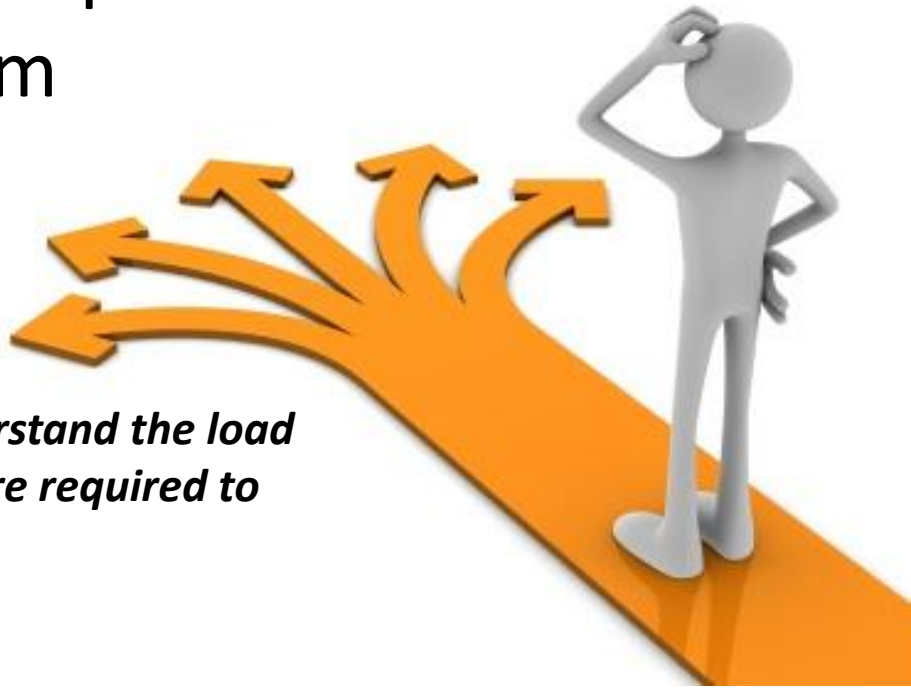
It is not enough to know you have a problem, our job is to help operators and planners solve the problem



We set out to find ways to fundamentally understand the load flow problem, and found entirely new tools were required to make this possible…..

Know Where you are – Know Where You are Going

Gridquant Inc.

Early 2000's	Red Eléctrica after major blackouts in Spain challenged Dr. Toni Trias of Group AIA to find a better way to develop Load Flow Constrained State Estimation
	Dr. Trias develops a fundamentally new approach. The Holomorphic Embedding Load Flow Method (**HELM**) and files patents
2000 -2004	ENDESA, CFE and PG&E install as initial large scale customers, but solution is "black box" and early stage
2004-2010	Application development and extensions
2010	Core HELM Patents granted
2011	Extension Patent granted
2012	Gridquant Inc. formed to expand HELM based technology globally – full technical disclosure now available
	Gridquant Inc. signs US/Canada commercialization agreement with Battelle – deep technical and consulting resources

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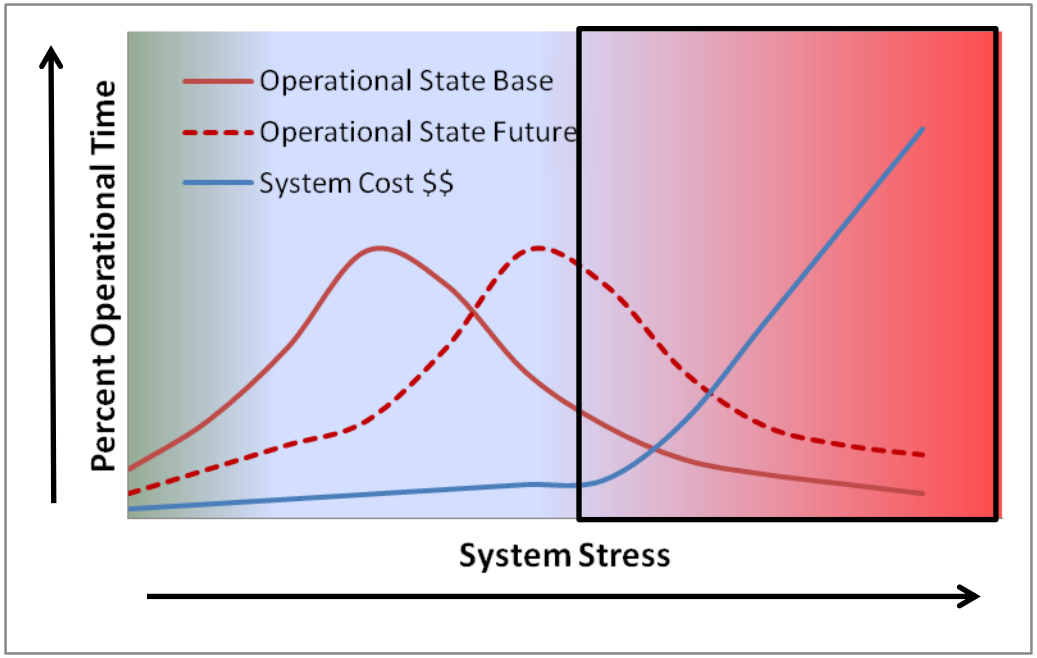
Grids and Grid Managers are Becoming More Stressed?

- Increasing congestion
- Increasing interconnection complexity
- Regulatory compliance requirements
- Changing Generation Mix
- Increasing transmission asset utilization
- Required security
- Expected efficiency
- Aged Assets

The Impact of the "Long Tail"



Current load flow and state estimation tools have fundamental mathematical limitations

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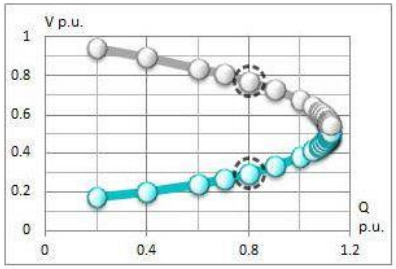
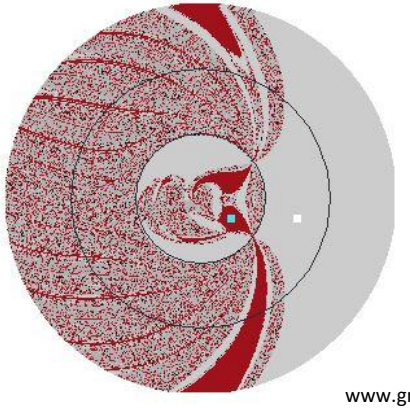
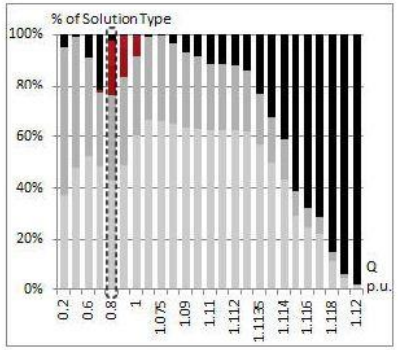
The well documented and understood limitations of NR based solutions …..

Move your mouse along the voltage collapse curve (top right). For each point along the curve, we've generated for over a million starting points, the load flow solution shown in the circular image (bottom left). The stacked histogram (bottom right) provides details of the frequency of each solution class.







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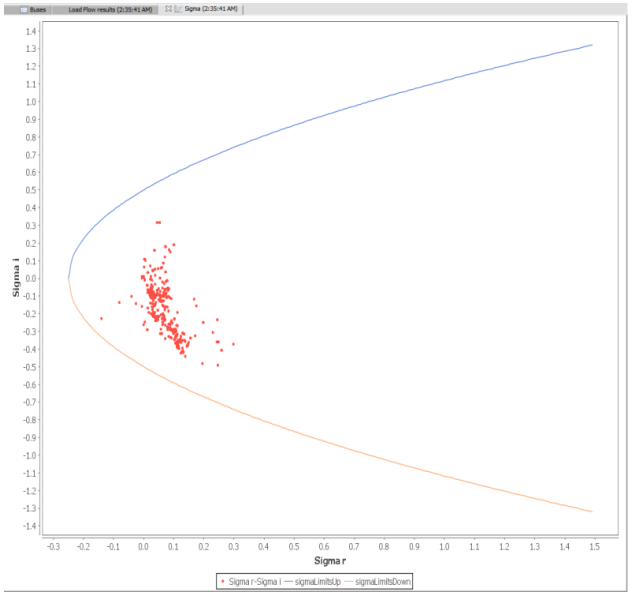
Are replaced by new ways of visualizing our grids and new tools to manage them….



New Capabilities:

- Evaluation of complex scenarios
- Solution under stressed conditions
- Distance to collapse
- Guided solution maneuvers

Solution to previously unsolvable problem creates new opportunities for grid management

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HELM Proof and Method Flow

$$\sum_{a\in\{all\}} Y_{na}V_a = y_n^{(zip)}V_n + I_n^{(zip)} + \frac{S_n^*}{V_n^*}$$

$$n \in \{all \setminus swing\}$$

$$\frac{S_{sw}^*}{V_{sw}^*} = -y_{sw}^{(zip)}V_{sw} - I_{sw}^{(zip)} + \sum_{a\in\{all\}} Y_{sw,a}V_a$$

Holomorphic embedding of the load flow equations with the non linear constant power contribution σ ->s σ (s=0 is the no load case, s=1 is the load flow problem to be solved)

The embedding function after elimination has an equivalent representation as **an algebraic curve in the complex plane** : a polyonimial with polynomial coefficients, being holomorphic

three bus antenna

$$P(s,t) \equiv t^4 - (1+2\alpha_R s)t^3 + (|\alpha|^2 s^2 + 2\beta_R s^2 + 2\sigma_{2R}s)t^2$$
$$-\left(2(\alpha_R\beta_R + \alpha_I\beta_I)s^3 + |\sigma_2|^2 s^2\right)t + |\beta|^2 = 0$$

Algebraic curves can be represented by their **power series** in a non null convergence radious

$$\sum_{n'\in\{nodes\}} Y_{nn'}V_{n'}(s) = -Y_{n,sw}V_{sw} + sy_n^{(zip)}V_n(s) + I_n + s\frac{S_n^*}{\overline{V}_n(s)}$$

The formal power series and its reciprocal is used in order to create a **recursive deterministic** way of **computing the coefficients** through solving linear equations system

$$V^{(-1)}[0]V[0]=1$$

$$\sum_{n=0}^{N+1} V^{(-1)}[n]V[N+1-n]=0 \quad : \quad N=0,1,\ldots$$

$$V^{(-1)}[N+1]=-\frac{1}{V[0]}\sum_{n=0}^{N} V^{(-1)}[n]V[N+1-n]=0 \quad : \quad N=0,1,\ldots$$

Fixed matrix at all systems guarantee **time efficiency**

Algebraic curves can be solved with maximal analytic continuation "convergence radious", by **continued fractions** of their power series (Stahl's theorem 1997)

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Methods for computing continuos fractions can employ algebraic approximants of different order. **Padé approximants** are algebraic approximates of first order are used.

Compute the continued fraction N+1-th truncation

$$\frac{A_{N+1}^{(n)}(s)}{B_{N+1}^{(n)}(s)} \quad : \quad n \in \{nodes\}$$

Check for error tolerance

$$\left| \frac{A_{N+1}^{(n)}(1)}{B_{N+1}^{(n)}(1)} - \frac{A_{N}^{(n)}(1)}{B_{N}^{(n)}(1)} \right| \quad : \quad n \in \{nodes\}$$

Finally evaluate at *s*=1 to deliver the solution to the original Load Flow Problem

Advanced Capabilities in Exploration and Guided Control

HELM Load Flow based State Estimation always a correct physical representative of a grid

HELM Load Flow

Deterministic either resolves or does not

HELM Theorem

Holomorphic Embedding Load Flow Method

Restoration, Limit Violation Solvers, OPF

Clearances, simulations at any point of the PV/QV curve

Easy to identify and resolve model and data errors

A fundamentally new and patented theorem

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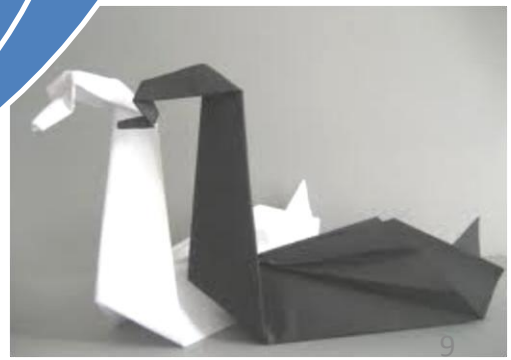

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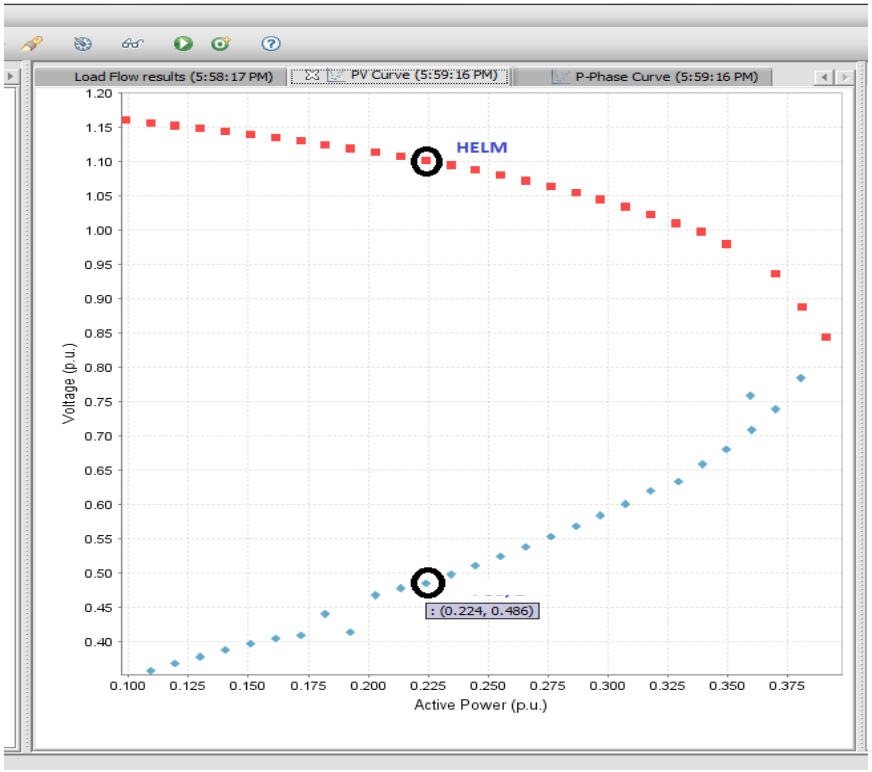
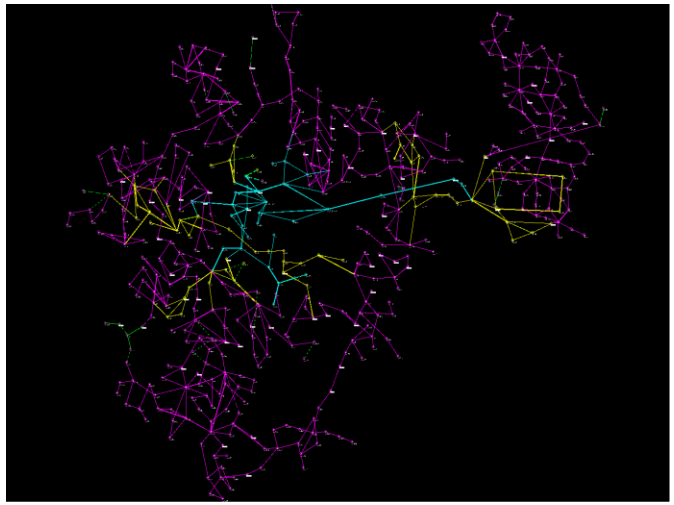
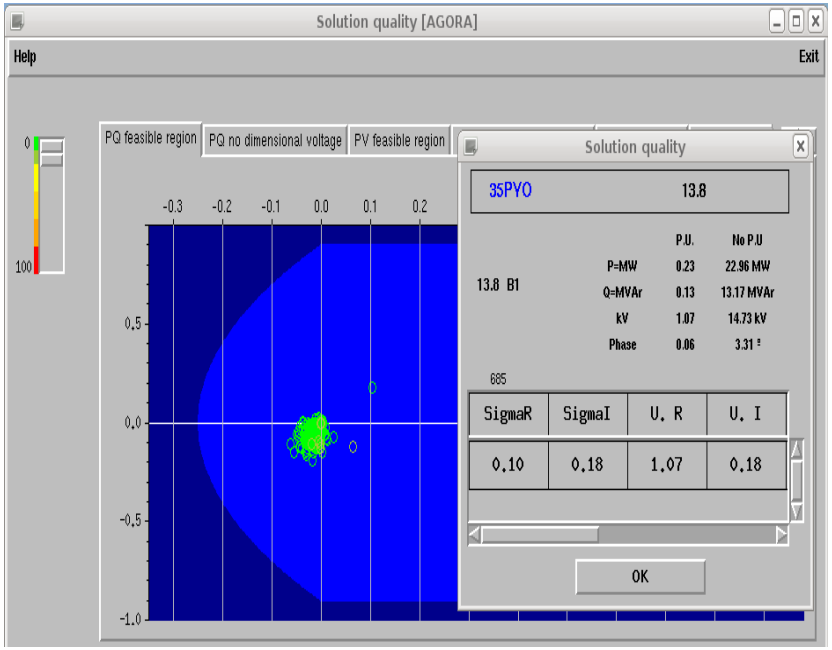
Know where you are



Real Time PV/QV curves



Automated One Line Diagrams – easy data import/export in industry standard formats



Node by Node Stability

… at all times

- Accurate current state
- Real Time analysis of all contingencies
- Distance to collapse

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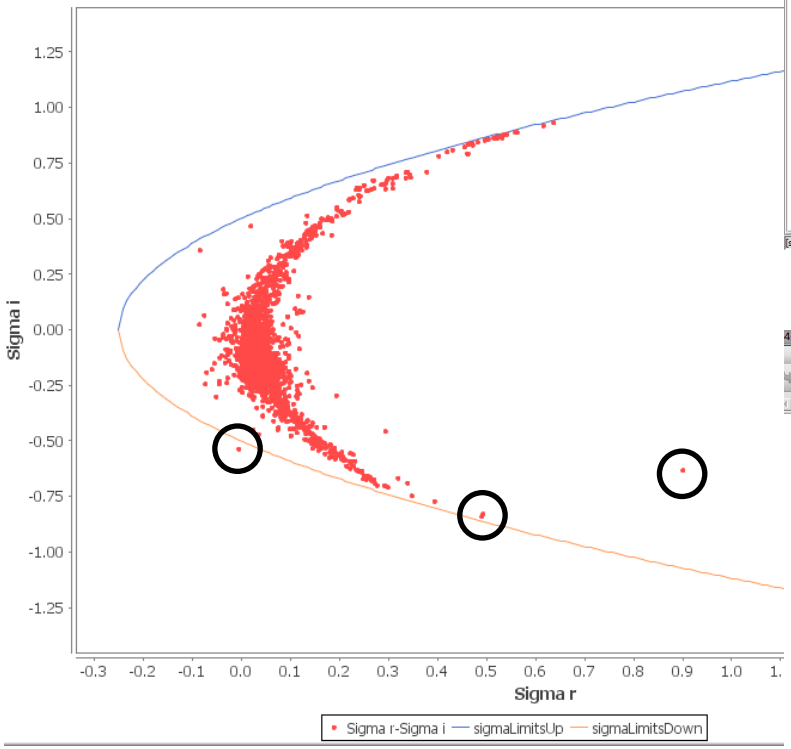
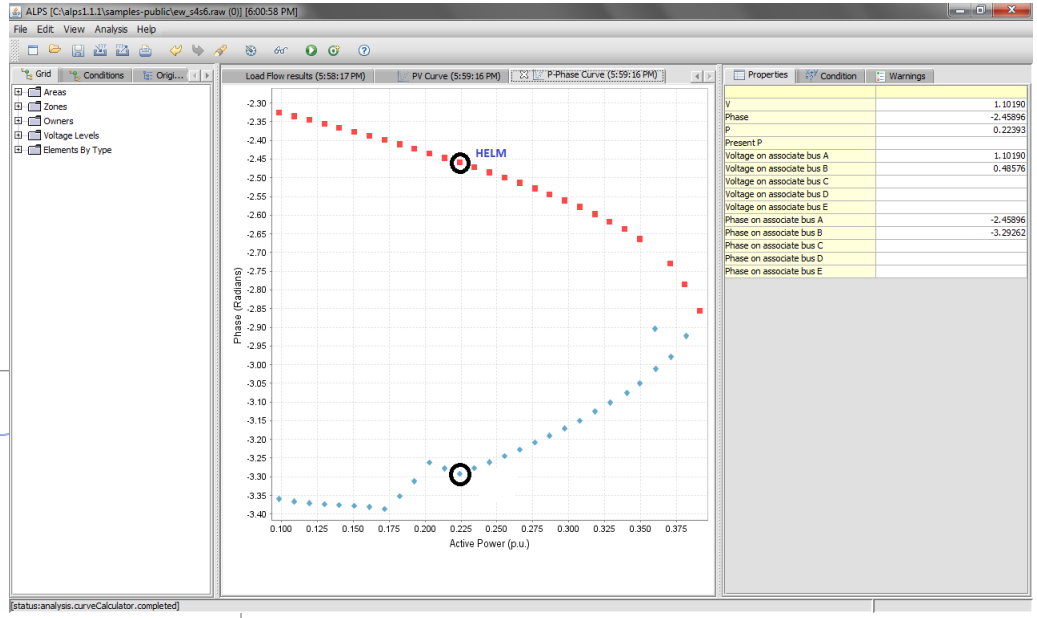
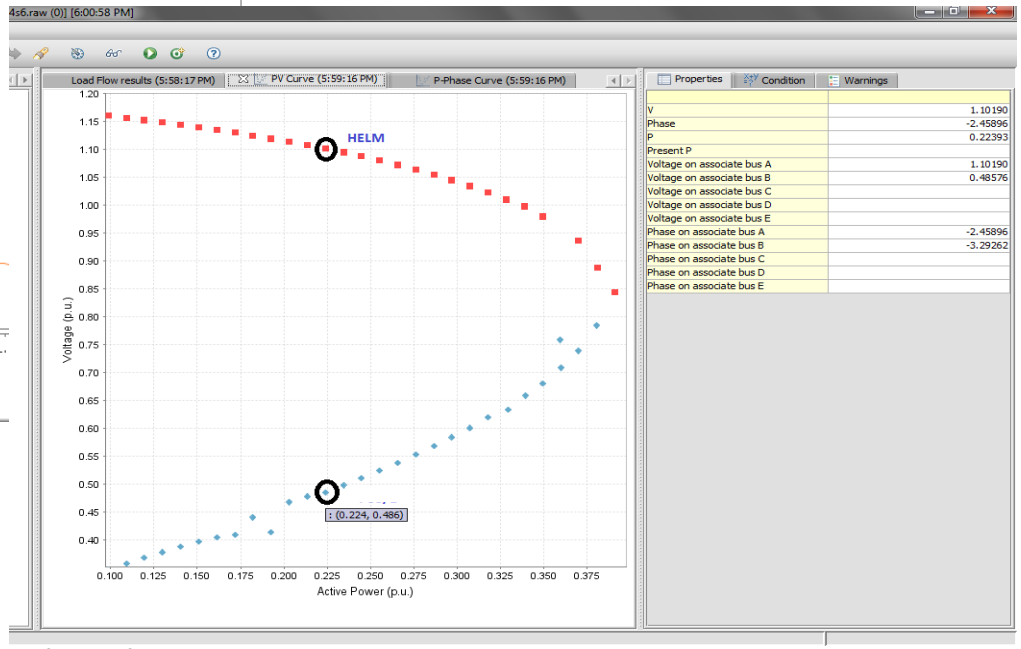
Current Systems can resolve to the non physical grid







We not only show that it does not resolve – we show why it does not and what to do about it

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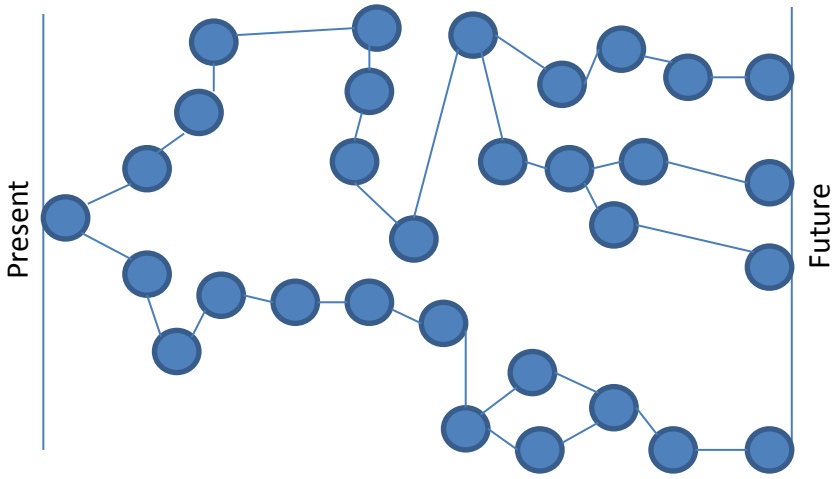

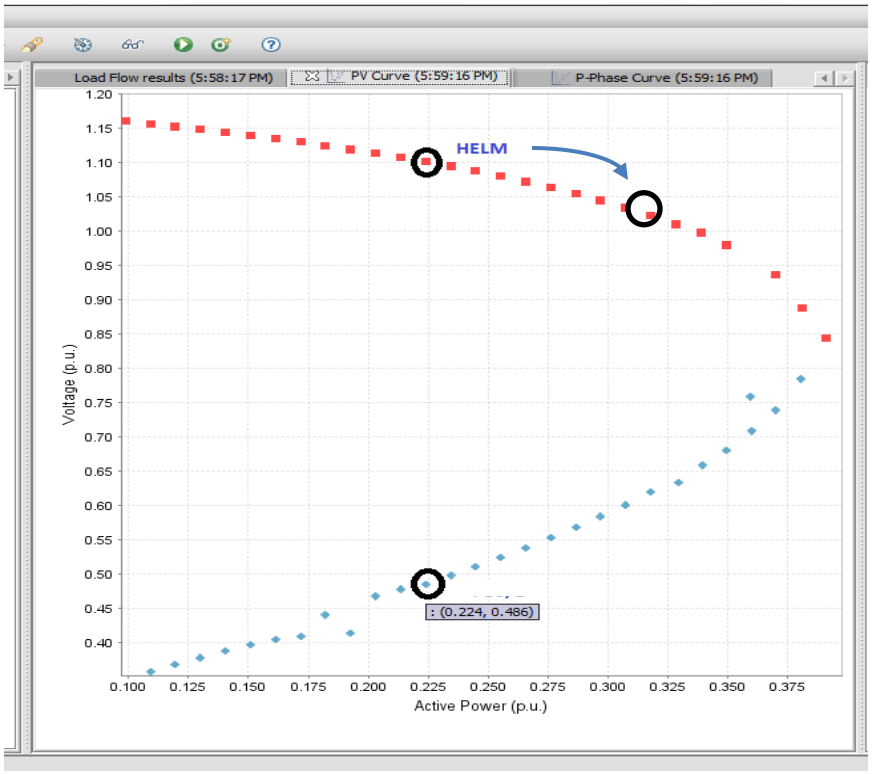

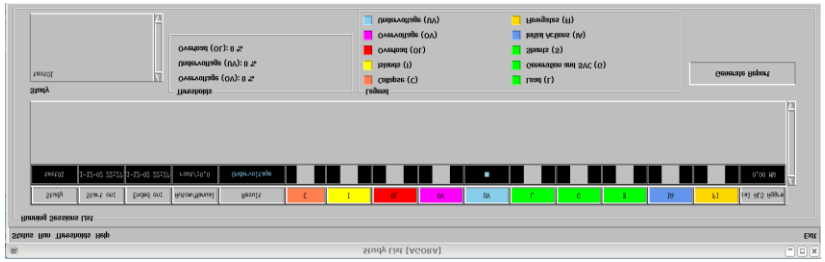

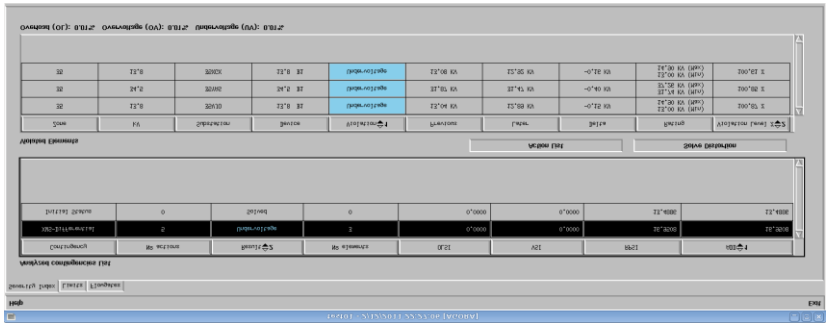

Easy exploration of multiple, physically correct, weighted and ranked potential future states (complex contingencies)

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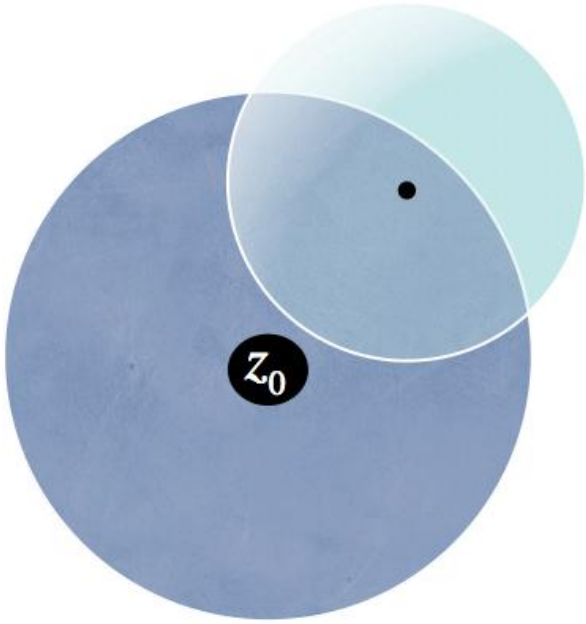
New and Enhanced Applications for Operations

- Operational Planning
  - RAS
  - SPS
  - Contingency Simulations
  - Clearances and maintenance scheduling
  - Forensic event analysis
  - Reserve Adequacy (locational)



- Situational Awareness
  - Limit violation solver
  - PV/QV analysis – know exact distance to collapse by node
  - Sigma Analysis - Rapid ID of problem nodes

The HELM algorithm opens a deeper understanding of transmission systems, providing expanded capabilities for the utility industry

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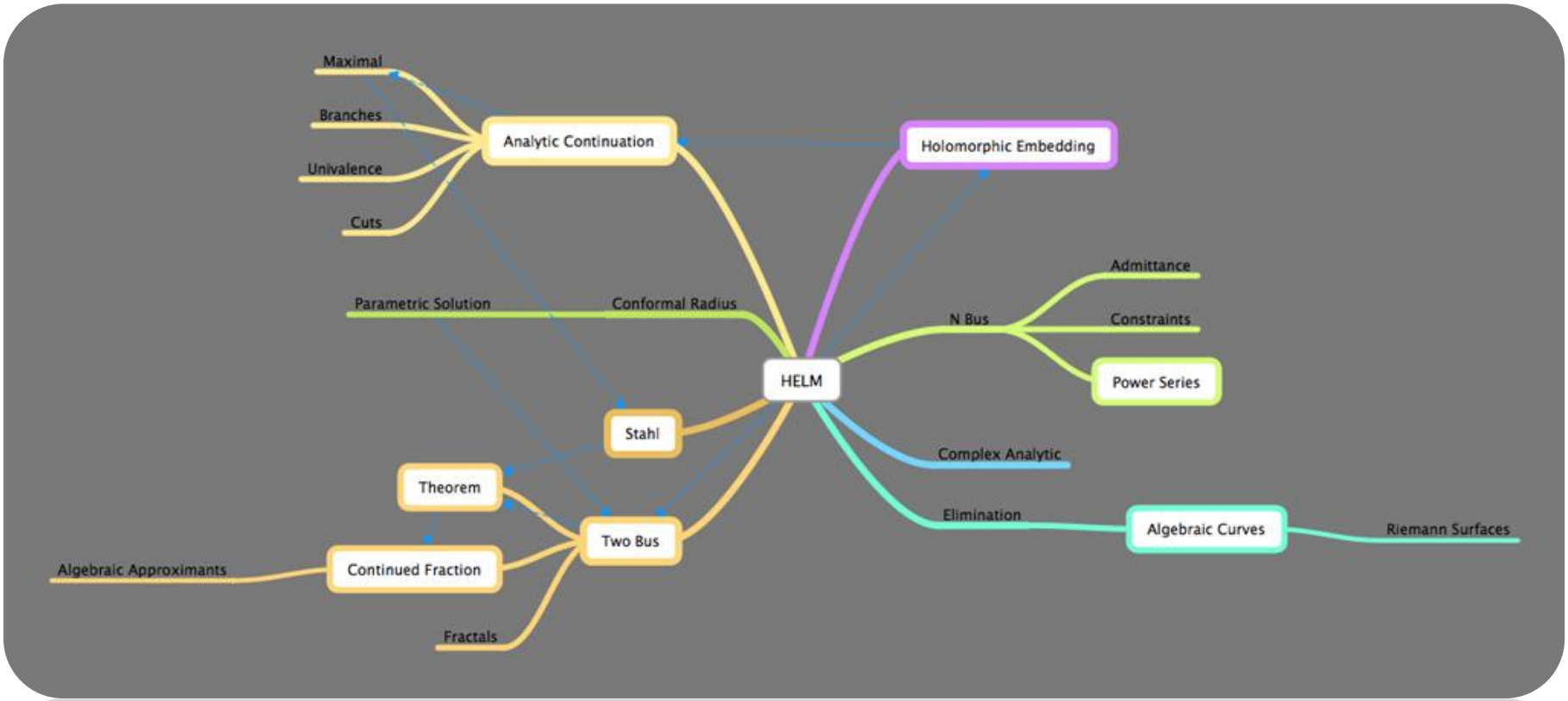
HELM
(Holomorphic Embedding Load Flow)

A modern foundation technology, 500 years in the making…



Maxwell *Cardano* *Riemann* *Cauchy* *Padé*

Tartaglia *Stahl* *Newton* *Weierstrass*