Smart Grid Integrated Modeling Hubs Linked to Tradeoff Analysis and Validation

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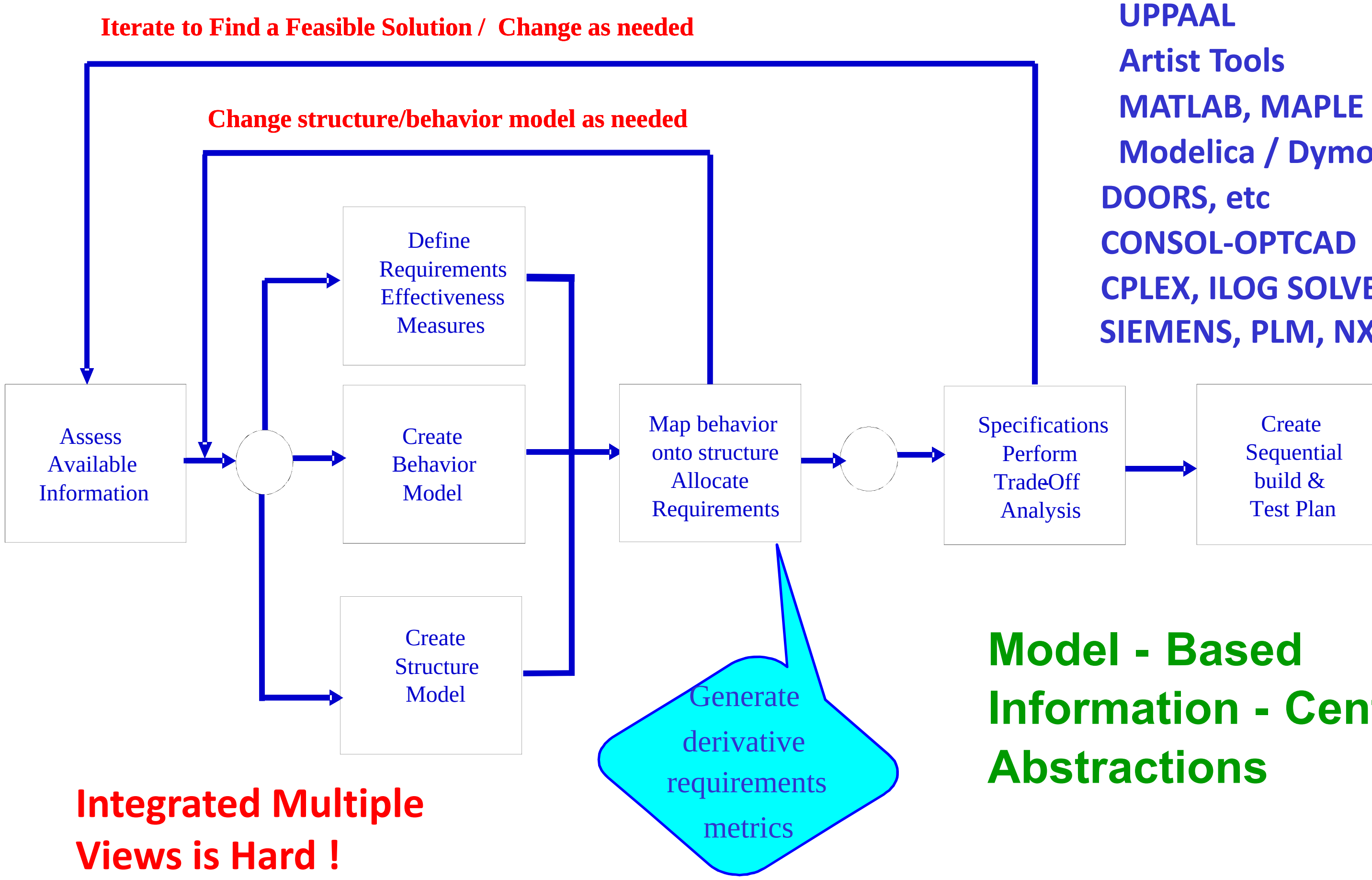
Model-Based Systems Engineering Components -- Architecture

Integrated System Synthesis Tools - & Environments missing

Model- - based
- **UML - SysML - GME - eMFLON**
- **Rapsody**
- **UPPAAL**
- **Artist Tools**
- **MATLAB, MAPLE**
- **Modelica / Dymola**

DOORS, etc
CONSOL-OPTCAD
CPLEX, ILOG SOLVER,
SIEMENS, PLM, NX, TEAM CENTER



Integrated Multiple Views is Hard !

Model - Based
Information - Centric
Abstractions

FOUR PILLARS OF SYSML

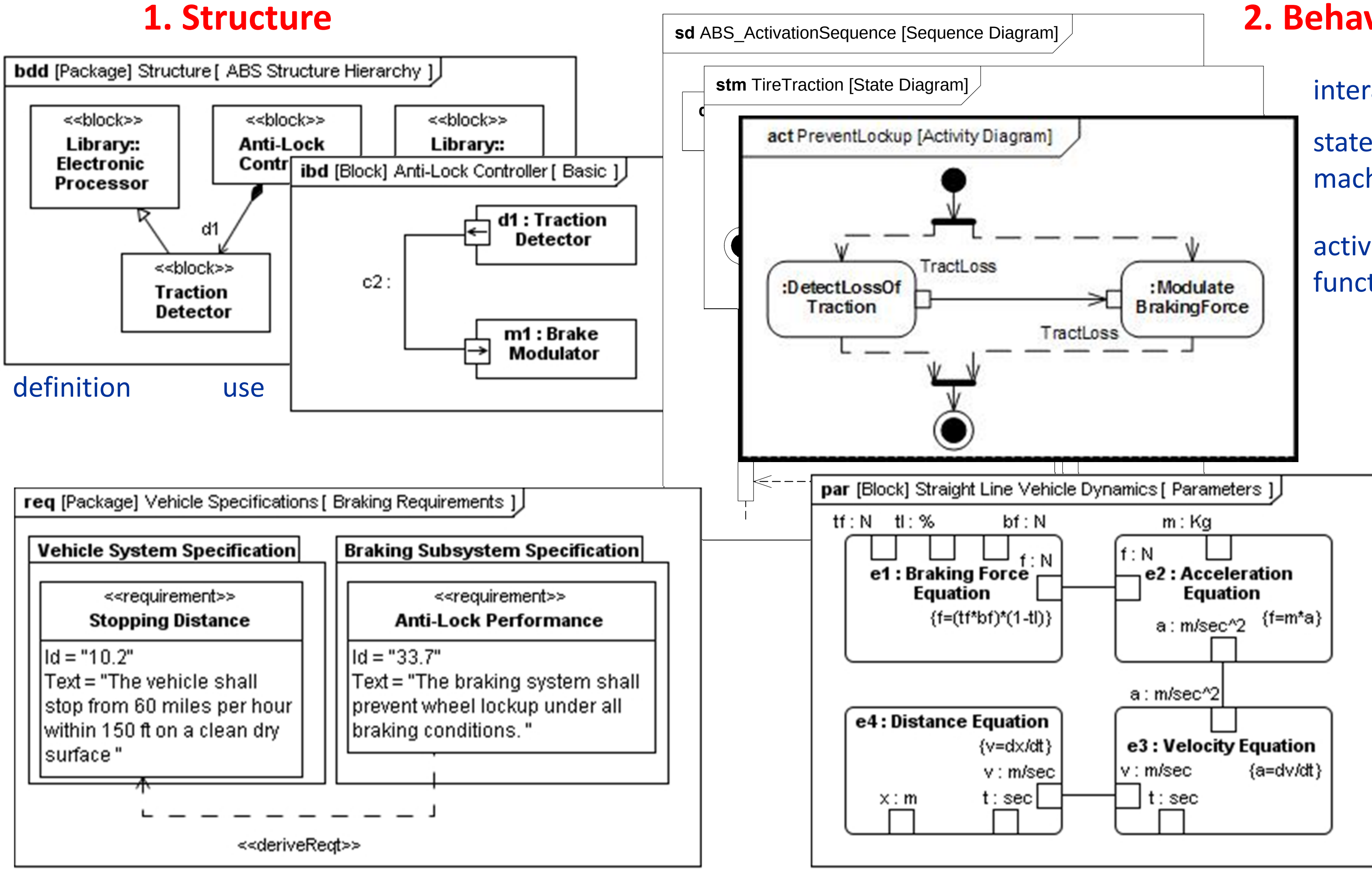
1. Structure

2. Behavior

interaction

state machine

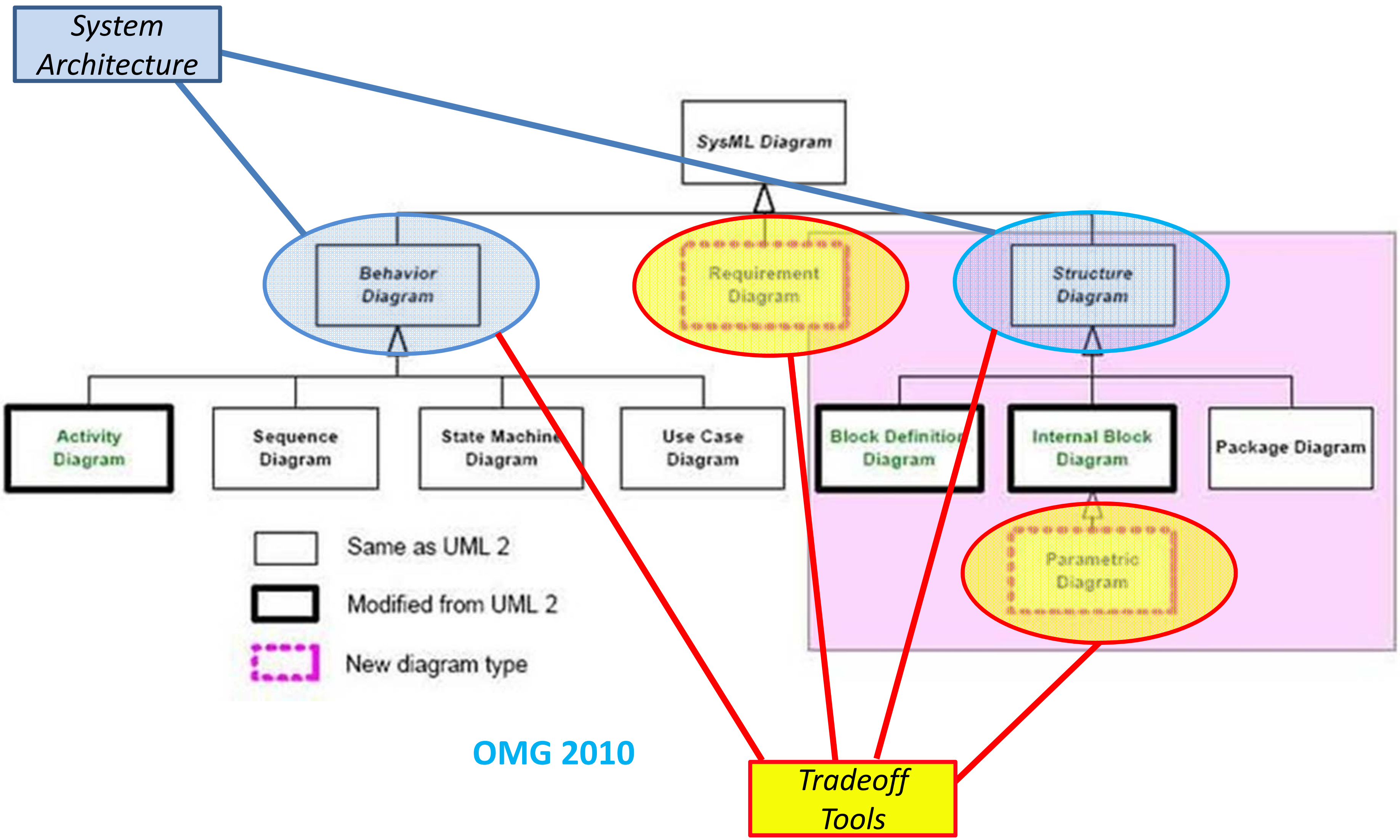
activity/ function



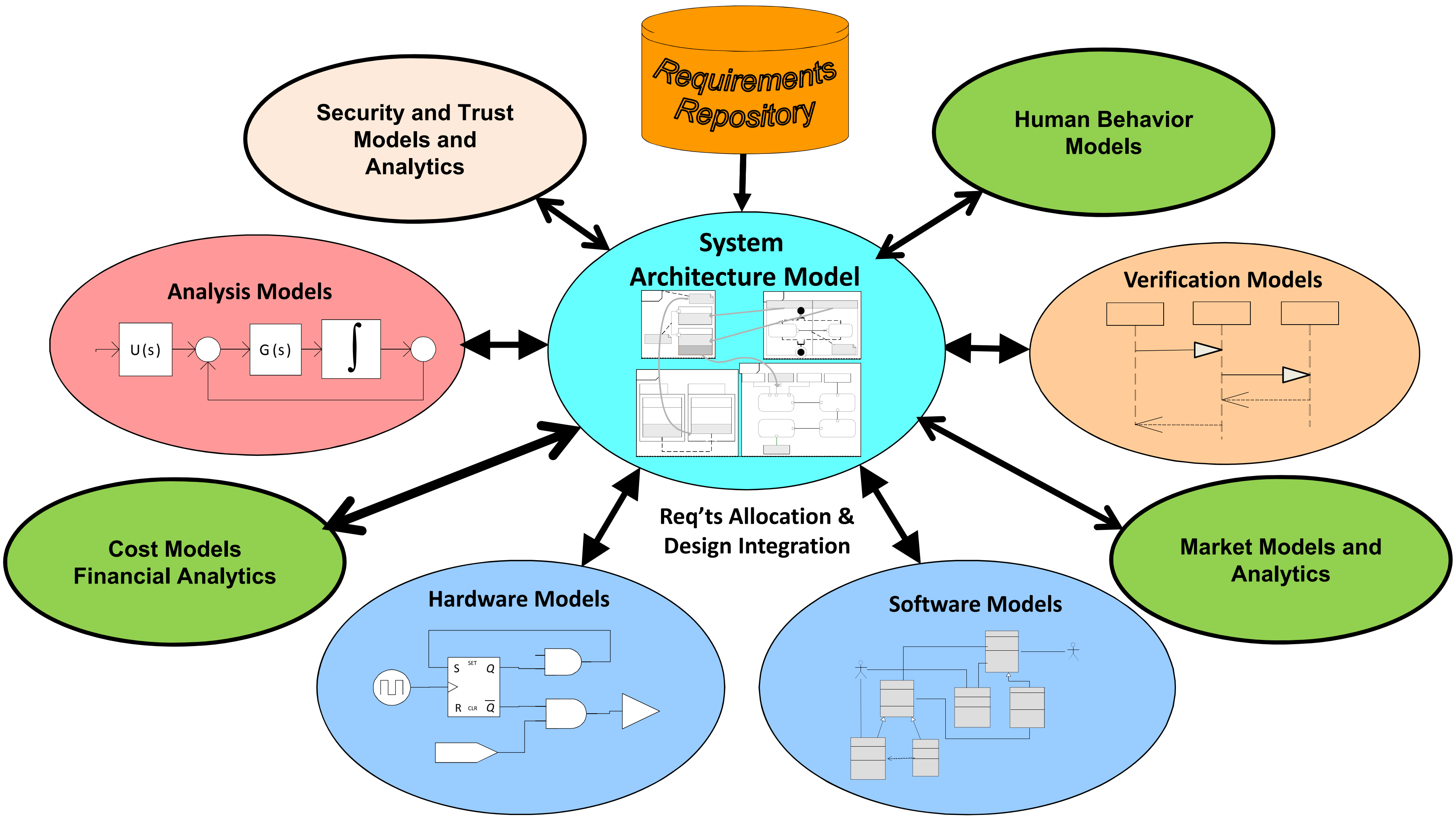
3. Requirements

4. Parametrics

SysML Taxonomy



Using *System Architecture Model* as an Integration Framework

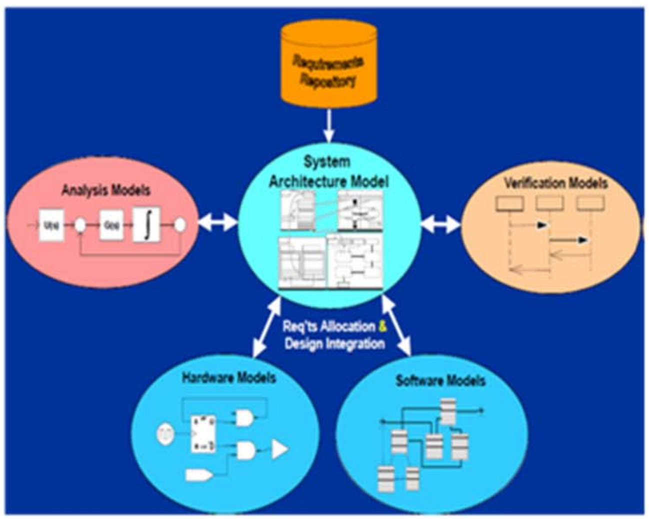


The Institute for Systems Research — A Rigorous Framework for Model-based Systems Engineering

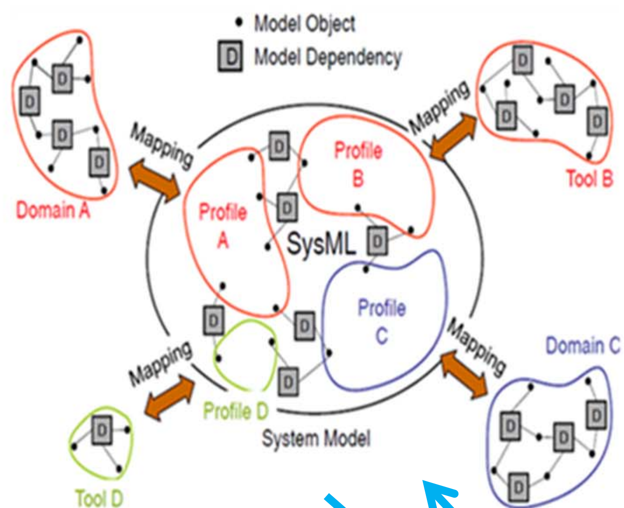
The Challenge & Need:

Develop scalable holistic methods, models and tools for enterprise level system engineering

Multi-domain Model Integration via System Architecture Model (SysML)



System Modeling Transformations



"Master System Model"

Update System Model

ILOG SOLVER, CPLEX, CONSOL-OPTCAD

Tradeoff parameters

ADD & INTEGRATE

Multiple domain modeling tools

- **Tradeoff Tools (MCO & CP)**
- **Validation / Verification Tools**
- **Databases and Libraries of annotated component models from all disciplines**

DB of system components and models

BENEFITS

- **Broader Exploration of the design space**
- **Modularity, re-use**
- **Increased flexibility, adaptability, agility**
- **Engineering tools allowing conceptual design, leading to full product models and easy modifications**
- **Automated validation/verification**

APPLICATIONS

- **Avionics**
- **Automotive**
- **Robotics**
- **Smart Buildings**
- **Power Grid**
- **Health care**
- **Telecomm and WSN**
- **Smart PDAs**
- **Smart Manufacturing**

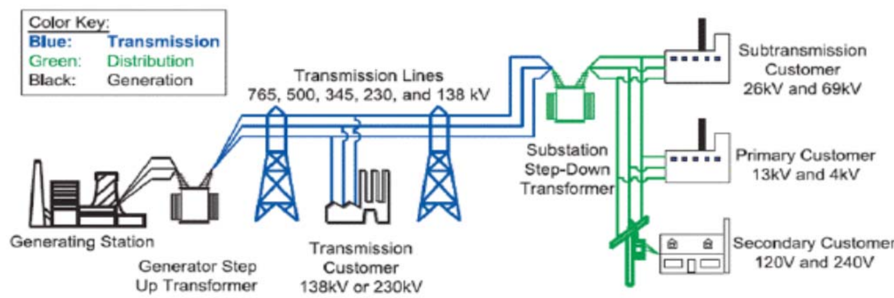
Requirements Engineering

- **How to represent requirements?**
  - Automata, Timed-Automata, Timed Petri-Nets
  - Dependence-Influence graphs for traceability
  - Set-valued systems, reachability, … for the continuous parts
  - Constraint – rule consistency across resolution levels
- **How to automatically allocate requirements to components?**
- **How to automatically check requirements?**
  - **Approach**: Integrate contract-based design, model-checking, automatic theorem proving
- **How to integrate automatic and experimental verification?**
- **How to do V&V at various granularities and progressively as the design proceeds – not at the end?**
- **The front-end challenge: Make it easy to the broad engineering user?**

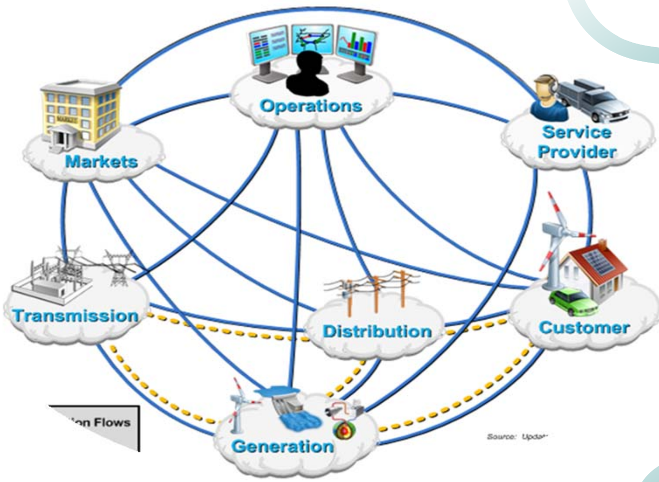
Framework for MBSE for CPS: Key Challenges Addressed

- **Methodology to develop integrated modeling hubs (IMH) for CPS – multi-physics and cyber**
- **Methodology to link IMHs with design space exploration via multi-criteria tradeoff methods and tools**
- **Linkage to component databases**
- **Working on the last remaining challenge: requirements management**
- **Developed new methods and tools to handle complexity in design space exploration**

Smart Grid – Microgrids Architecture



Grid 1.0
Legacy Grid

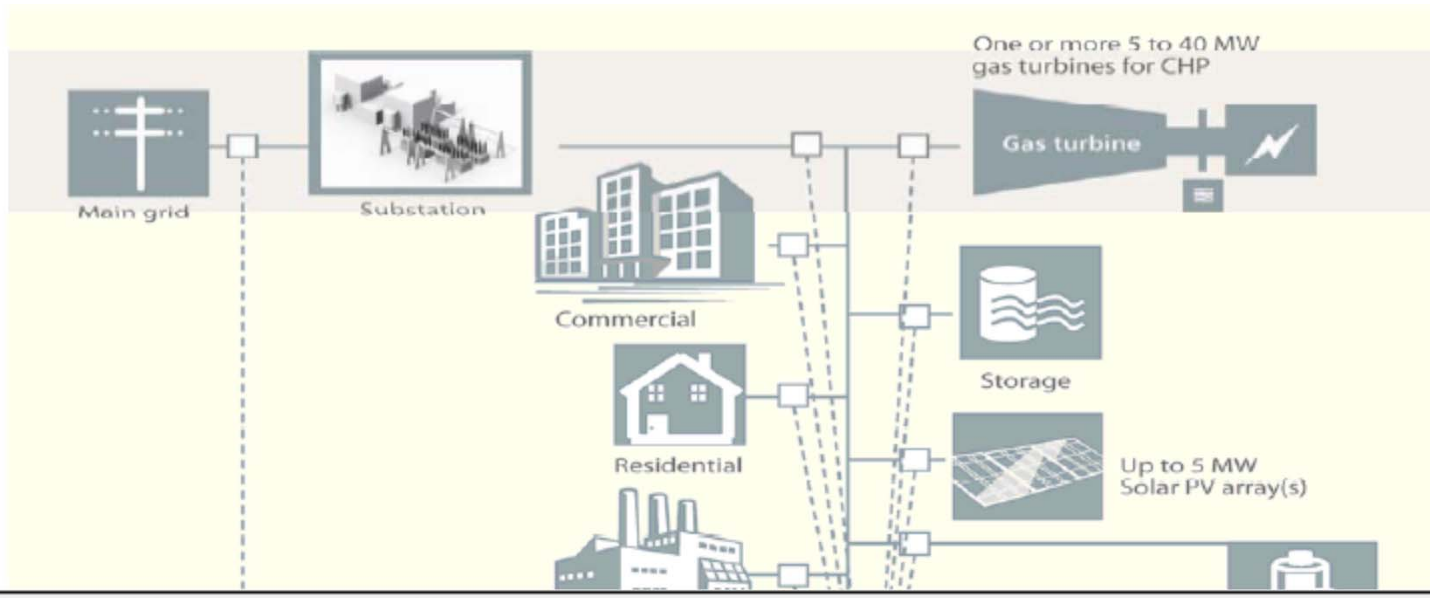


Grid 2.0
Smart Grid

Grid 3.0
Future Grid

NIST-EPRI

Business Case for Microgrids

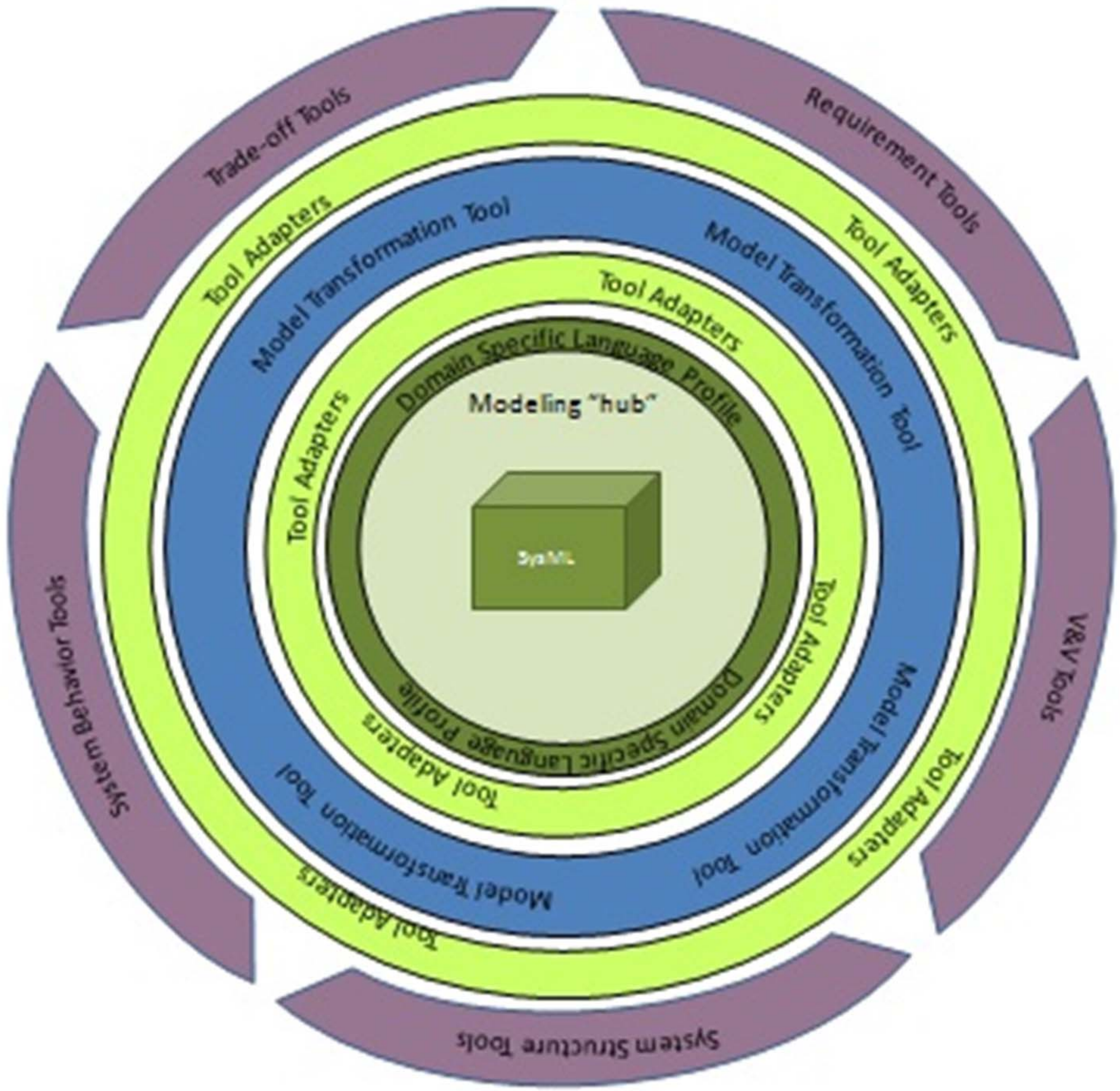


Microgrid value proposition

- Efficiency: Lower energy intensity and distribution system loss
- Reliability: Near 100 percent uptime for critical loads
- Security: Enable cyber security and physical security
- Quality: Stable power to meet exacting consumer energy requirements
- Sustainability: Expand generation to renewables and cleaner fuel sources

The System Modeling "Hub"

- Aim to realize the MBSE vision
- SysML in the center of the "hub" – Used for high-level systems design
- Three layer approach to integrate SysML with external multi-domain and multi-disciplinary tools



Focus on Trade-Off Analysis for Design Space Exploration

- Trade-off analysis is a principal methodology for design space exploration
- Today's systems have multiple competing objectives and requirements to satisfy and a lot of design parameters
- Capabilities for sophisticated trade-off analysis offered by system modeling tools are limited
- Faster and more confident decisions can be made
- First step towards having the design and optimization processes interacting and working in parallel

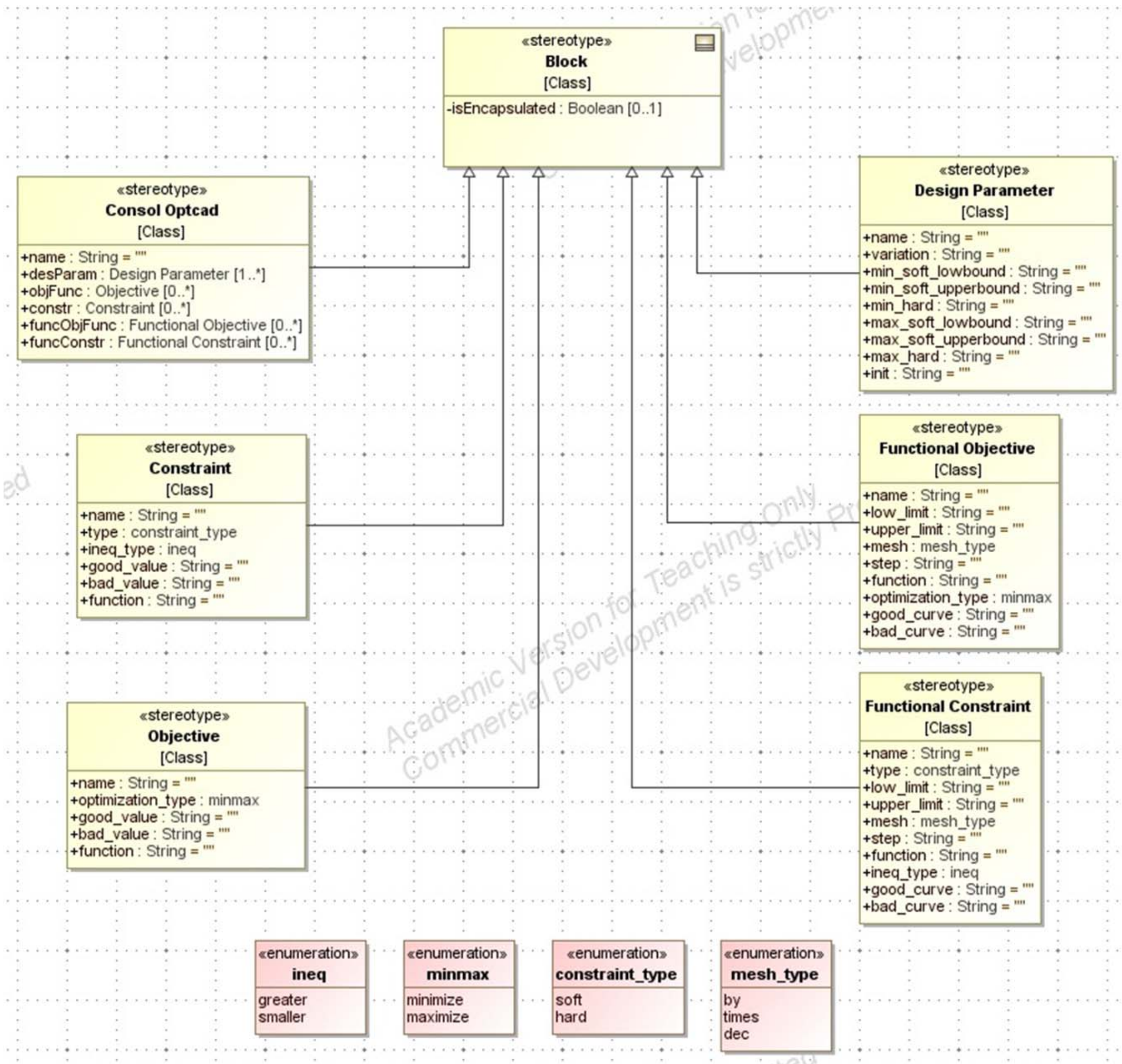
Differences from Other Approaches

- Clear framework for integrating SysML with external tools
- Consol-Optcad can perform sophisticated trade-off studies based on FSQP algorithm
- Allows interaction with the user while the optimization is in process
- Consol-Optcad allows for design space exploration
- Emoflon toolsuit was used for the first time for such an integration

Domain Specific Profile

- A profile is used to extend the notation of SysML language by allowing Domain Specific Language constructs to be represented in SysML

- A profile is created by declaring new <<stereotypes>>, their relationships between them as well as the relationships with existing constructs

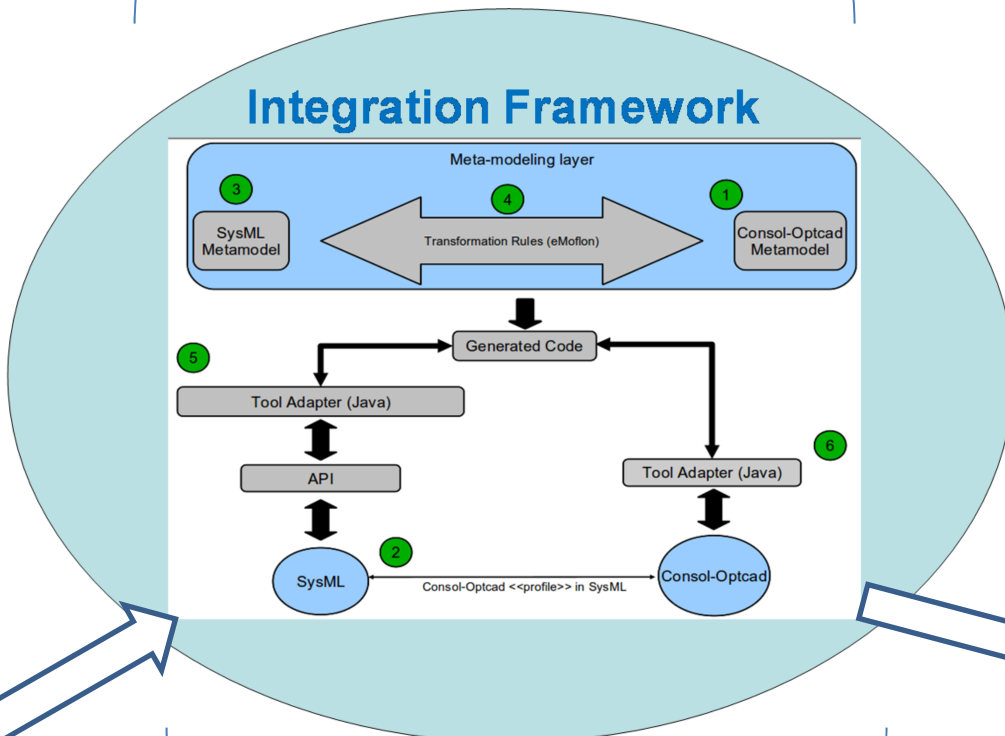


SysML and Consol-Optcad Integration

Overview

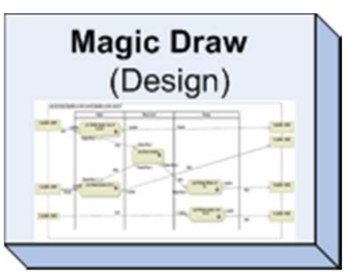
Meta-modeling Layer

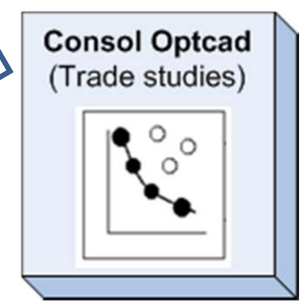
(Enterprise Architect + eMoflon, Eclipse development environment)



Tool Adapter Layer

(Middleware)





Tool Layer

(Magic Draw, Consol Optcad)

Meta-modeling Layer - eMoflon

Characteristics

- ✓ Meta-models are following the Ecore format
- ✓ Story Diagrams are used to express the transformation rules
- ✓ Graph transformations is the underlying theory
- ✓ It generates Java code for the transformations

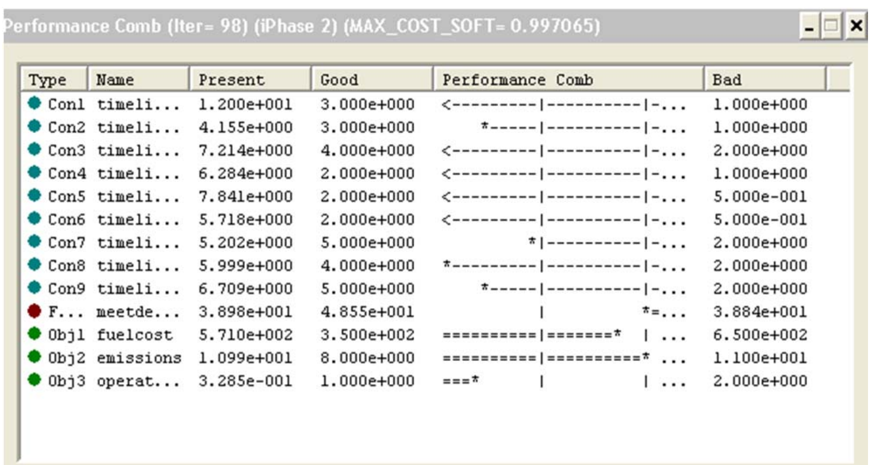
Advantages

- ✓ Graph transformation theory provides strong semantics and can lead to satisfaction of formal properties, i.e correctness, completeness, etc
- ✓ Graphical representation of meta-models and transformation rules
- ✓ Generated Java code could be easily integrated with modern tools
- ✓ Strong support/developing team
- ✓ Eclipse - open source environment

IMH and Consol-Optcad Integration

Consol-Optcad

- **Trade-off tool** that performs multi-criteria optimization for continuous variables (FSQP solver) – **Extended to hybrid** (continuous / integer)
- **Functional** as well as non-functional objectives/constraints can be specified
- Designer initially specifies **good** and **bad** values for each objective/constraint based on experience and/or other inputs
- Each objective/constraint value is scaled based on those good/bad values; fact that effectively treats **all objectives/constraints fairly**
- Designer has the flexibility to see results at every iteration (**pcomb**) and allows for **run-time changing** of good/bad values



Performance Comb (Iter= 98) (iPhase 2) (MAX_COST_SOFT= 0.997065)

Type	Name	Present	Good	Performance Comb	Bad
Con1	timeli...	1.200e+001	3.000e+000	<---------|----------|-...	1.000e+000
Con2	timeli...	4.155e+000	3.000e+000	*-----|----------|-...	1.000e+000
Con3	timeli...	7.214e+000	4.000e+000	<---------|----------|-...	2.000e+000
Con4	timeli...	6.284e+000	2.000e+000	<---------|----------|-...	1.000e+000
Con5	timeli...	7.841e+000	2.000e+000	<---------|----------|-...	5.000e-001
Con6	timeli...	5.718e+000	2.000e+000	<---------|----------|-...	5.000e-001
Con7	timeli...	5.202e+000	5.000e+000	*|----------|-...	2.000e+000
Con8	timeli...	5.999e+000	4.000e+000	*---------|----------|-...	2.000e+000
Con9	timeli...	6.709e+000	5.000e+000	*-----|----------|-...	2.000e+000
F...	meetde...	3.898e+001	4.855e+001	| *=...	3.884e+001
Obj1	fuelcost	5.710e+002	3.500e+002	==========|=======* | ...	6.500e+002
Obj2	emissions	1.099e+001	8.000e+000	==========|==========* ...	1.100e+001
Obj3	operat...	3.285e-001	1.000e+000	===* | | ...	2.000e+000

Fig. 1: Pcomb

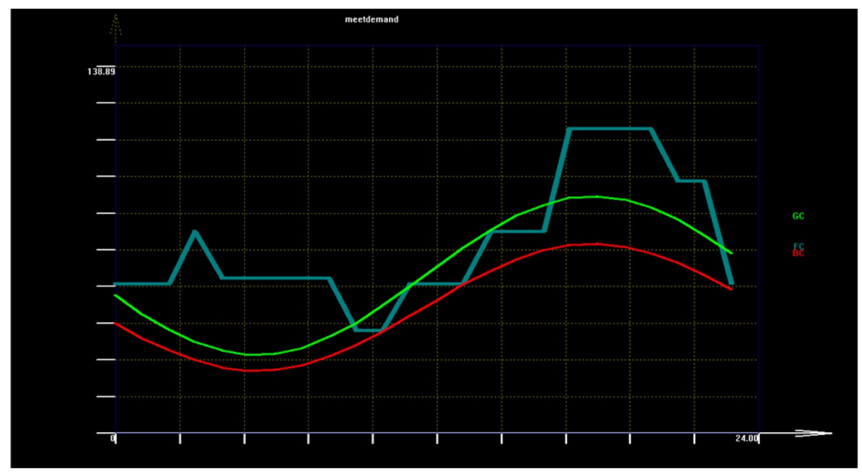


Fig. 2: Example of a functional constraint

IMH and Consol-Optcad integration

Metamodeling Layer

- Both **metamodels** are defined in Ecore format
- **Transformation rules** are defined within EA and are based on graph transformations
- **Story Diagrams** (SDMs) are used to express the transformations
- **eMoflon** (TU Darmstadt) plug-in generates code for the transformations
- An Eclipse project hosts the implementation of the transformations in Java

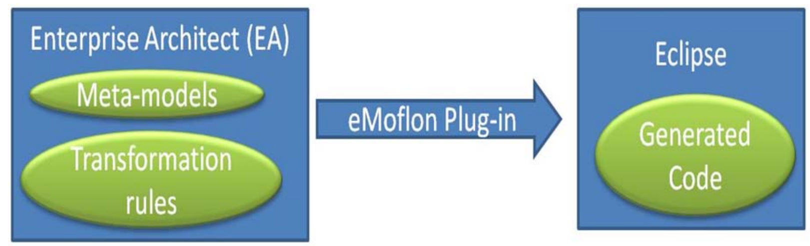


Fig. 3: eMoflon high-level architecture

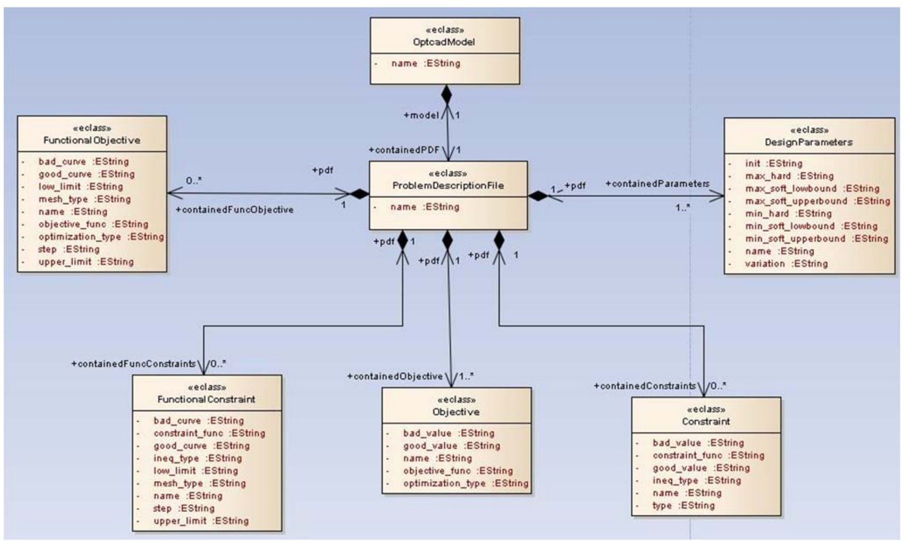


Fig. 4: Consol-Optcad metamodel

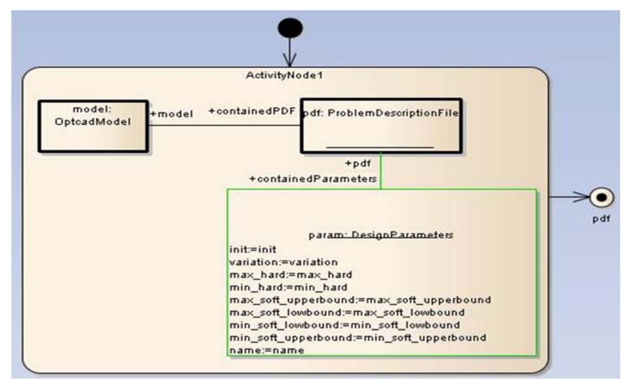


Fig. 5: Story diagram

IMH and Consol-Optcad Integration

Working Example

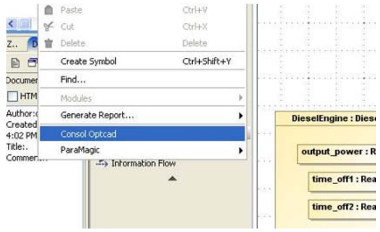


Fig. 11: Initiate transformation

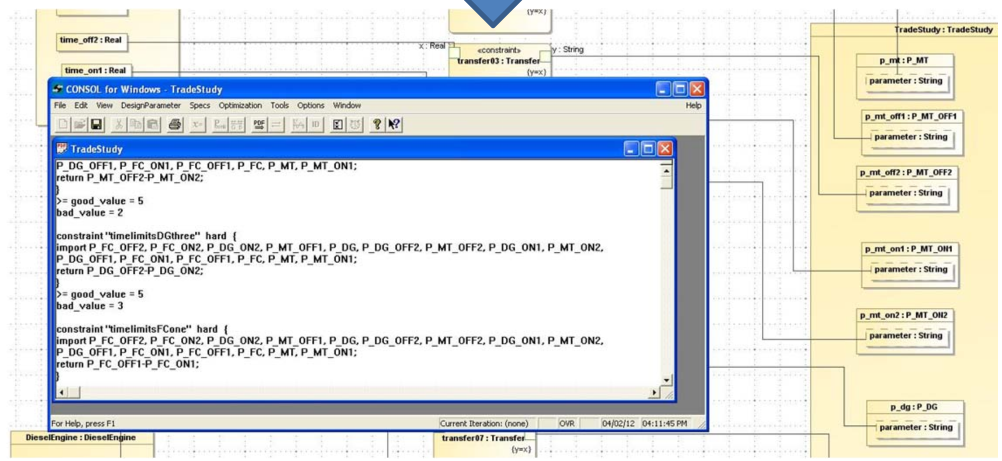


Fig. 12: Consol-Optcad environment

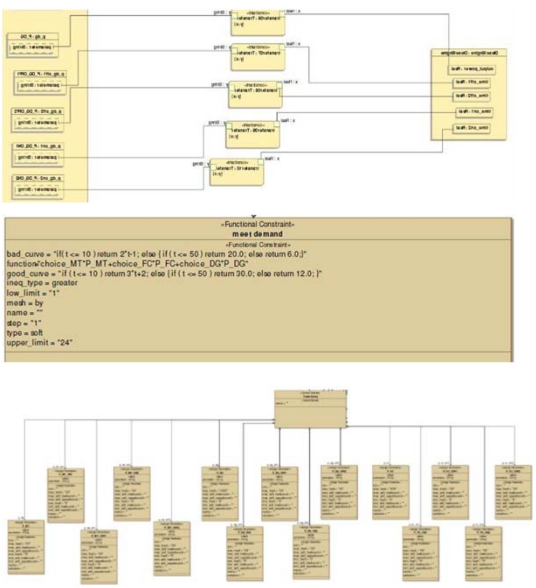


Fig. 10: Models in SysML

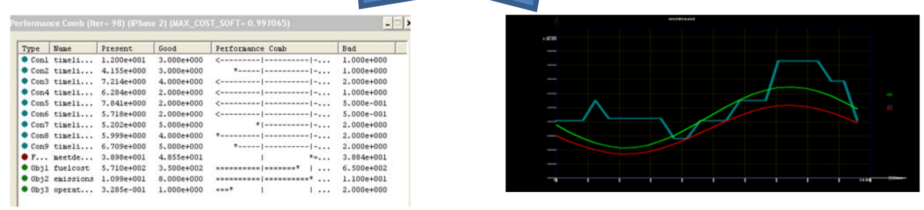


Fig.13: Perform trade-off analysis in Consol-Optcad

Microgrid

Microgrid is a collection of distributed energy resources (DERs) and loads, that operate as a single controllable entity.

Advantages

- Local production, low cost energy, less power losses due to transmission
- Can be used for both heat and power
- DERs offer very good power quality with less frequency variations, voltage transients or other disruptions
- Ideal for low power generation and as a back-up to the main network

Microgrid Problem Formulation

Objectives

Minimize Operational Cost: $OM(\$) = \sum_{i=1}^{N} K_{OM_i} P_i t_{i_{operation}}$

Minimize Fuel Cost: $FC(\$) = \sum_{i=1}^{N} C_i \frac{P_i t_{i_{operation}}}{n_i}$

Minimize Emissions: $EC(\$) = \sum_{i=1}^{N} \sum_{i=1}^{M} a_k (EF_{ik} P_i t_{i_{operation}} / 1000)$

P_i : power output of each generating unit

t_i : time of operation during the day for the unit i

n_i : efficiency of the generating unit i

N : number of generating units

M : number of elements considered in emissions objective

$K_{OM_i}, C_i, a_k, EF_{ik}$: constants defined from existing tables

Microgrid Problem Formulation

Constraints

- Meet electricity demand : $P_i \geq Demand(kW) = 50 \cdot (0.6\sin(\frac{\pi t}{12}) + 1.2)$

  Functional constraint and shall be met for all values of the free parameter *t*
- Each power source should turn on and off only 2 times during the day

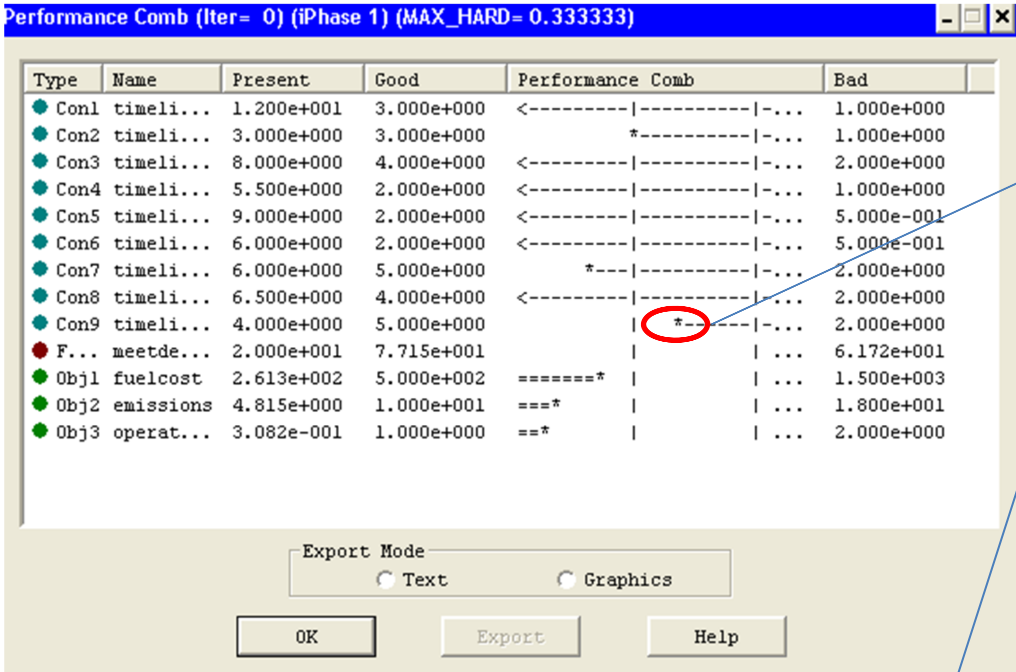
Constraints for correct operation of the generation unit

- Each generating unit should remain open for at least a period x_i defined by the specifications: $t_{i\_off\,1} - t_{i\_on1} \geq x_i$ and $t_{i\_off\,2} - t_{i\_on2} \geq x_i, \quad i = 1,2,...N$

- Each generating unit should remain turned off for at least a period y_i defined by the specifications: $t_{i\_on2} - t_{i\_off1} \geq y_i, \quad i = 1,2,...N$

The problem has a total of *15 design variables, 10 constraints and 3 objective functions*

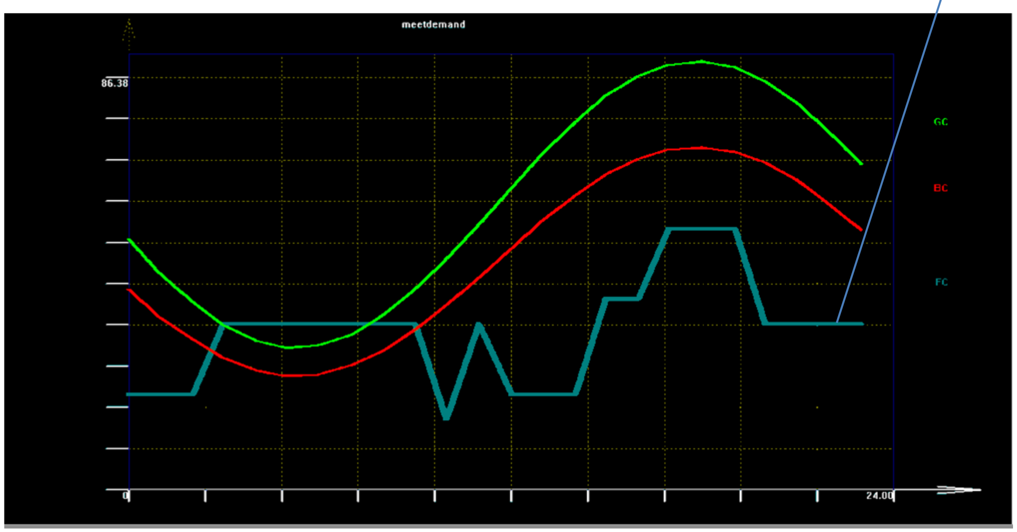
Tradeoff Study in Consol-Optcad


Performance Comb (Iter= 0) (iPhase 1) (MAX_HARD= 0.333333)

Type	Name	Present	Good	Performance Comb	Bad
Con1	timeli...	1.200e+001	3.000e+000	<---------|----------|-...	1.000e+000
Con2	timeli...	3.000e+000	3.000e+000	*----------|-...	1.000e+000
Con3	timeli...	8.000e+000	4.000e+000	<---------|----------|-...	2.000e+000
Con4	timeli...	5.500e+000	2.000e+000	<---------|----------|-...	1.000e+000
Con5	timeli...	9.000e+000	2.000e+000	<---------|----------|-...	5.000e-001
Con6	timeli...	6.000e+000	2.000e+000	<---------|----------|-...	5.000e-001
Con7	timeli...	6.000e+000	5.000e+000	*---|----------|-...	2.000e+000
Con8	timeli...	6.500e+000	4.000e+000	<---------|----------|-...	2.000e+000
Con9	timeli...	4.000e+000	5.000e+000	| *-----|-...	2.000e+000
F...	meetde...	2.000e+001	7.715e+001	| | ...	6.172e+001
Obj1	fuelcost	2.613e+002	5.000e+002	=======* | | ...	1.500e+003
Obj2	emissions	4.815e+000	1.000e+001	===* | | ...	1.800e+001
Obj3	operat...	3.082e-001	1.000e+000	==* | | ...	2.000e+000

Export Mode: Text / Graphics

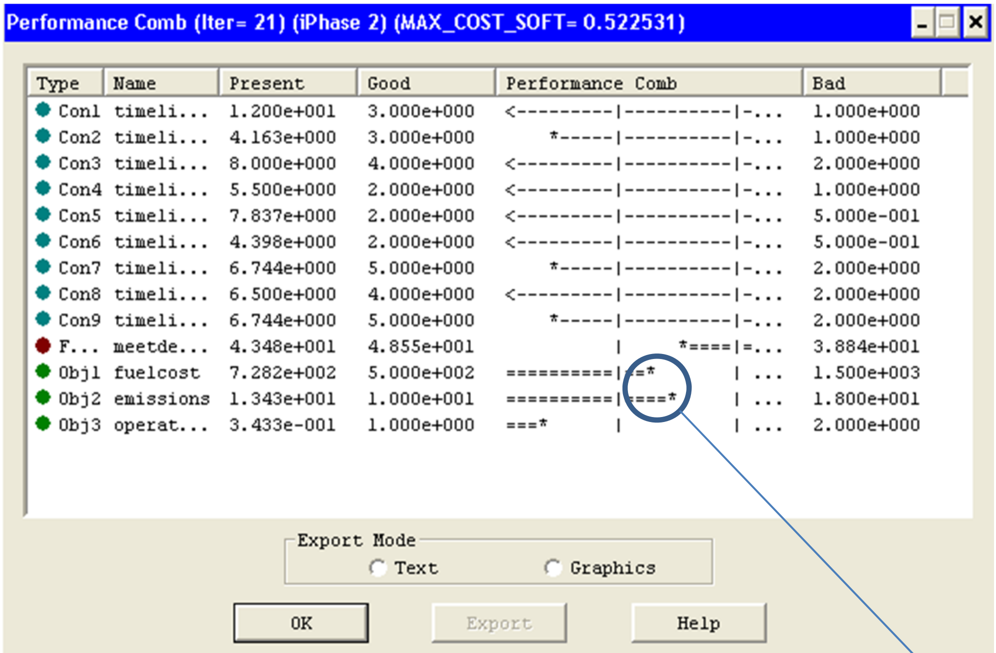
OK | Export | Help



Iteration 1 (Initial Stage)

- ✓Hard constraint not satisfied
- ✓ Functional Constraint below the bad curve
- ✓ All other hard constraints and objectives meet their good values
- ✓ Usually the user does not interact with the optimization process **until all hard constraints are satisfied**

Microgrid: Trade-off Study



Performance Comb (Iter= 21) (iPhase 2) (MAX_COST_SOFT= 0.522531)

Type	Name	Present	Good	Performance Comb	Bad
Con1	timeli...	1.200e+001	3.000e+000	<---------|----------|-...	1.000e+000
Con2	timeli...	4.163e+000	3.000e+000	*-----|----------|-...	1.000e+000
Con3	timeli...	8.000e+000	4.000e+000	<---------|----------|-...	2.000e+000
Con4	timeli...	5.500e+000	2.000e+000	<---------|----------|-...	1.000e+000
Con5	timeli...	7.837e+000	2.000e+000	<---------|----------|-...	5.000e-001
Con6	timeli...	4.398e+000	2.000e+000	<---------|----------|-...	5.000e-001
Con7	timeli...	6.744e+000	5.000e+000	*-----|----------|-...	2.000e+000
Con8	timeli...	6.500e+000	4.000e+000	<---------|----------|-...	2.000e+000
Con9	timeli...	6.744e+000	5.000e+000	*-----|----------|-...	2.000e+000
F...	meetde...	4.348e+001	4.855e+001	| *====|=...	3.884e+001
Obj1	fuelcost	7.282e+002	5.000e+002	==========|==* | ...	1.500e+003
Obj2	emissions	1.343e+001	1.000e+001	==========|====* | ...	1.800e+001
Obj3	operat...	3.433e-001	1.000e+000	===* | | ...	2.000e+000

Export Mode

Text Graphics

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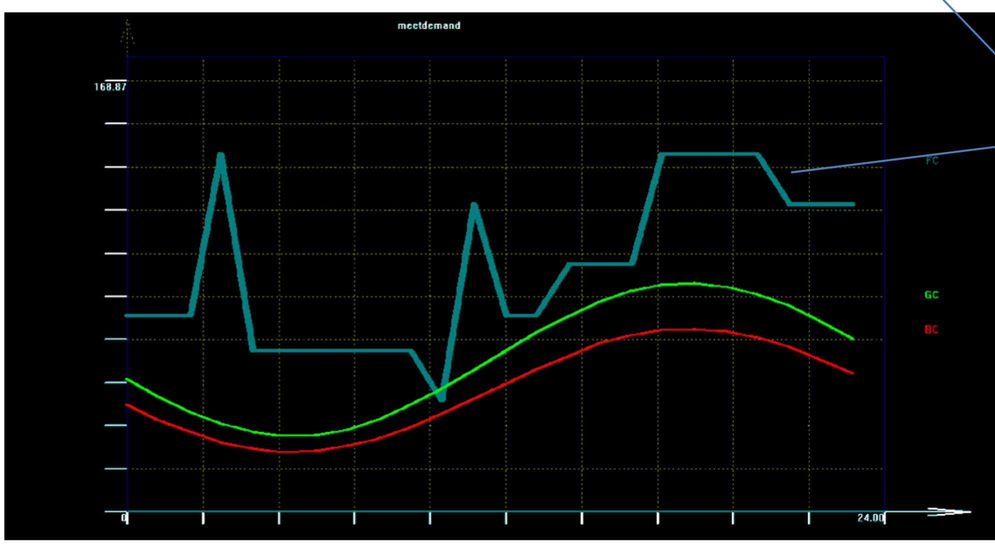


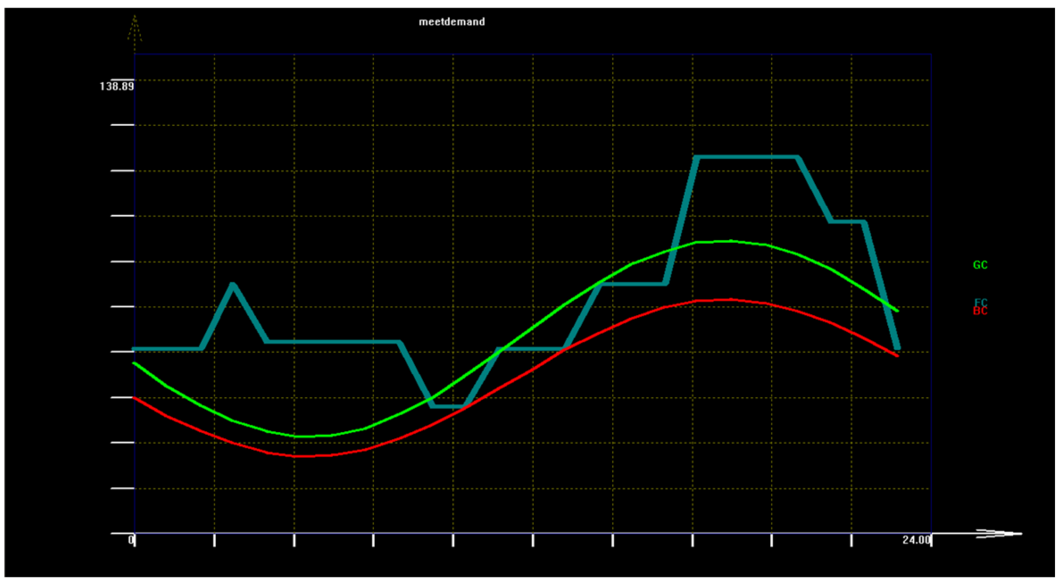
Iteration 28 (User Interaction)

- ✓All hard constraints are satisfied
- ✓ Functional Constraint meets the specified demand. Goes below the good curve only for a small period of time but as a soft constraint is considered satisfied
- ✓All objectives are within limits
- ✓ Because at this stage we generate a lot more power than needed we decide to make the constraints for fuel cost and emissions tighter
- ✓ At this stage all designs are feasible (FSQP solver)

Trade-off Study in Consol-Optcad

Performance Comb (Iter= 98) (iPhase 2) (MAX_COST_SOFT= 0.997065)

Type	Name	Present	Good	Performance Comb	Bad
Con1	timeli...	1.200e+001	3.000e+000	<---------|----------|-...	1.000e+000
Con2	timeli...	4.155e+000	3.000e+000	*-----|----------|-...	1.000e+000
Con3	timeli...	7.214e+000	4.000e+000	<---------|----------|-...	2.000e+000
Con4	timeli...	6.284e+000	2.000e+000	<---------|----------|-...	1.000e+000
Con5	timeli...	7.841e+000	2.000e+000	<---------|----------|-...	5.000e-001
Con6	timeli...	5.718e+000	2.000e+000	<---------|----------|-...	5.000e-001
Con7	timeli...	5.202e+000	5.000e+000	*|----------|-...	2.000e+000
Con8	timeli...	5.999e+000	4.000e+000	*---------|----------|-...	2.000e+000
Con9	timeli...	6.709e+000	5.000e+000	*-----|----------|-...	2.000e+000
F...	meetde...	3.898e+001	4.855e+001	| *=...	3.884e+001
Obj1	fuelcost	5.710e+002	3.500e+002	==========|=======* | ...	6.500e+002
Obj2	emissions	1.099e+001	8.000e+000	==========|==========* ...	1.100e+001
Obj3	operat...	3.285e-001	1.000e+000	===* | | ...	2.000e+000



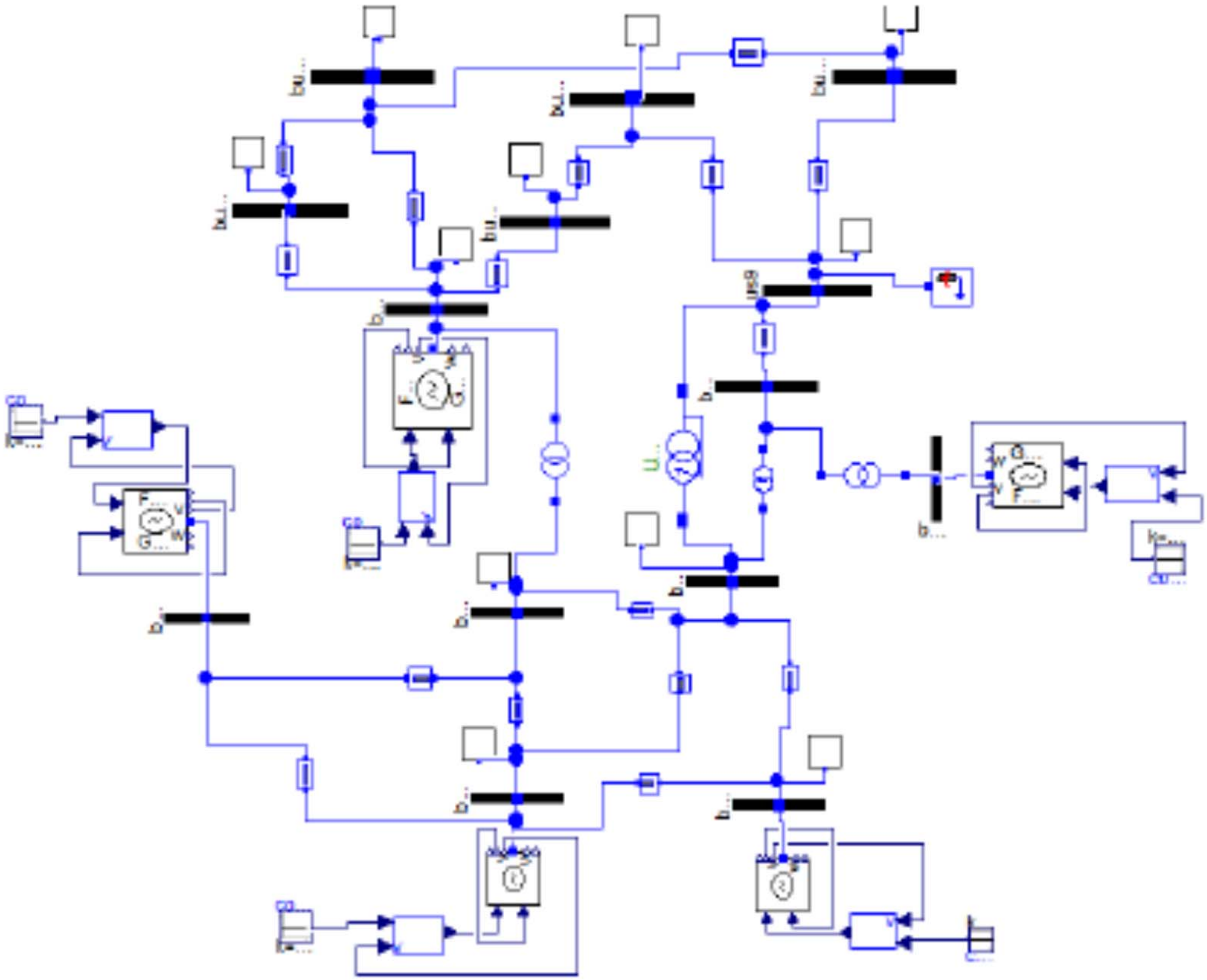
Iteration 95 (Final Solution)

- ✓All hard constraints are satisfied
- ✓ All objectives are within the new tighter limits
- ✓ Functional Constraint meets the specified demand -- It never goes below the bad curve

New Integrated Modeling Hub

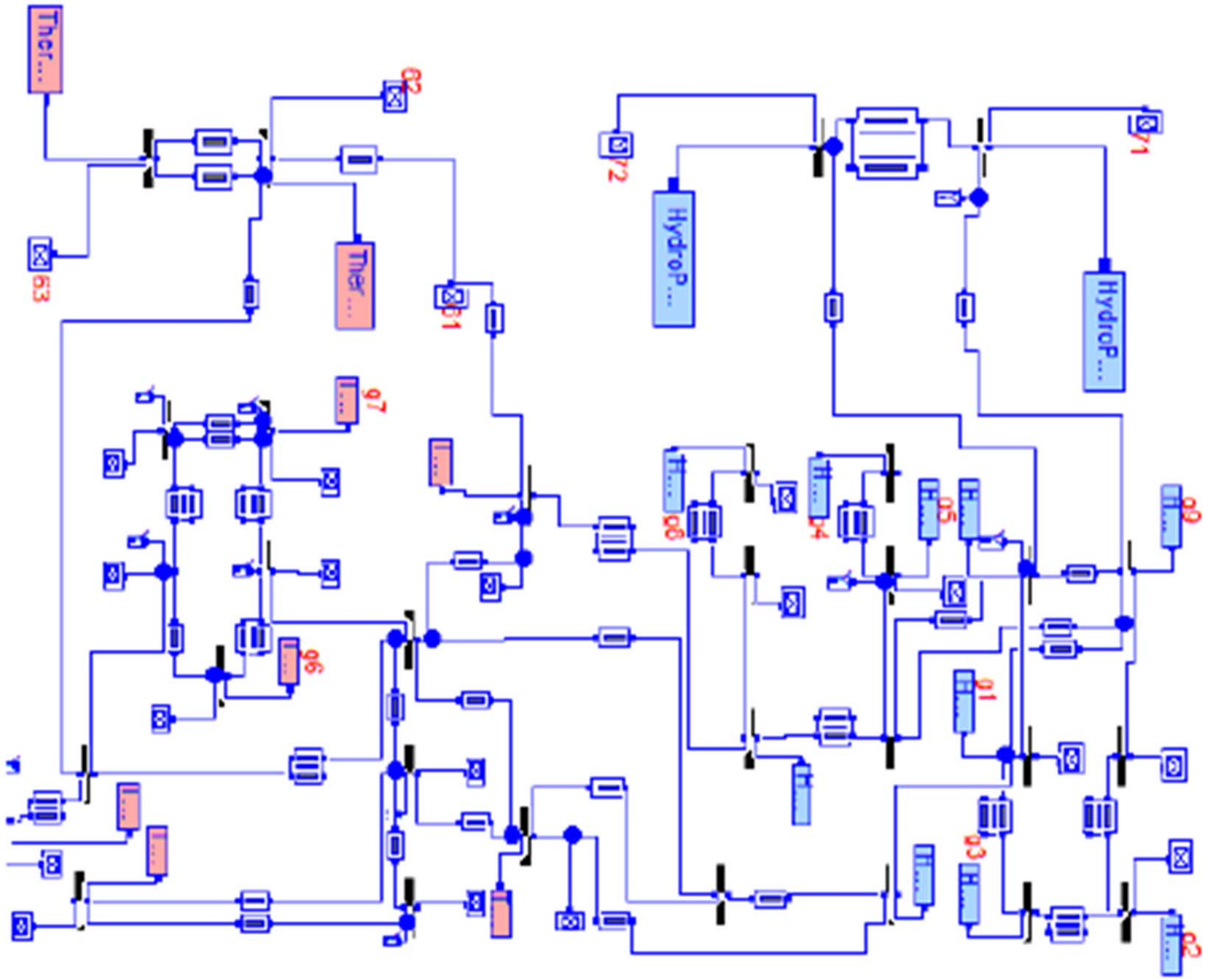
- Open source to the extend possible
- Open Modelica
- UML/SysML Papyrous
- SciLab
- Building results and models of the iTesla project (EU) http://www.itesla-project.eu/
- Libraries of components
- Examples from Norwegian Grid
- Validate components
- Hybrid systems models result

iTesla Models - Modelica



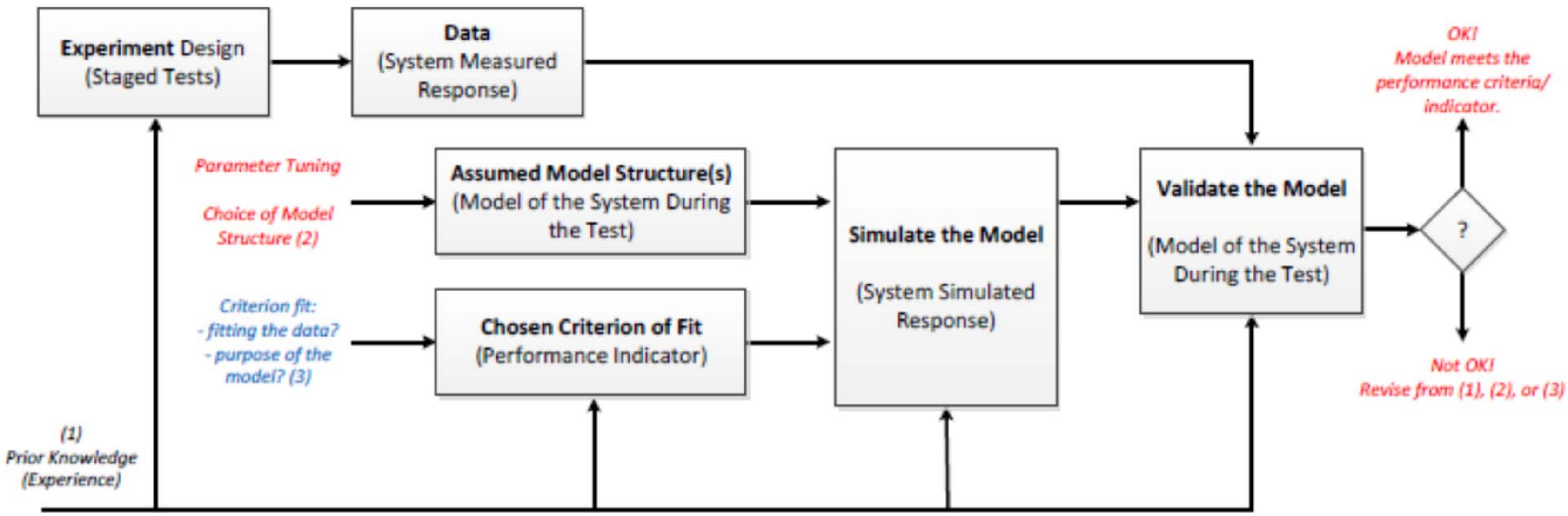
IEEE 14 bus system model

iTesla Models - Modelica



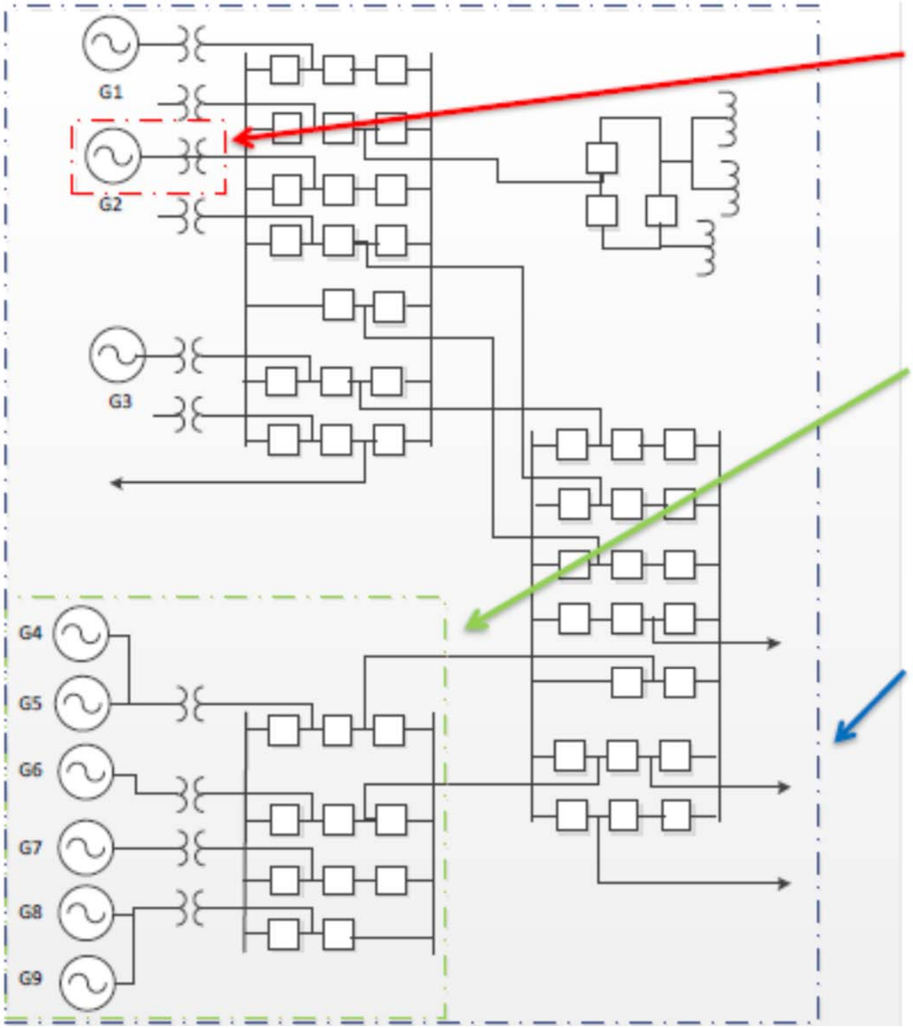
IEEE Nordic 32

Model Validation -- Composability



- A model should never be accepted as a final true description
- of the actual power system
- Just a suitable "good enough" description of the system for
- Specific aspects
- Model validation: confidence, uncertainties, tolerances
- Major challenge: Composition and uncertainty quantification

Different Validation Levels



- Component level
  - e.g. generator such as wind turbine or PV panel
- Cluster level
  - e.g. gen. cluster such as wind or PV farm
- System level
  - e.g. power system small-signal dynamics (oscillations)

Major challenge: Quantify accuracy and uncertainty as we move up and down the levels, for both logical and numerical variables

Port-Hamiltonian Models to the Rescue

Key ideas:

- Plant and controller – energy processing dynamical systems
- Exploit the interconnection – control as interconnection
- Shape energy
- Modify dissipation
- Work across multiple physics
- Work for many performance metrics not just stability
- Automatic composability -- scalable
- Underlying math models for Modelica!

Port-Hamiltonian Models: Power Grids

- Power grid structure components: generators, loads, buses, transmission lines, switch-gear, …
- Handle transient stability problem naturally
- Power network as graph
- Edges: generators, loads, transmission lines
- Nodes: Buses
- Reduced graph – transmission lines

Edge Dynamics

Each edge element is represented as a

port-Hamiltonian system

$$\dot{x} = [\mathcal{J}(x) - \mathcal{R}(x)]\nabla H(x) + g(x)u,$$

$$y = g^T(x)\nabla H(x)$$

where x is the state, $\mathcal{J}^t(x) = -\mathcal{J}(x), \mathcal{R}^t(x) = \mathcal{R}(x) \geq 0$, and $H(x)$ are the interconnection, damping and energy functions, respectively.

The interconnection of all these port-Hamiltonian systems using Kirchhoff's laws will result in a total port-Hamiltonian system.

Complete Model

In shorthand notation we have the port-Hamiltonian model

$$\dot{x} = [\mathcal{J} - \mathcal{R}]\nabla H(x) + gu$$
$$y = g^t \nabla H(x)$$

where

$$\mathcal{J} = \begin{bmatrix} 0 & 0 & \mathbb{I} & 0 & 0 & 0 & 0 \\ 0 & 0 & M_1^t & M_2^t & 0 & 0 & 0 \\ -\mathbb{I} & -M_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & -M_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -\mathbb{I} \\ 0 & 0 & 0 & 0 & 0 & \mathbb{I} & 0 \end{bmatrix}$$

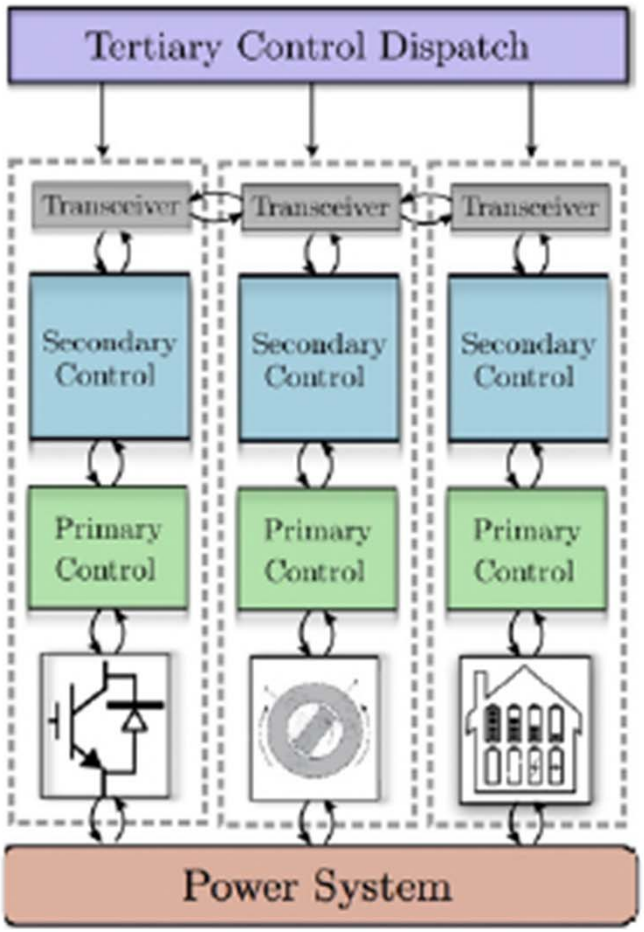
Port-Hamiltonian Models

- Other port-Hamiltonian subsystems can be added like capacitor banks, transformers etc.
- Another model of the transmission line, e.g., partial differential equation models.
- Other load models.
- A different (simpler) port-Hamiltonian model of the generator.
- Techniques like Kron reduction can be used to simplify the graph.

- We have extended the concept to hybrid systems
- Port-Hamiltonian on hypergraphs
- Connections with Noether's Theorem and Invariants – very useful in optimization
- Very useful in Uncertainty quantification

Control Architecture From This to ??

Hierarchical frequency control architecture & objectives



3. **Tertiary control** (offline)
   - Goal: optimize operation
   - Strategy: centralized & forecast
2. **Secondary control** (minutes)
   - Goal: maintain operating point in presence of disturbances
   - Strategy: centralized
1. **Primary control** (real-time)
   - Goal: stabilize frequency & share unknown load
   - Strategy: decentralized

Q: Is this layered & hierarchical architecture still appropriate for tomorrow's power system?

To ??

Need to adapt the control hierarchy in tomorrow's grid

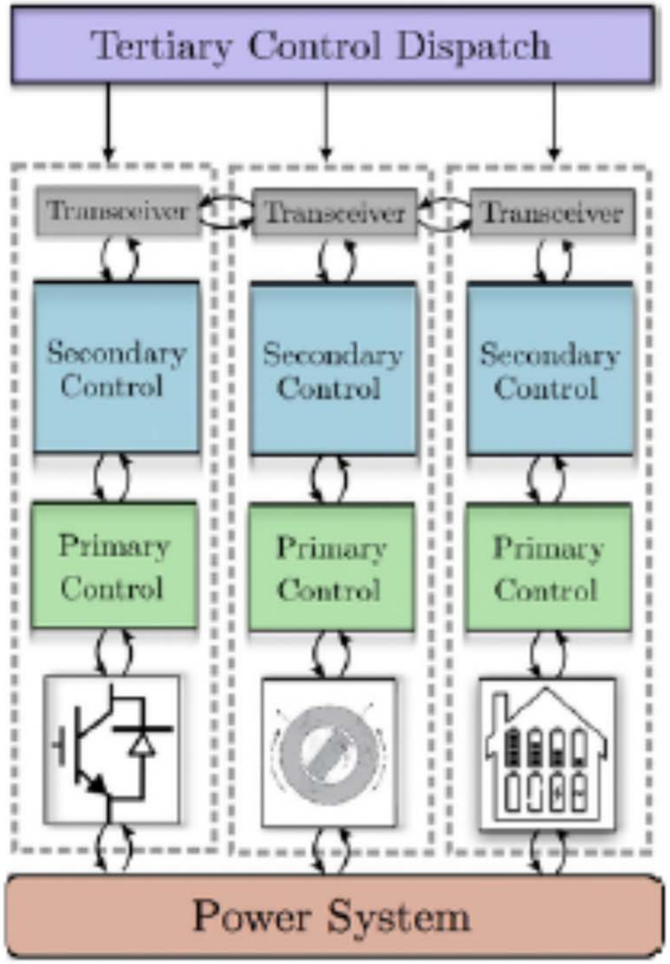
☹ perational challenges

- more uncertainty & less inertia
- more volatile & faster fluctuations
- plug'n'play control: fast, model-free, & without central authority

☺ pportunities

- re-instrumentation: comm & sensors
- more & faster spinning reserves
- advances in control of cyber-physical & complex systems

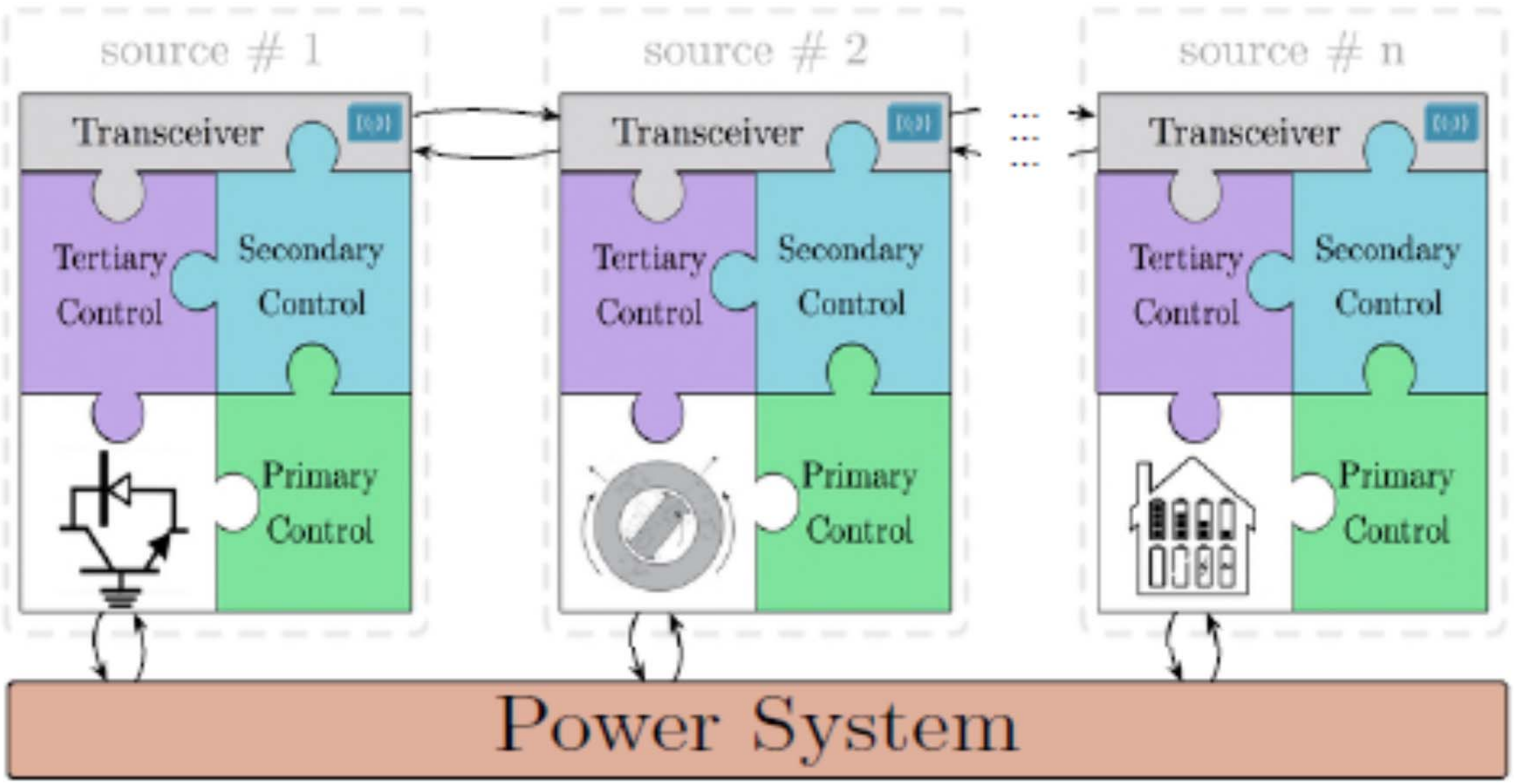
⇒ break vertical & horizontal hierarchy



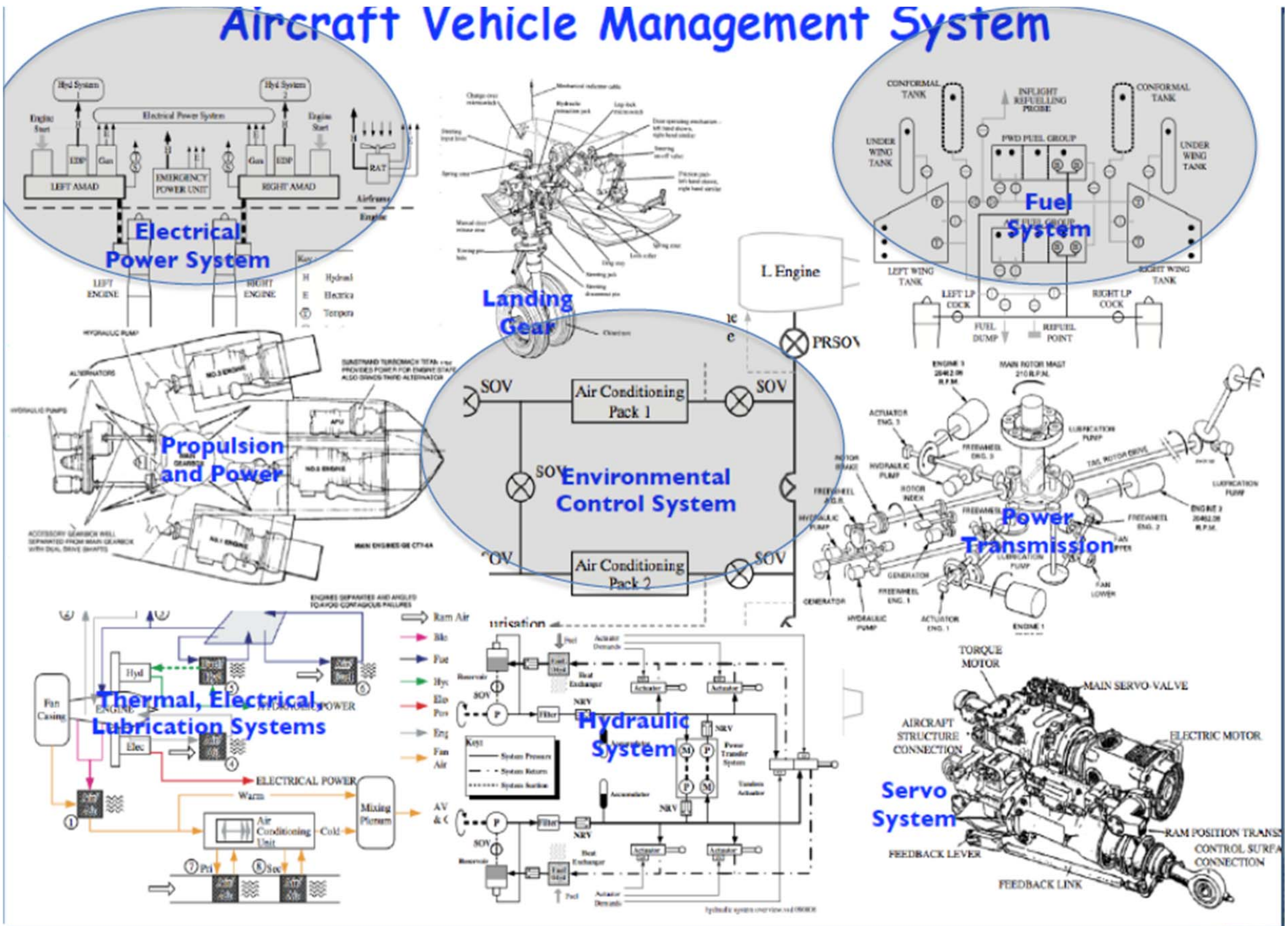
To This ??

Plug'n'play architecture

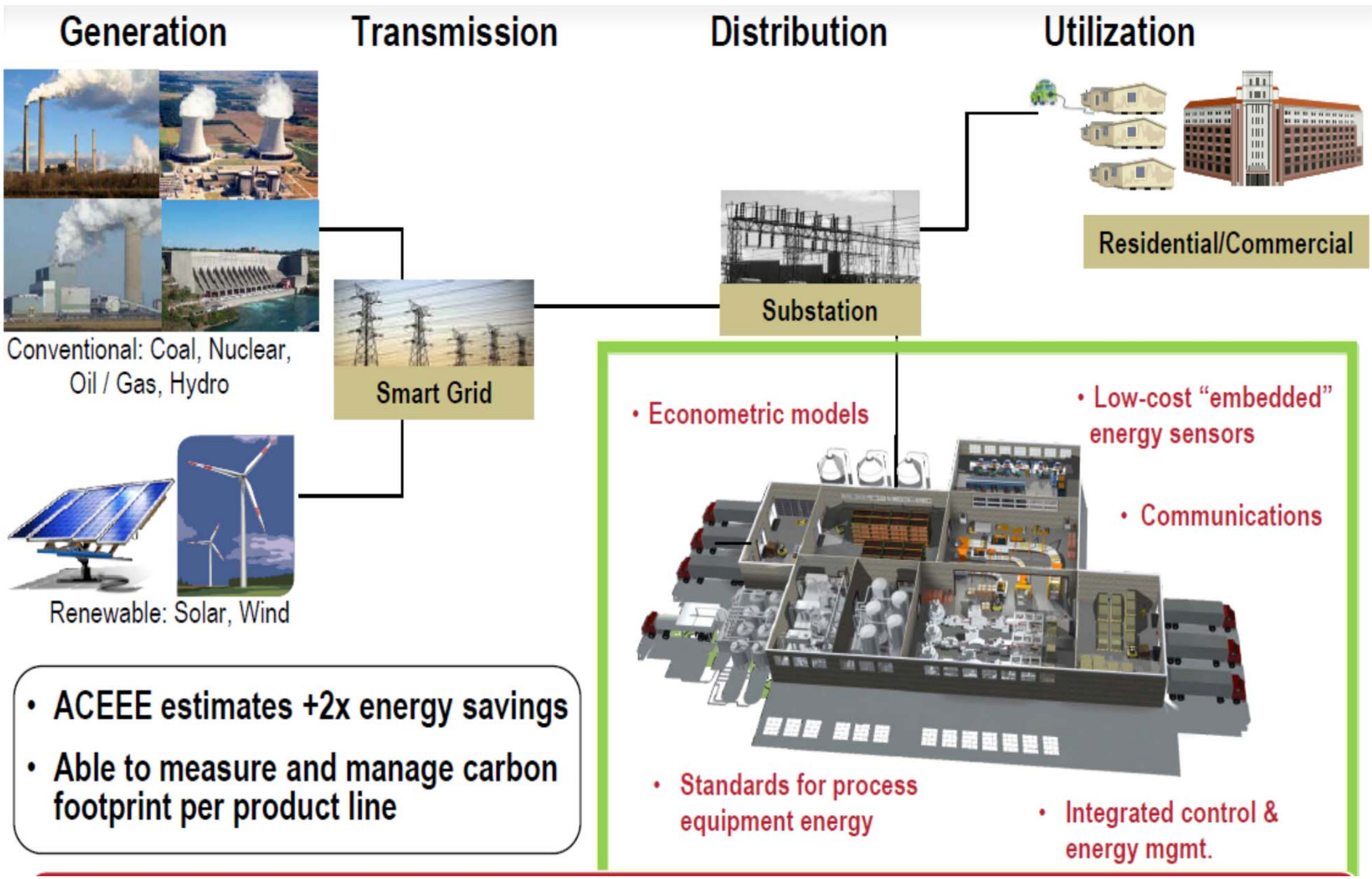
flat hierarchy, distributed, no time-scale separations, & model-free



Aircraft Vehicle Management System



Smart Grids in a Network Immersed World



NET-zero Energy

NIST Net Zero Energy Residential Test Facility

Courtesy J. Kneifel (2012)

MULTI-OBJECTIVE OPTIMIZATION

Simulation

Next Iteration

Design Parameters:

x1 - Exterior Wall Insulation [R] = **30.00**

x2 - Roof Insulation [R] = 50.00

x3 - Window U-Value [U] = 0.35

x4 - Window SHGC [SHGC] = 0.35

x5 - Infiltration [ACH] = 3.00

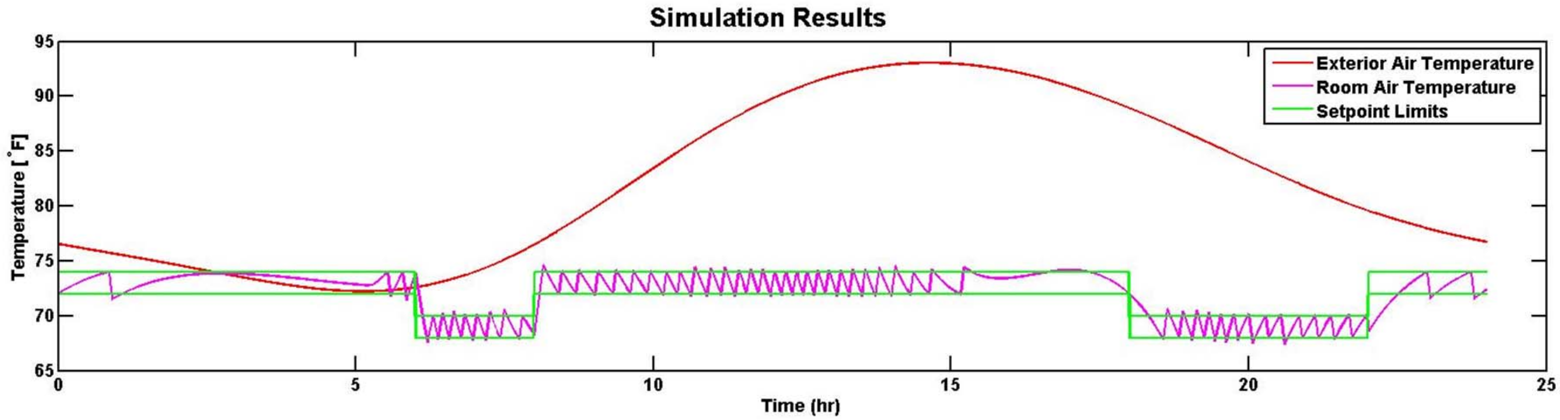
x6 - HRV/Ventilation [% Energy Recovered] = 0.00

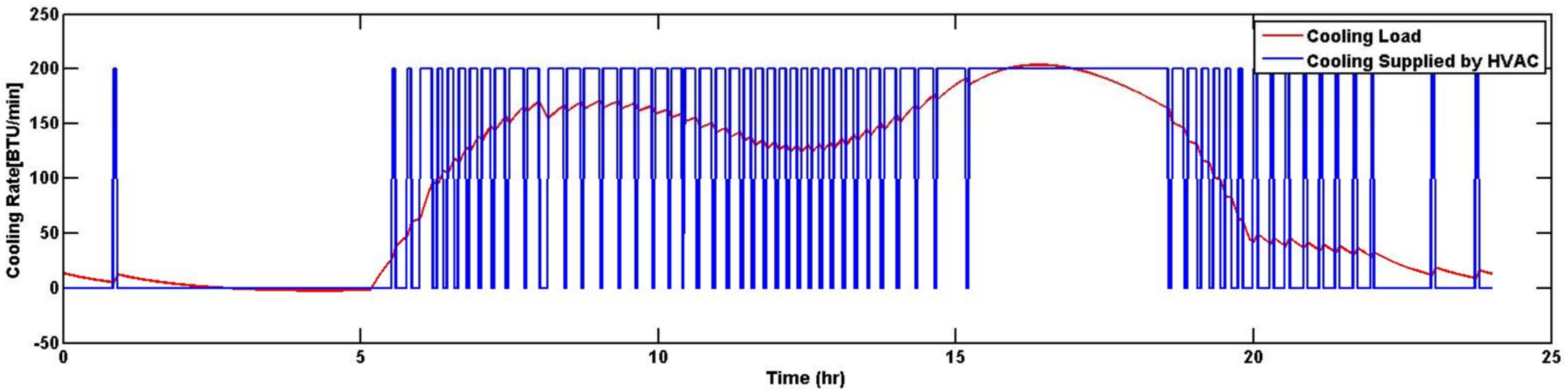
x7 - Lighting [% Efficient Lighting] = 0.75

x8 - PV [Watt] = 0

MULTI-OBJECTIVE OPTIMIZATION

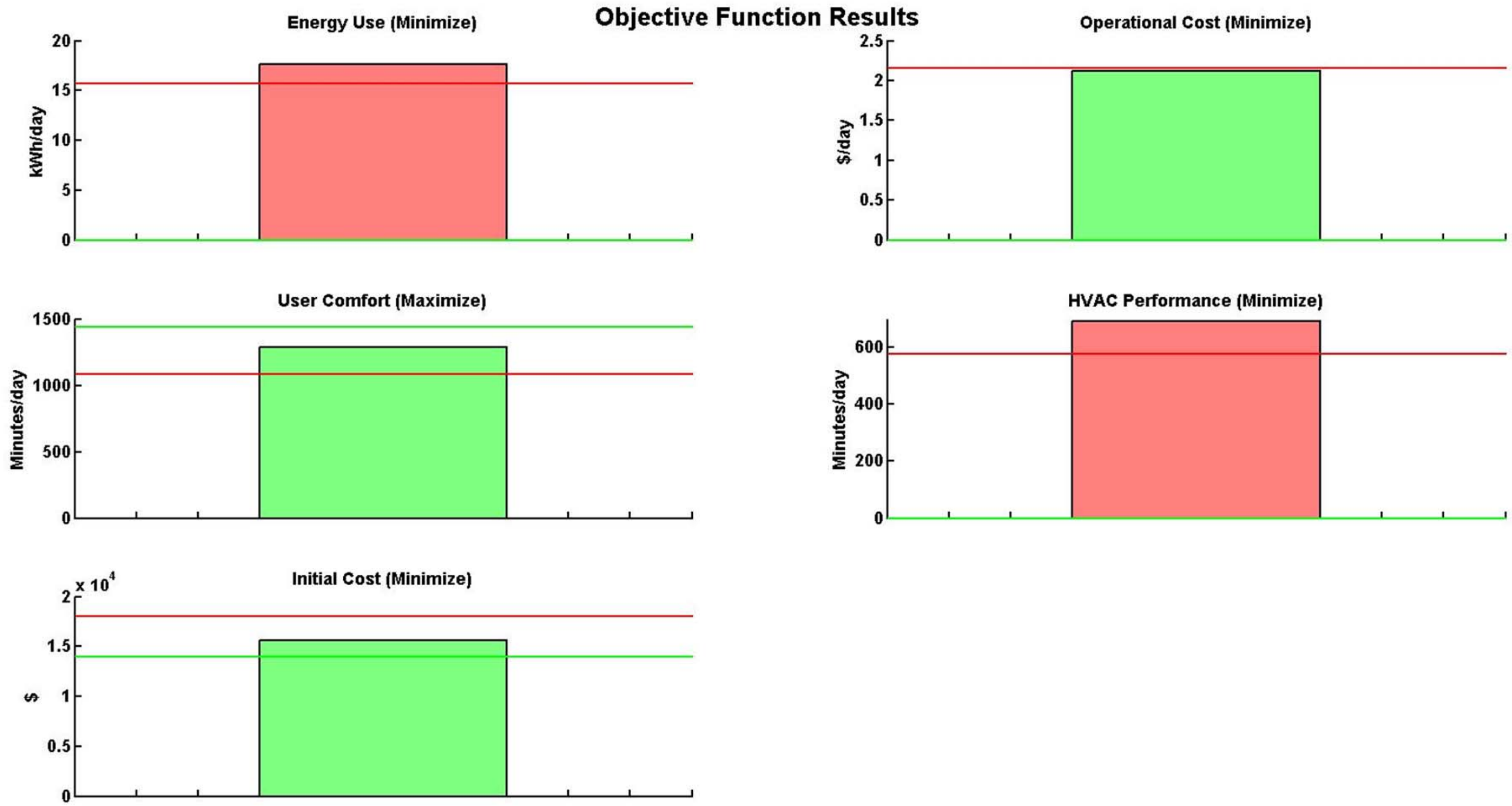
Simulation





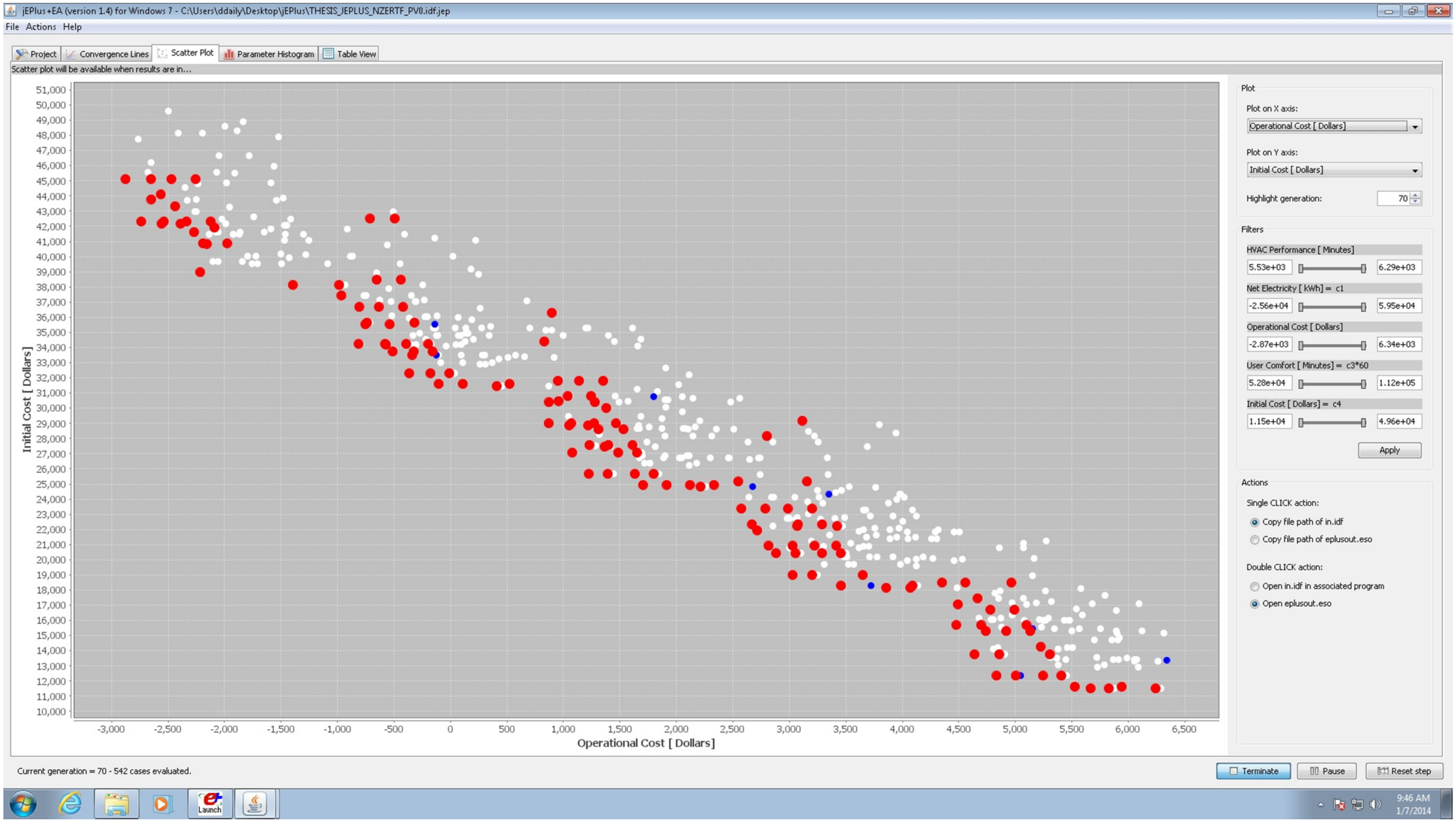
MULTI-OBJECTIVE OPTIMIZATION

Simulation



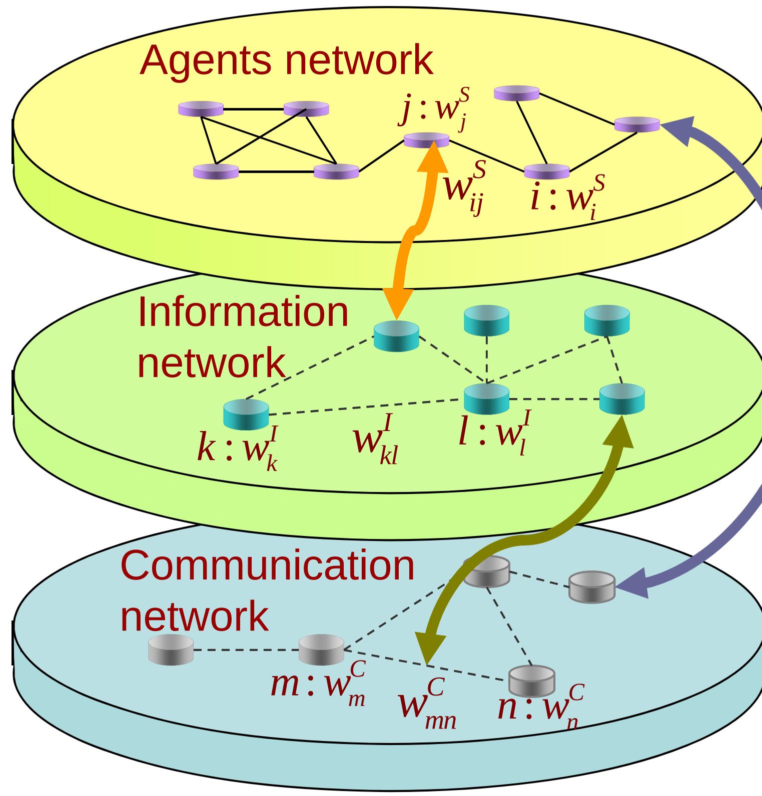
JEPLUS+EA OPTIMIZATION

Simulation



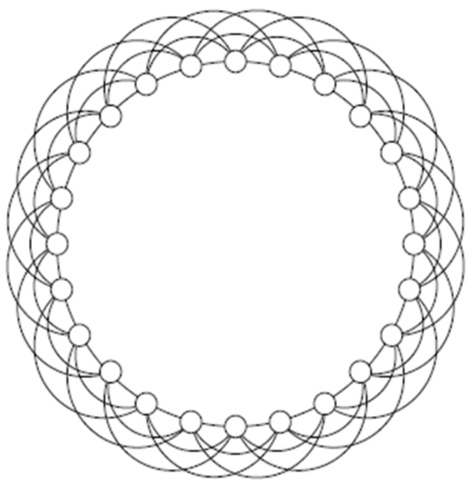
Multiple Coevolving Multigraphs

- Multiple Interacting Graphs
  - *Nodes*: agents, individuals, groups, organizations
  - Directed graphs
  - *Links*: ties, relationships
  - Weights on links : value (strength, significance) of tie
  - Weights on nodes : importance of node (agent)
- **Value directed graphs with weighted nodes**
- **Real-life problems: Dynamic, time varying graphs, relations, weights, policies**

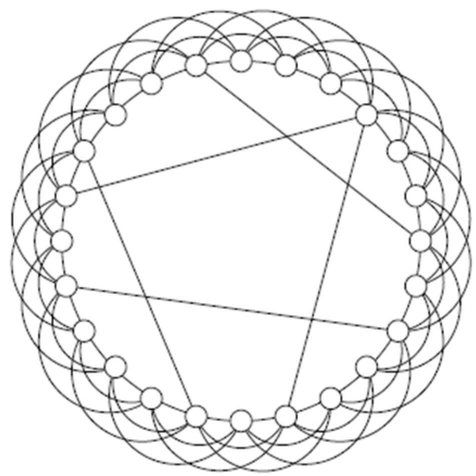


Networked System architecture & operation

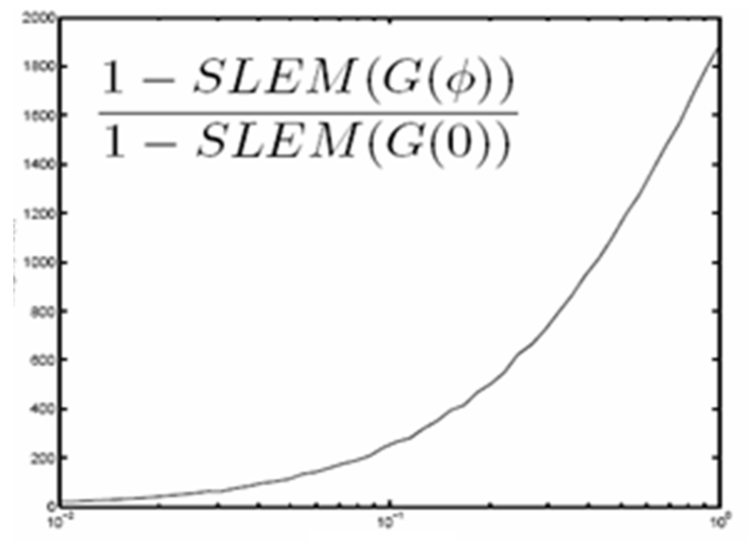
Small World Graphs



Simple Lattice
C(n,k)



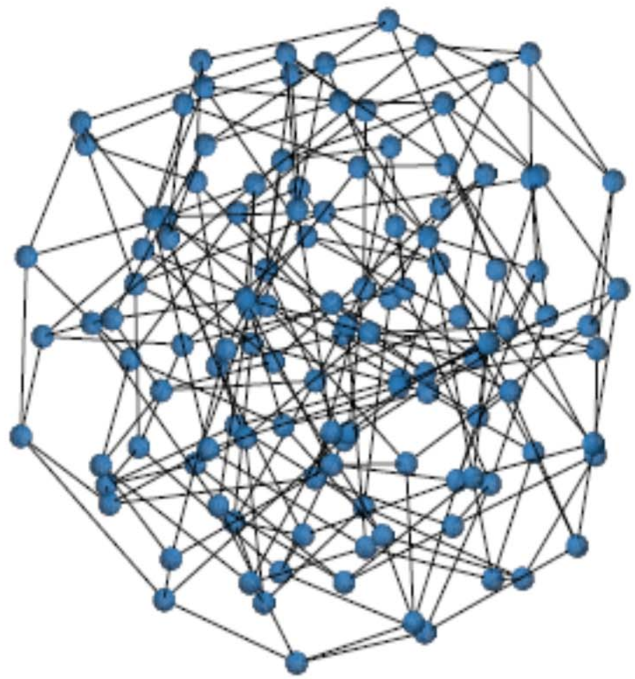
Small world: Slight variation adding $nk\Phi$

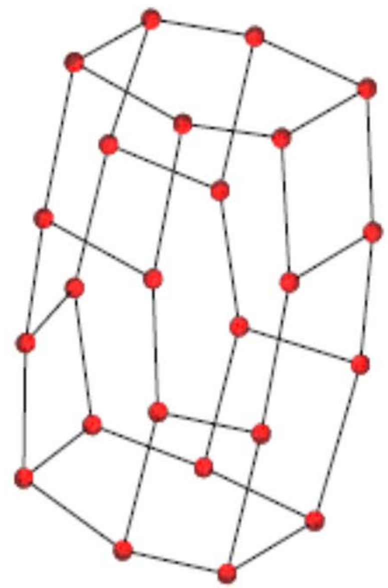


\phi
C(1000,5)

Adding a **small portion** of well-chosen links → **significant increase** in convergence rate

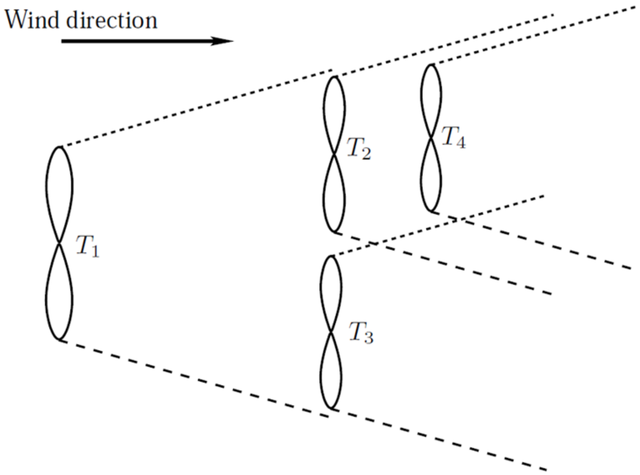
Expander Graphs – Ramanujan Graphs





Motivation: Maximizing Power Production of a Wind Farm

Horns Rev 1. Photographer Christian Steiness



Schematic representation of a wind farm depicting individual turbine wake regions.

- No good models for aerodynamic interaction between different turbines.
- Need on-line decentralized optimization algorithms to maximize total power production.

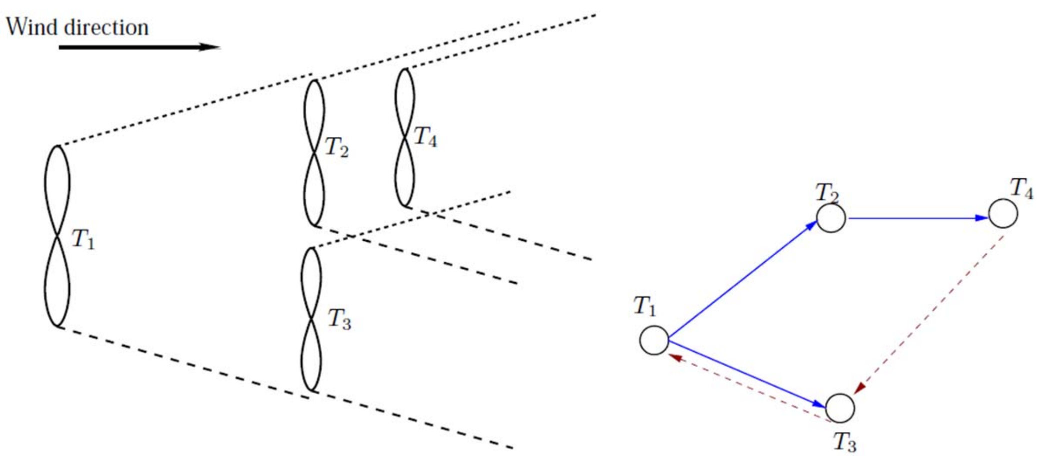
Assign individual utility
$u_i(t)$ = power produced by turbine *i* at time *t*
such that maximizing $\sum_i u_i(t)$ leads to desirable behavior.

System Designer's Perspective

Like agents, system designer does not know exact functional form of the payoffs.
→ The system designer may have "coarse information" about which agents' action can affect which others.

Interaction graph models such coarse information: It's a directed graph where a link from i to j implies actions of agent i affect the payoff of agent j.

Communication graph models explicit inter agent communications: It's a directed graph where a link from i to j implies agent i can send information to agent j.

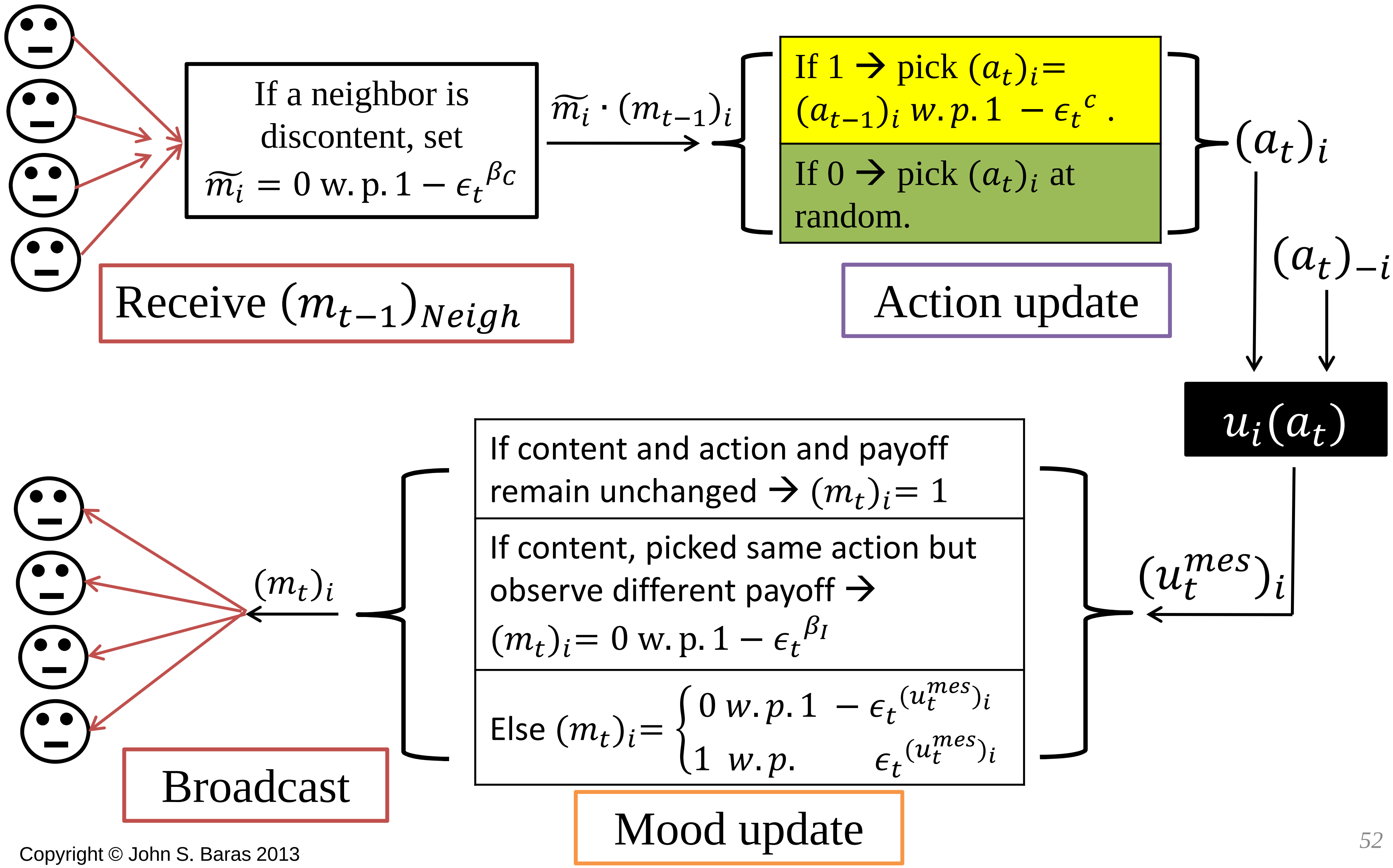


The wind farm example is considered in the figure:

- blue lines are edges in the interaction graph and,
- the red lines in the communication graph.

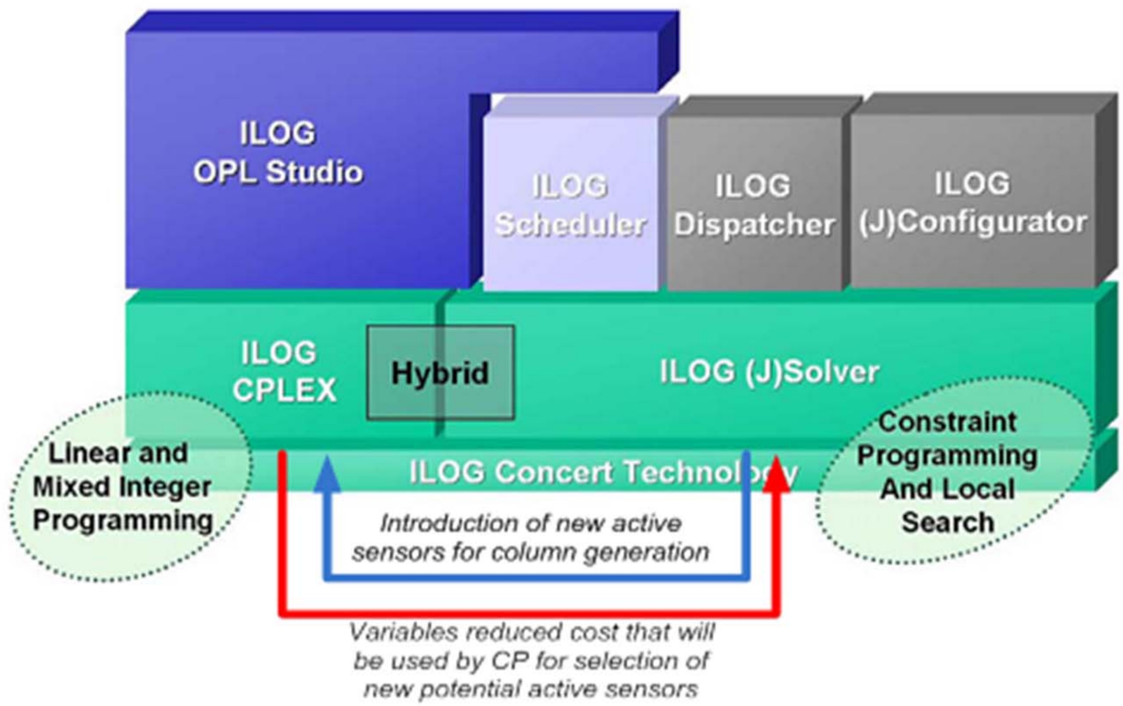
Proposed Algorithm

State $x_i = (a_i, m_i)$; $m_i = 1 \leftrightarrow$ content and $m_i = 0 \leftrightarrow$ discontent.

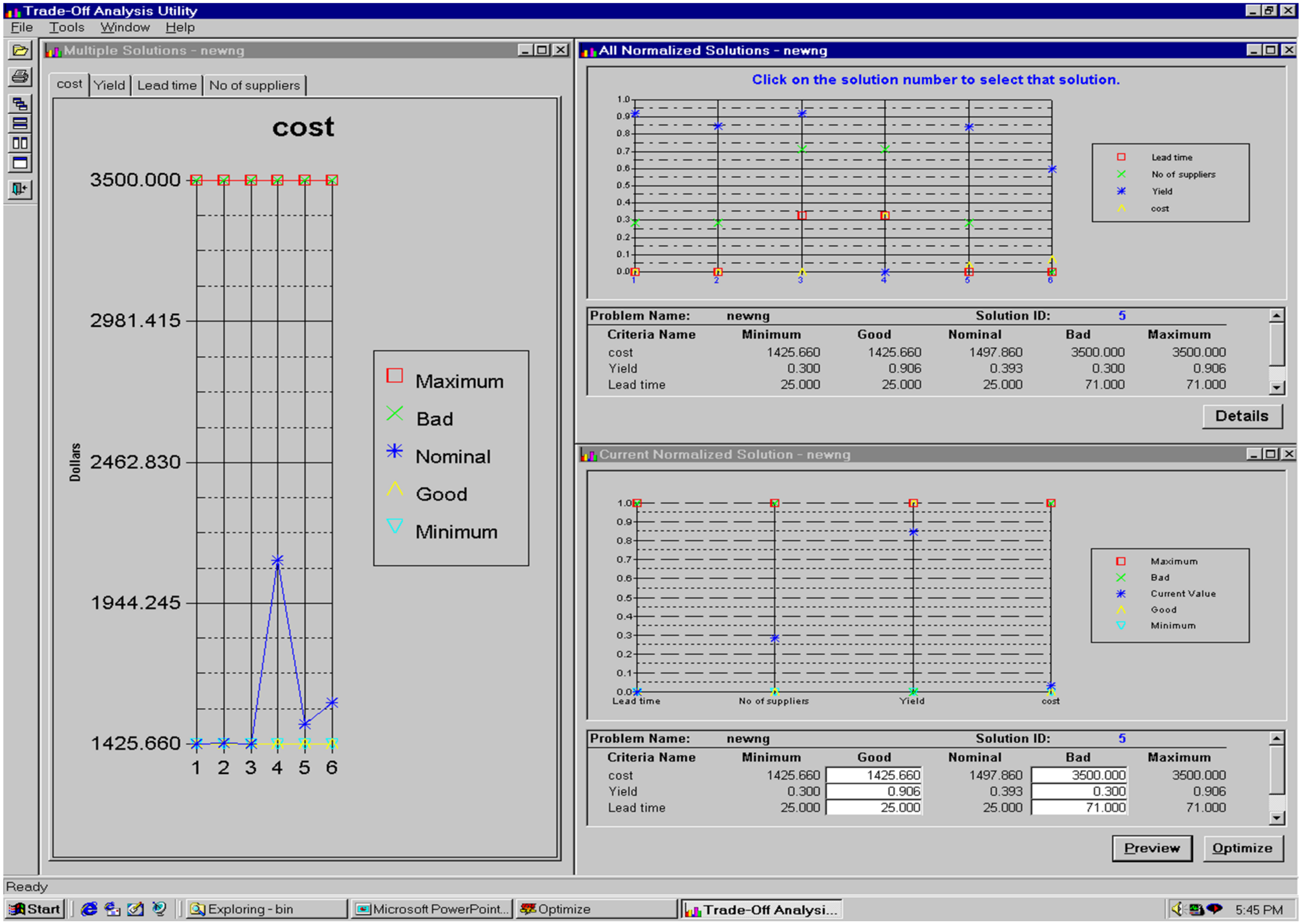


INTEGRATION OF CONSTRAINT-BASED REASONING AND OPTIMIZATION FOR NETWORKED CPS TRADEOFF ANALYSIS AND SYNTHESIS

To enable rich design space exploration across various physical domains and scales, as well as cyber domains and scales



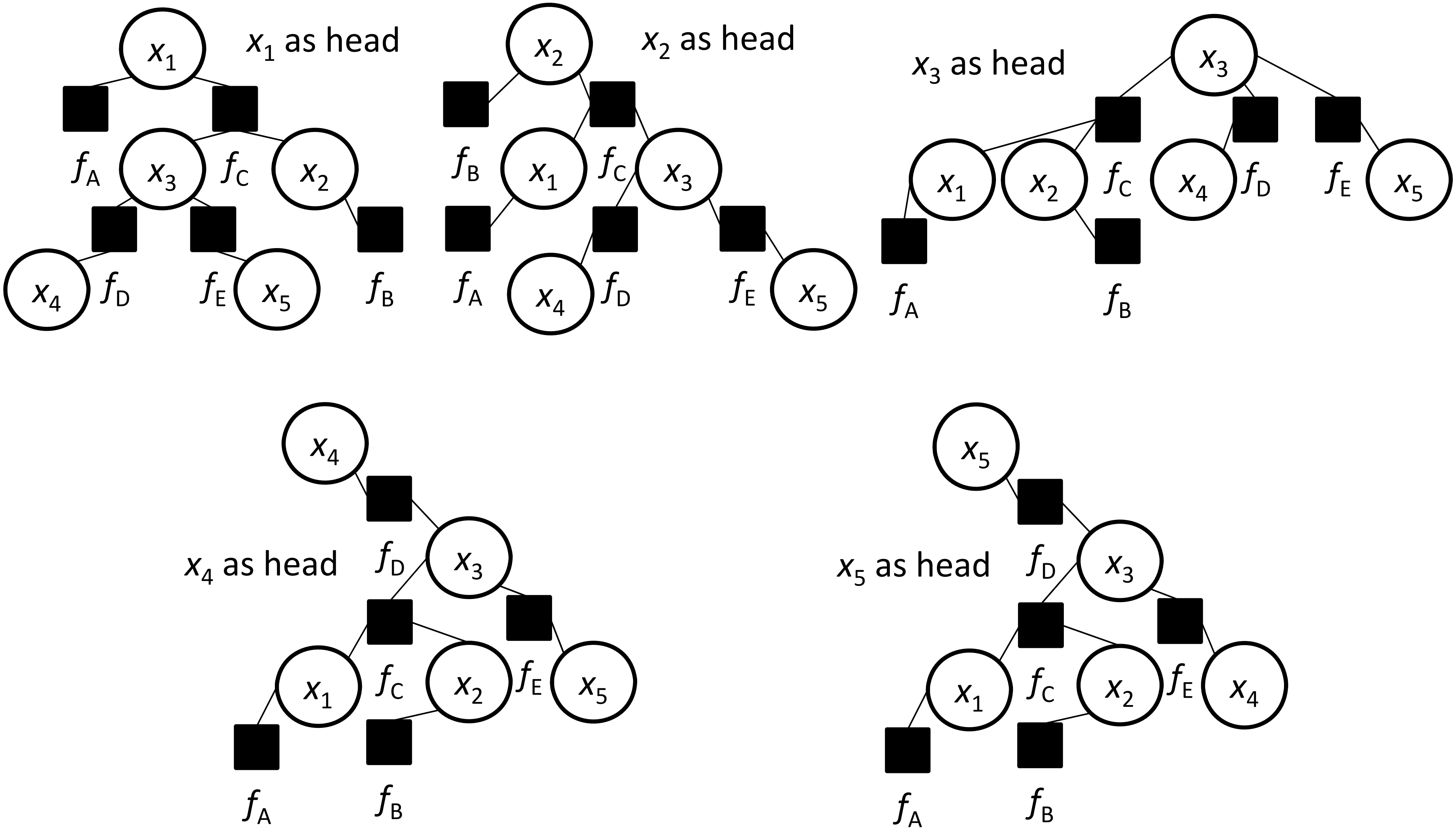
Tradeoff Analysis via Multicriteria Optimization



Design Space Exploration Problem

- Large, complex systems have many tunable parameters
- To perform **tradeoff analysis at system level**, a simplified view of the underlying components must be available
- **Challenge**: create an abstract, tractable representation of underlying components.
- **Hypothesis**: Although components are not perfectly decoupled, structure provides useful information for parametric decomposition

Query Induced Hierarchies



How to Use It?

- Input constraints of SysML Parametric Diagrams
- Interact with our tool to generate a factor join tree
- Roll back if necessary
- Create SysML Block Diagrams
- Revise the original SysML Parametric Diagrams
- Analyze the system using summary propagation

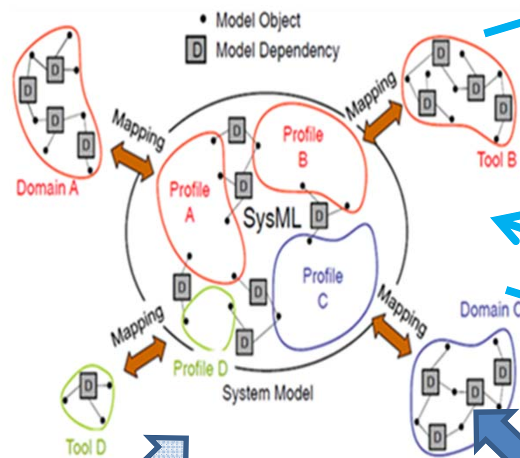
Latest Vision and Collaborations

MBSE Challenge & Need:
Develop scalable holistic methods, models and tools for future grids
Real-time distributed dispatch
Distributed sensing and control
Architecture design and evaluation

UMD: Integrated Modeling Hub
Power grids, Smart grids

Multi-domain Model Integration via System Architecture Model (SysML)

System Modeling Transformations

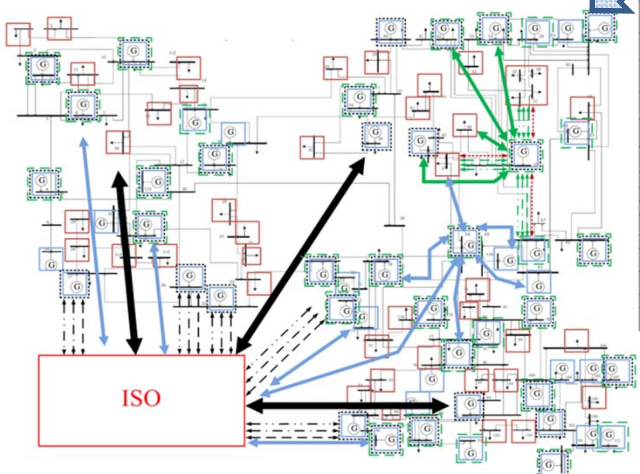


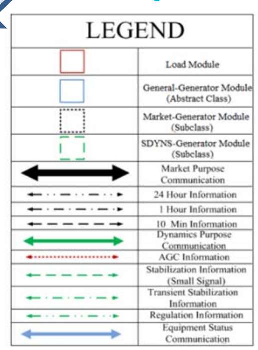
ILOG SOLVER, CPLEX, CONSOL-OPTCAD

Databases Libraries of system components and models

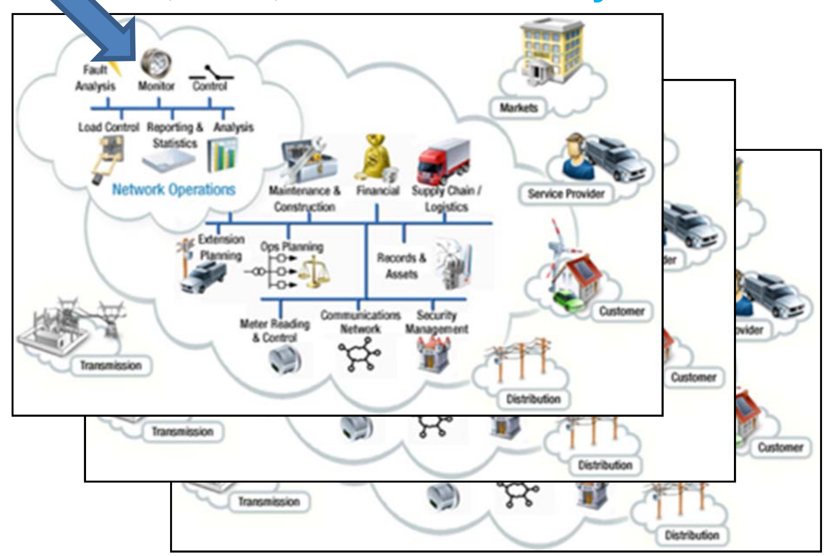
Multi-metric tradeoffs
Design/Operation space Exploration
System model updates
Architecture exploration
Real-time user interaction

CMU: DyMonDS based Smart Grid in a Room Simulator
End-to-End Stable Optimal Dispatch Concepts





HU, UMD, NIST and Industry Testbeds



Thank you!

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Questions?