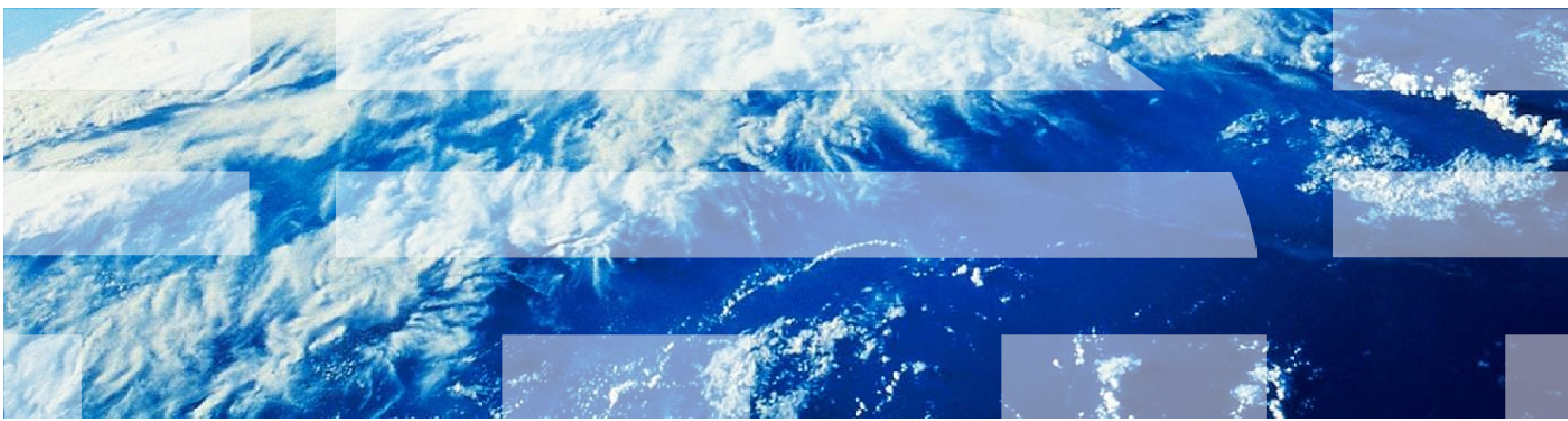
iPower WP4 Simulation Platform

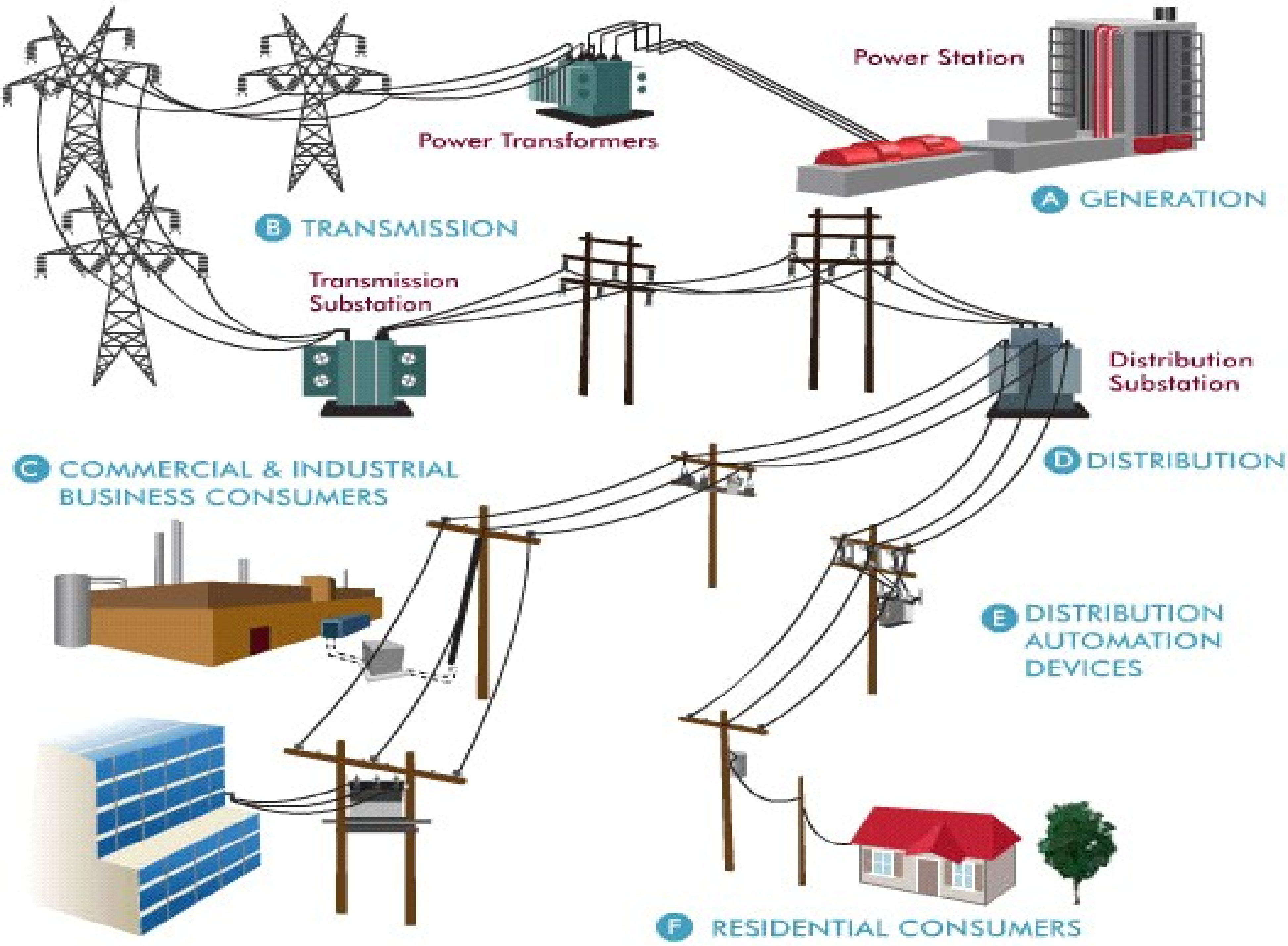
WP4 Workshop, Feb 6-8 2012

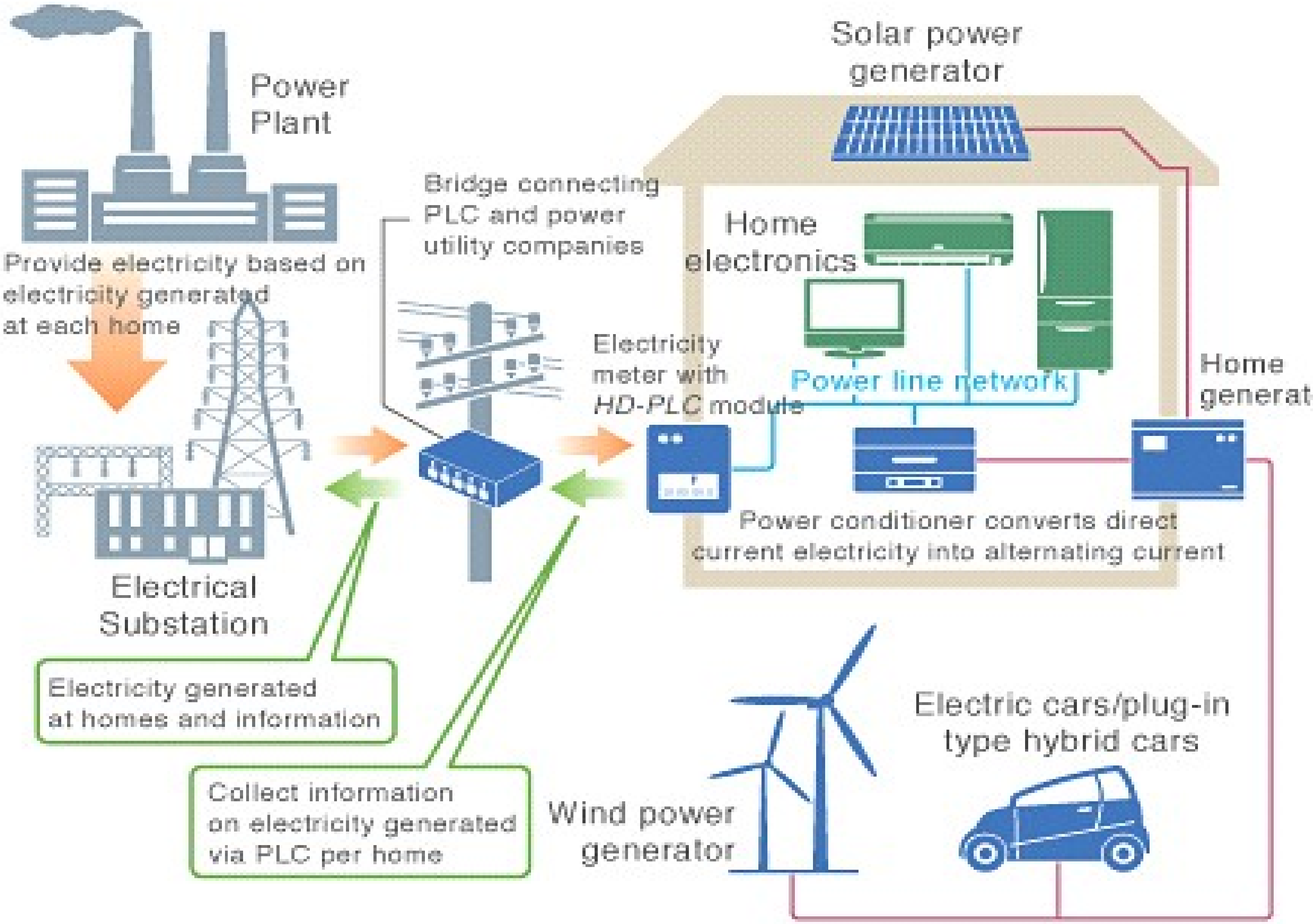
Carl Binding, Olle Sundström, Olivier Corradi
IBM Zurich Research



Outline

- Problem landscape
- Objectives
- Solution proposal
- The role of device models
- Some words on the grid
- Simulation platforms
- Conclusion and discussion
- Relationship to IBM Smart Grid Maturity Model


Power Station
Power Transformers
A GENERATION
B TRANSMISSION
Transmission Substation
Distribution Substation
C COMMERCIAL & INDUSTRIAL BUSINESS CONSUMERS
D DISTRIBUTION
E DISTRIBUTION AUTOMATION DEVICES
F RESIDENTIAL CONSUMERS



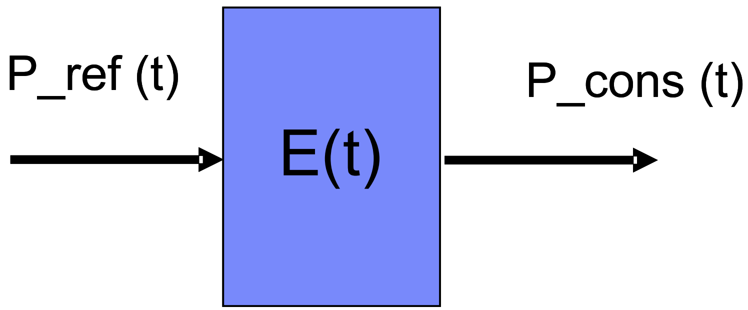
Power Plant
Provide electricity based on electricity generated at each home
Electrical Substation
Bridge connecting PLC and power utility companies
Electricity meter with *HD-PLC* module
Solar power generator
Home electronics
Power line network
Home generat
Power conditioner converts direct current electricity into alternating current
Electricity generated at homes and information
Collect information on electricity generated via PLC per home
Wind power generator
Electric cars/plug-in type hybrid cars

Objectives

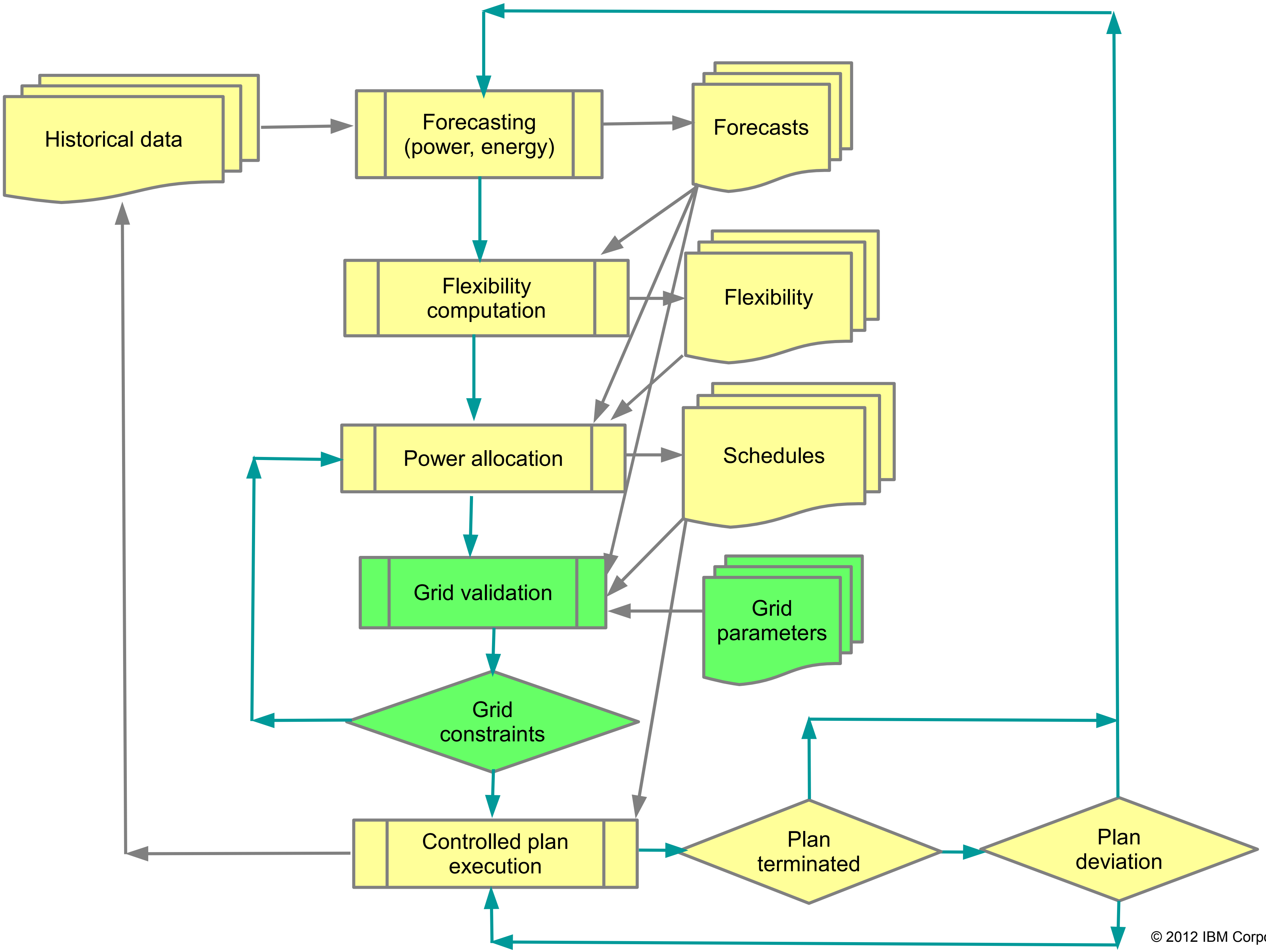
- Simulate electrical power grid scenarios with associated control of flexible loads in order to balance stochastic supply with uncertain demand whilst maintaining grid stability
  - Physical non-availability of real system
  - Experiments with real system not feasible
- Realistic modelling of grid including market schemes
- Possibility to tie in hardware-in-the-loop by equating simulation time to real-time
- Scalable, flexible, robust, reliable, usable...
- Interface to external environments (legacy, HW in the loop)

Our view of the iPower world

- Stochastic generation: wind, PV
- Flexible demand
  - Energy buffering
  - Power nodes (ETH/DTU), BBB model (AAU), EDISON IBM ZRL simulation…
  - 1st order linear continuous state-space models (Aarhus, November 2011, DONG)
  - E(t) = inflow – outflow + initial energy
- Power grid interconnecting generation and loads
  - Grid stability: voltage, angle, thermal load



MPC cycle for power grid



Methodological approach

- We assume historical data of the system's behaviour
  - e.g. **time-series** on generation, load, weather, etc
  - This data is either real-world observation or from some simulation model
- We use historical data and **forecasting/prediction** models to build up a forecast of power generation and loads' energy requirements.
  - Time-horizon flexible
  - Forecast can be “external” to platform
  - Generated power (time)
- We compute the **flexibility** of the loads over time such that the forecast energy constraints are met.
  - Requires **energy consumption over time** (which can be time-shifted from energy delivered)
  - Minima and maxima of P(t), E(t)
- **Optimize power allocation** such that predicted generation is balanced with predicted power allocation that satisfies predicted energy requirements
  - Results in an execution plan: load power(time)
  - Execution plan can be validated against grid-constraints and be constrained as necessary and feasible.
  - Can be (future) market based
- Plan execution can imply **control** – either direct or indirect (real-time incentives).
  - But we based our planning on **forecast of energy needed**.
- During plan execution, **re-planning** occurs to account for deviation between predicted generation and load behaviours.
  - Re-planning also when plan is exhausted...

What does this imply?

- Historical data
  - We may only have partial or summary historical data
  - Additional “historical” data derived by estimation or simulation or …
  - We need very detailed consumption data of flexible loads (usage data)!
- Forecasting models based on available historical data
  - Forecasts may come externally (ex. weather forecast)
  - Forecasting/prediction might require a model of loads and their energy usage
  - Essentially again: a time-series with uncertainty into the future (of energy required for use)
- Flexibility
  - Data formalism to express flexibility
  - Computational methods to compute flexibility based on available usage data
  - Scalable, performant
- Power allocation
  - Some allocation criteria (optimization) with constraints on the power and energy levels
  - Power allocation can be direct or indirect
  - Incentives map to direct power allocation via sensitivity analysis (*not shown here*)
- Grid constraints
  - In addition to the non-grid constrained power allocations
  - Grid stability: voltage, angle, thermal loads on infrastructure
  - Are transients needed here?
  - Grid constraints can possibly be alleviated by additional power allocation constraints; alternatively grid re-inforcements
- Plan execution
  - Simulate plan execution with seeded deviations between forecasts and execution
  - Apply control schemes; direct or indirect
  - Record data traces for future use as historical data
  - Re-invoke planning as necessary

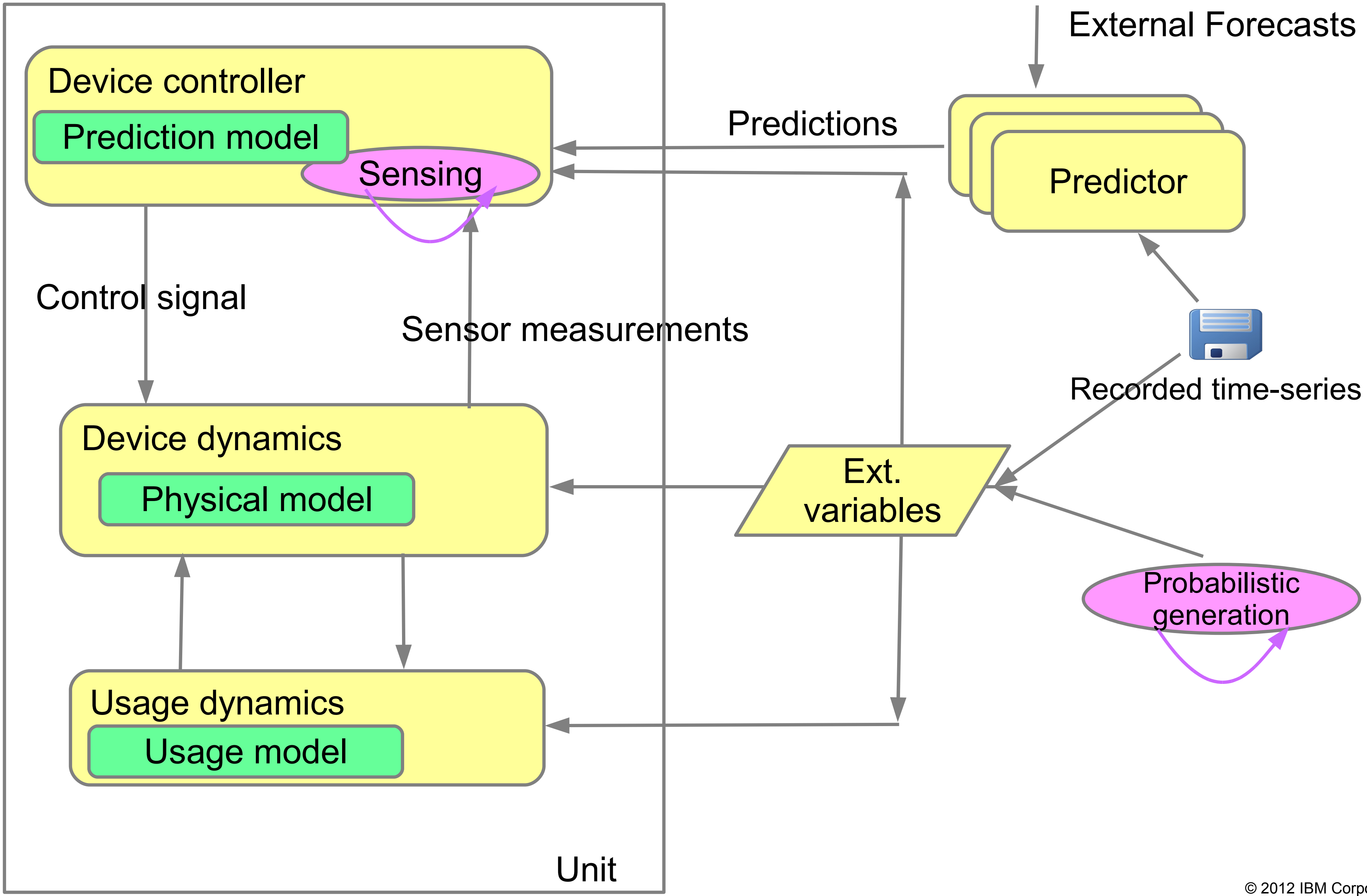
Functional requirements

- Characterization and models of system to be simulated
- Identification and validation of model parameters
- Flexible handling of time-series for generation, consumption, weather, etc. and other data (e.g. grid parameters)
- Forecasting models and methods to predict energy generation and energy consumption, taking into account uncertainty, historical data, etc. Validation of forecasting approach against statistical data.
- Determination of flexibility requiring some formalism to express flexibility and associated computational methods
- Power allocation schemes satisfying some optimization criteria (cost, benefit, CO2, …); associated solvers for underlying optimization schemes
  - Direct control
  - Indirect control
- Power grid modeling and stability analysis against predicted power allocation (e.g. schedules)
- Control schemes and their embedding into the system under simulation to simulate execution of forecast power allocation and trigger re-planning on-need.

Some requirements for simulation

- Linear 1st order state space models, with constraints appear a good start
- AAU & Sundstroem categorization: which seems to fit
  - **Battery** – Fixed-end buffer
  - **Bucket** – Open-end buffer
  - **Bakery** – Time-shifted buffer
- These devices have **time-continuous behaviour** (state) combined with **asynchronous events** (human interaction, external factors)
- We postulate a **hybrid simulation** environment in which **discrete events** occur and influence **time-continuous state** behaviour.
  - Time-continuous state monitoring can also generate events
  - Some discrete events are **not** state dependent: external influences
- **We want to study impact on control approaches to balance flexible energy demand with stochastic generation**
- The approach is **Model-Prediction-Controller**
  - We **model** the system the best we can
  - We **predict** its behaviour based on history and forecasts
  - We apply **control** such that constraints are met
- **Benchmarking** of scenarios
- Modularity, scalability, re-usability, performance etc. also needed

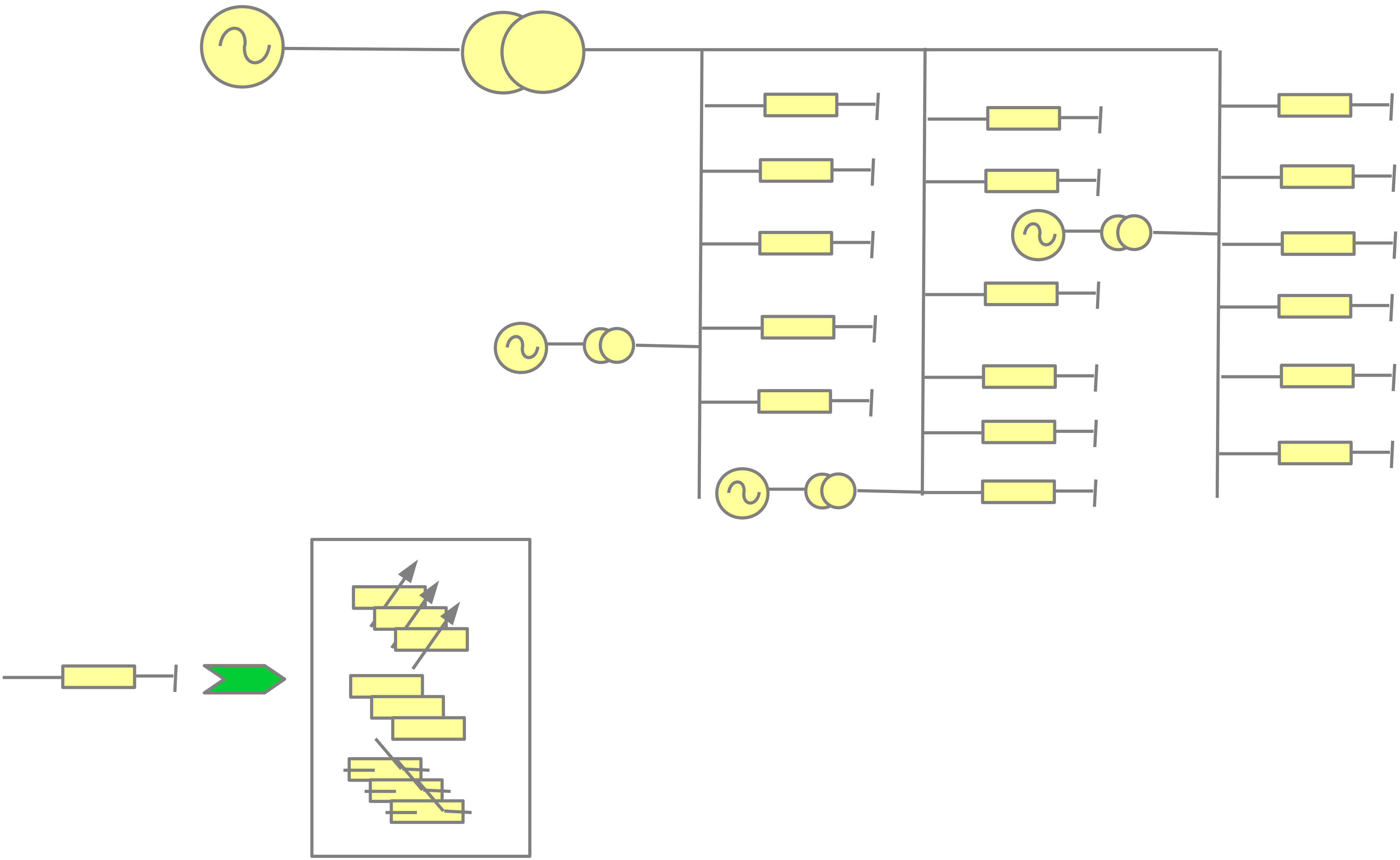
Detailed load (device) model



Roles of device model

- Generation of “historical” usage data when no real-world data exists model in past).
  - Partially driven by real-world data or by probabilistic usage patterns
  - Build a landscape of units of interest
    - Households with energy flexible devices
      - Dish-washer, dryer, washing machine
      - Heat-pump
      - Fridge, freezer, electrical boilers
      - Electrical space heating?
      - Air conditioning units?
- Plan execution against simulated physical model (model in present)
  - Observe state evolution against plan; detect plan or limit deviations
- Controller predictions against a simulated controller prediction device model during plan execution (model into the plan future)
  - Arbitrary simulated controller prediction device model, must not be identical with simulated physical model.
- We can start with linear continuous time/state-space models which capture a wide range of energy consuming devices
  - Evidently non-linear models are also possible

Grid model: distribution grid



Simulation platforms

- A wide range does exist
- Some are good for some things, but not others
  – Feel for an integrated approach
- Investment costs not negligible
- Learning curves
  – Languages for modelization, set-up, maintenance, etc.
- Maintenance issues
- Scalability, flexibility, robustness, interface to external environments, usability, performance....
- Distributed simulation platforms are tricky because of simulation clock synchronization and causal dependencies between “federates”
- We believe that a hybrid (i.e. discrete event combined with continuous state-time) approach is required
- Time-scales do matter: transient, power, energy, economics
  – Variable integration step-sizes can alleviate some problems
- Flexible data handling is essential, although canonical data models are well known (time-series, grid parameters)
  – Data parsing, mapping, etc doable upon need
- We can distinguish between the power/energy aspects and the grid constraints
  – i.e. grid constraints can be isolated
- Prediction features and time series handling to be built in all cases
- Visualization, reporting not considered here but also necessary.

Simulation platforms

Name	Application domain	type	run-time env.	language	Grid	Loads/generation	Flexible loads
Matlab/Simulink/SimPower	Control with support for power grid	time-continuous	local	Matlab	small scale	yes	possible
Digsilent PowerFactory	Power grid planning	time-discrete	local	PowerFactory	yes	yes	no
PowerWorld	Power grid planning	time-discrete	local		yes	yes	no
Modelica	Control	time-continuous	local	Modelica	not built in	no	possible
HLA (various RTI vendors)	Large scale, military, transport	time-discrete	distributed	C, C++	not built in	no	possible
GridLab-D	Power grid planning		local	C, C++	yes	yes	no
OpenDSS	Power grid planning		local	C, C++	yes	yes	no
IPSYS	Power engineering	hybrid	local		yes	yes	
AMES	Market modelling		local				no
SEPIA	Market modelling		local				no
IBM-ZRL	Control and power grid	hybrid	local	Java	planned	In progress	In progress
Desmo-J	Generic discrete events	time-discrete	local	Java	no	no	no
RTDS	Transients in power grids	time-continuous	Distributed, proprietary HW	RTDS	yes	no	no
Arena	Generic discrete events	time-discrete	Possibly distributed (HLA)	Visual Basic	no	no	no
Extend	Generic discrete events	time-discrete	local	ModL, VBA, C++	no	no	no

Simulation platforms (continued)

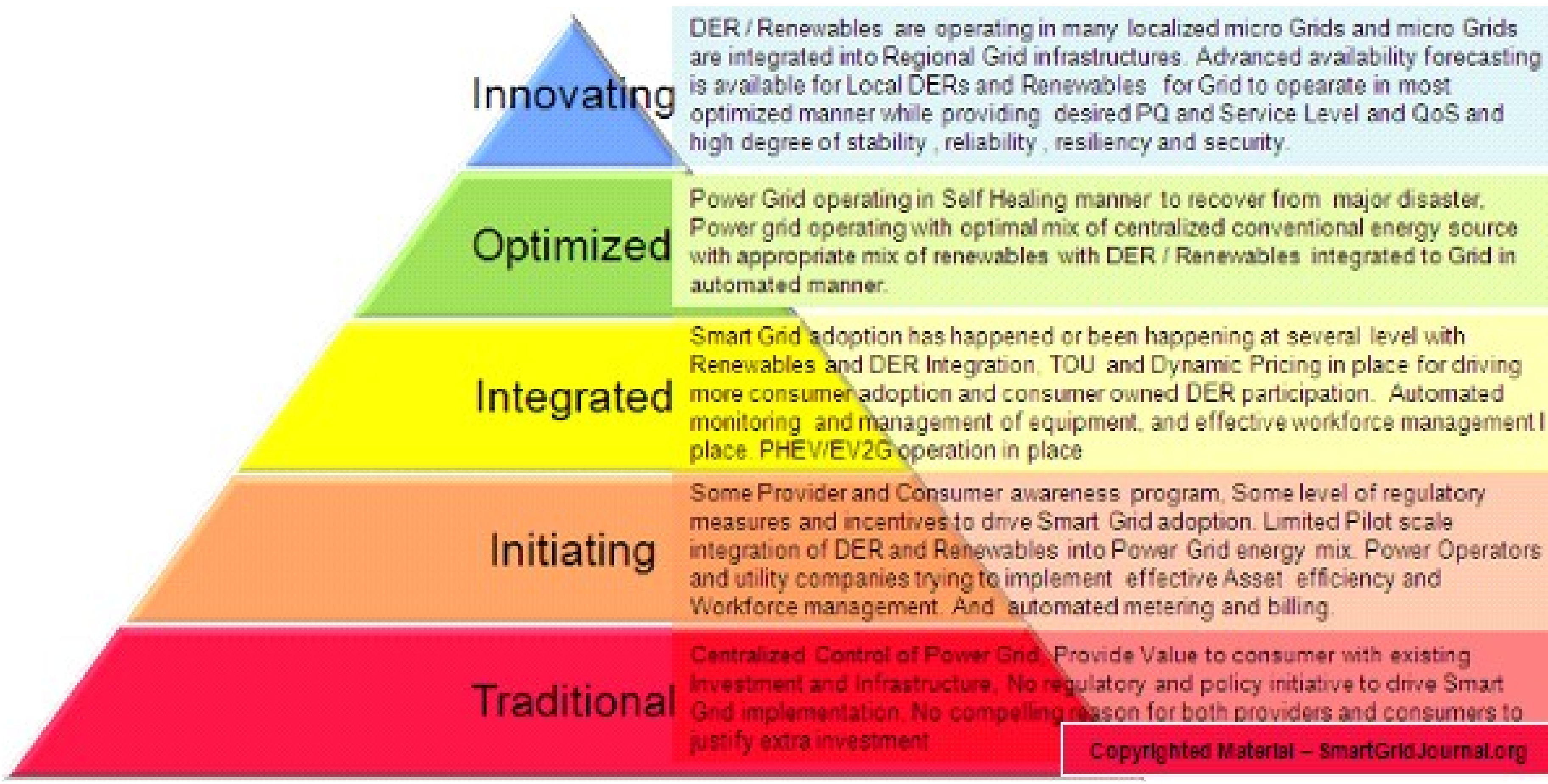
Name	load-flow	External data	cost		parallelized	openness	
Matlab/Simulink/SimPower	yes	yes	high	commercial	yes	extensible	
Digsilent PowerFactory	yes		high	commercial		extensible	
PowerWorld	yes		high	commercial		closed	
Modelica	no		low	Open source	no	open	
HLA	no	yes	high	commercial	yes	extensible	
GridLab-D	yes		low	Open source		open	
OpenDSS	yes		low	Open source		open	
IPSYS	yes	yes	low	Research prototype			
AMES							
SEPIA							
IBM-ZRL	planned	yes	low	Research prototype	yes	open	
Desmo-J	no	yes	low	Open source	no	open	
RTDS	yes		high	commercial	yes	closed	
Arena	no	yes	high	commercial		extensible	
Extend	no	yes	high	commercial		extensible	

Summary and Discussion

- None of the known platforms seems to fit perfectly
- A truly distributed platform is hard
  - Extensions to external, remote or hardware-in-the-loop abstractions feasible as long as clock remains centralized
  - Performance would be a big issue in time-continuous ODE usage
- Do we really agree upon what we want to simulate?
  - Operational scenarios
    - Time-scales
    - Model complexity and size
    - What is target?
- Forecasting/prediction models are essential
  - And not readily provided by any of the known simulation platforms...
- Energy/power optimization requires detailed knowledge on energy/power utilization
  - Aggregation may be possible and is desirable
- What is the flexibility modelization?
  - Flexibility must be based on predicted energy use
- Grid validation can be outsourced to something like RTDS
  - Establish (simulated) power time-series and apply this to transient model of RTDS
- System parameters and historical data necessary
  - Model validation
  - Format is secondary
  - Flexible handling desirable

IBM/SEI Smart Grid Maturity Model

- More of a business related aspect
- If we had the envisioned platform, enterprise wide operational optimizations can be envisioned
- It assumes that integration is done (i.e. integrated and available data)
  - Detailed metering, possibly near-real time, effective **energy consumption** is relevant
  - Grid parameters on-line
  - External data feeds for wind and PV forecasting
- It enables optimized operations and planning



Term and Issues

- Time domain: transient, power, energy, economics
- Simulation time vs real-time
- Solver engines: load flow, ODEs
- Scalability
  – RAM, CPUs, distribution (networked)
- Reliability/Robustness