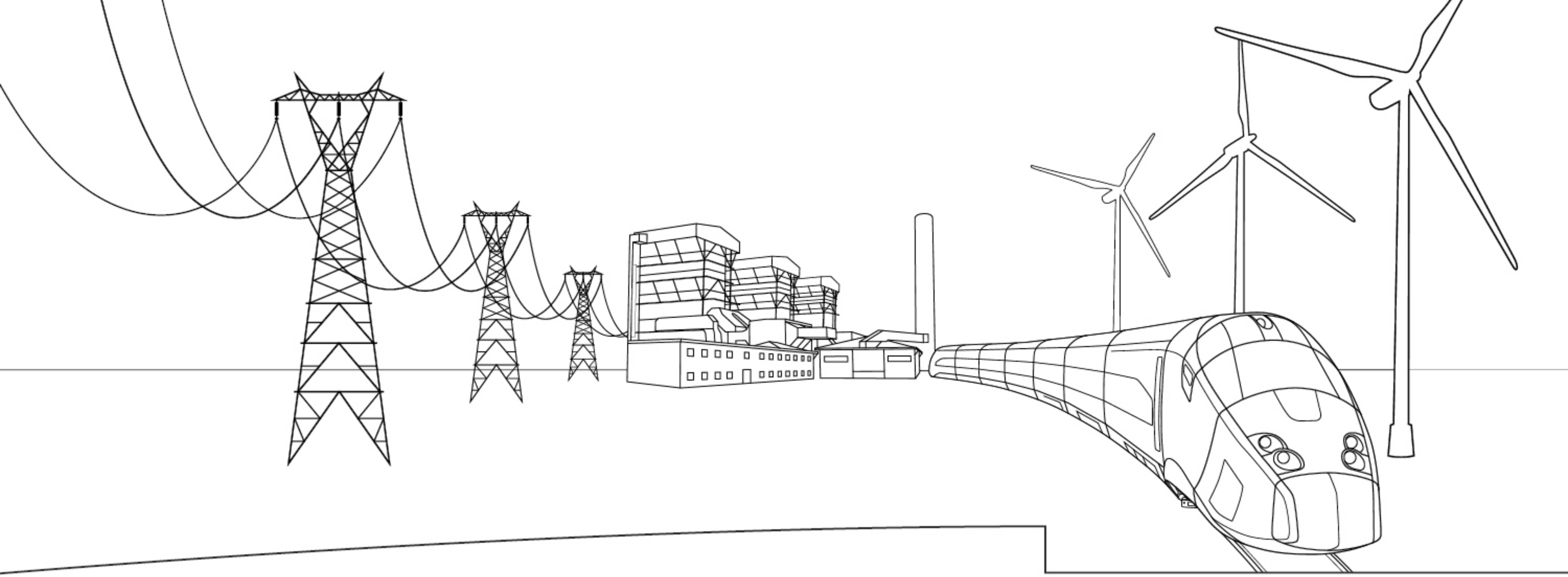


Integrated System Design and Optimization

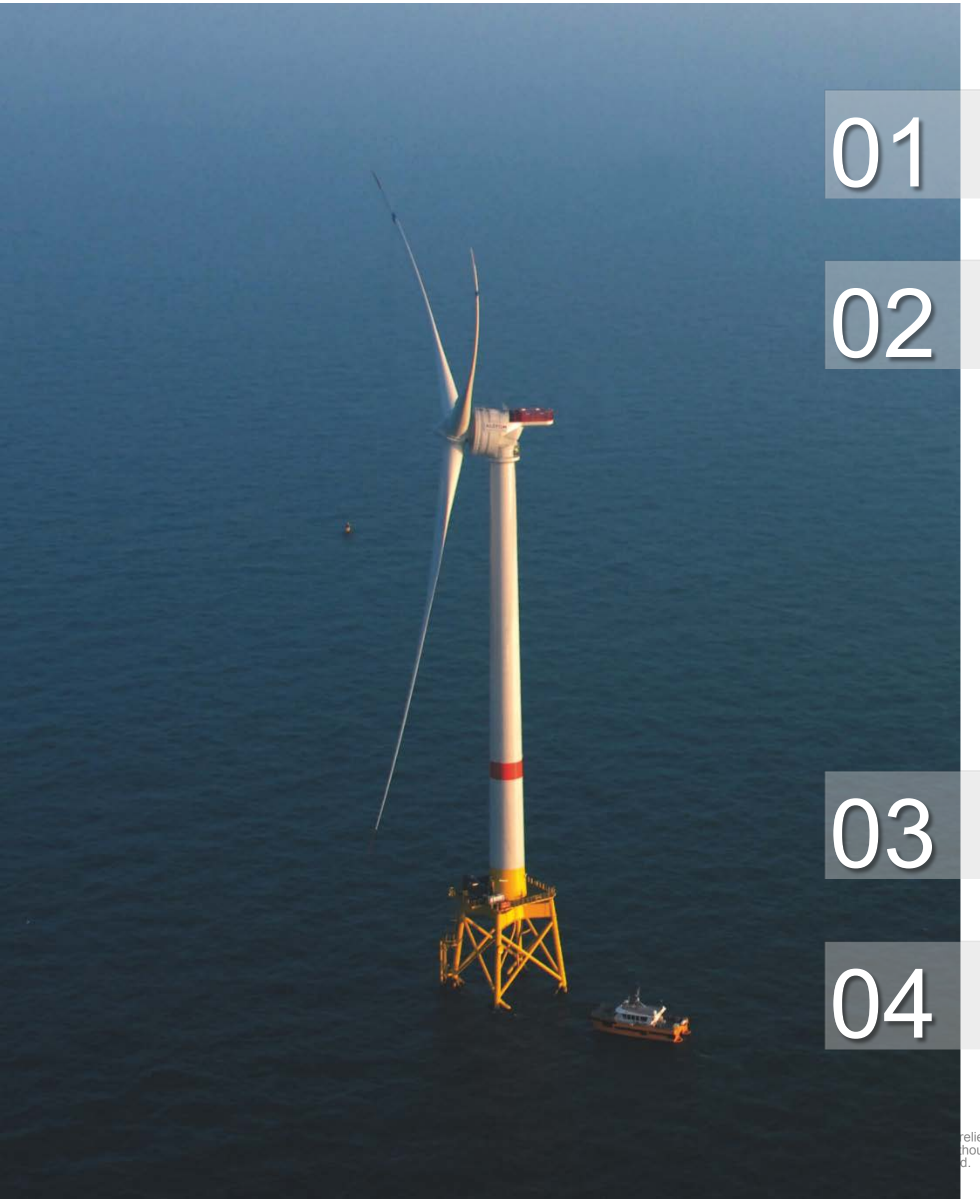
NREL WESE Workshop - Boulder, CO

Jon Campbell

1/15/2015

ALSTOM
Shaping the future

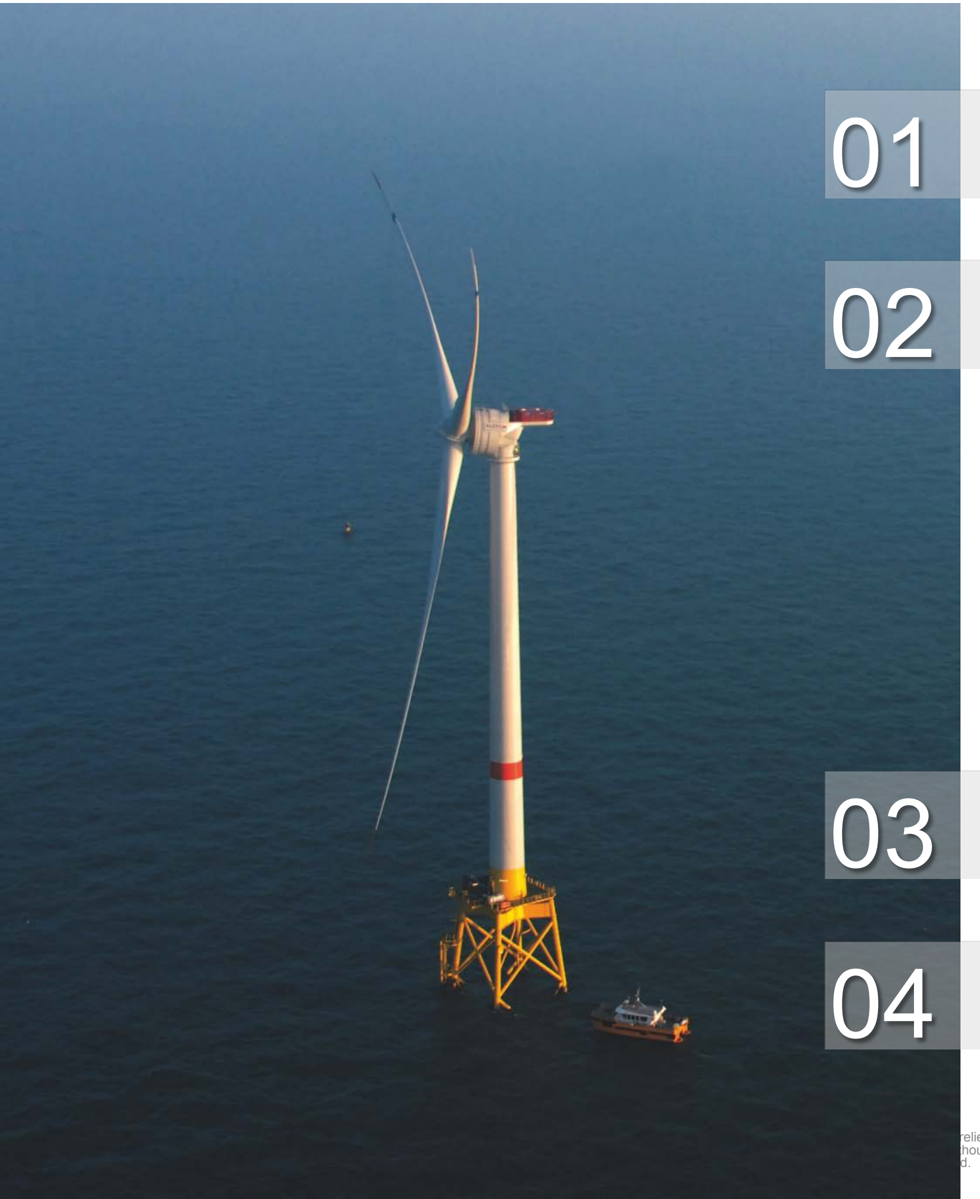
Agenda



Introduction

- The need for Integrated System Design and Optimization is understood and accepted.
- Driven by market competitiveness – must minimize costs and maximize performance.
- Wind farms fall into the category of “mass customization”.
- Use of Integrated System Design (ISD) has multiple benefits:

  1. Identification of system design drivers → reduction of time at early stages of the project; R&D cost savings.
  2. Reduction of cost of energy and project risk → more room to optimize and identify critical risks due to multiple results.
  3. Increases competitive advantage → enables OEM’s to deliver optimized solutions to customers, reduces time to market.



01 Introduction

02 Current Methods

- Drive train
- Tower and Substructure
- Wind Farm
- Value Analysis

03 Future Work

04 Management of ISD Tools

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Alstom Current Methods

Component Level	Turbine Level	Wind Farm Level
• SAMCEF • ANSYS • Ncode • modeFrontier • Hyperworks • Matlab • Excel • Several others	• SAMCEF • modeFrontier • BLADED • Matlab • FAST • Excel	• Openwind • Excel

Applications for various system levels and phase in the design process

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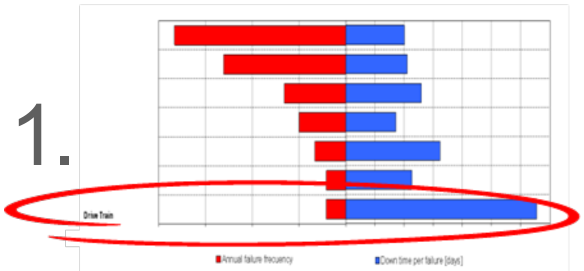
Drive train

Conceptual Design: Haliade™ 150-6MW

Major design choices targeting to reduce wind offshore CoE

1.

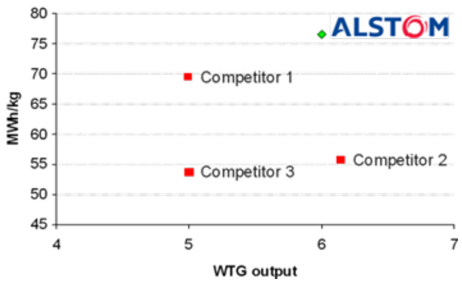
Failure frequency/ vs. down time



Drive Train → DIRECT DRIVE

2.

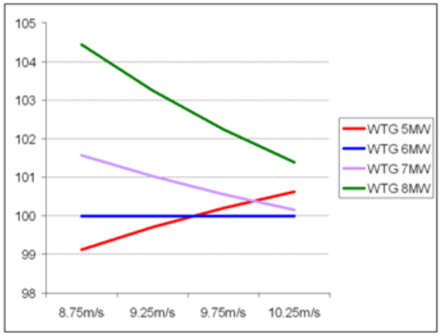
Annual energy yield Vs wind turbine weight



Rotor diameter → 150M

3.

CoE - Index 100 on WTG 6MW



Power rating → 6MW

Direct Drive decision derived at the wind farm level

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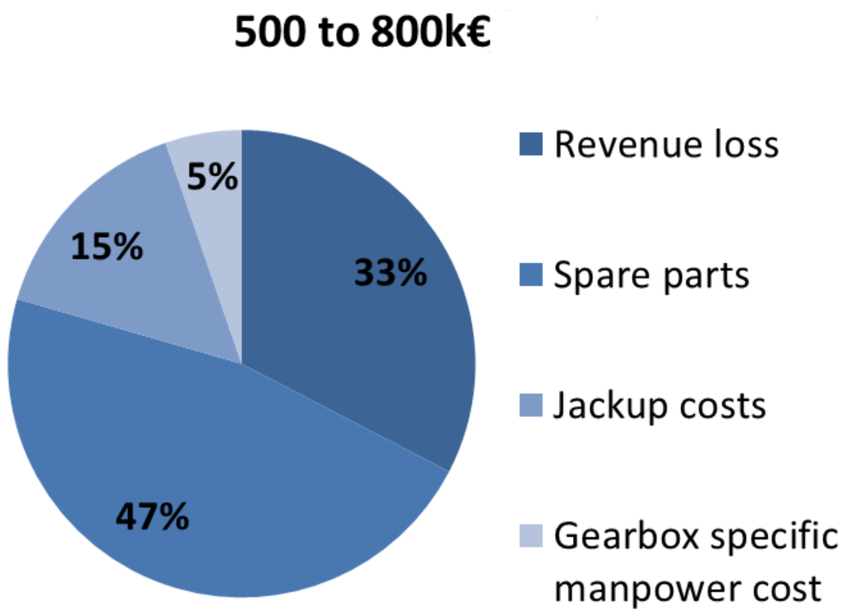
Drive train

Cost-benefit analysis during conceptual design phase

Net Present Value of costs: 500-800k€ estimated lifetime extra costs for a 6MW geared turbine



NPV of Gearbox specific costs (Alstom estimate)

- Considering one gearbox change over 20 years
- 2 campaigns of 50% of gearbox replacement around WF midlife
- Assuming perfect planning of gearbox repairs (predictive condition monitoring avoiding unscheduled downtime)
- Extra preventive maintenance for lubrication and oil changes

Conceptual design studies supported by “Pro Forma” analysis

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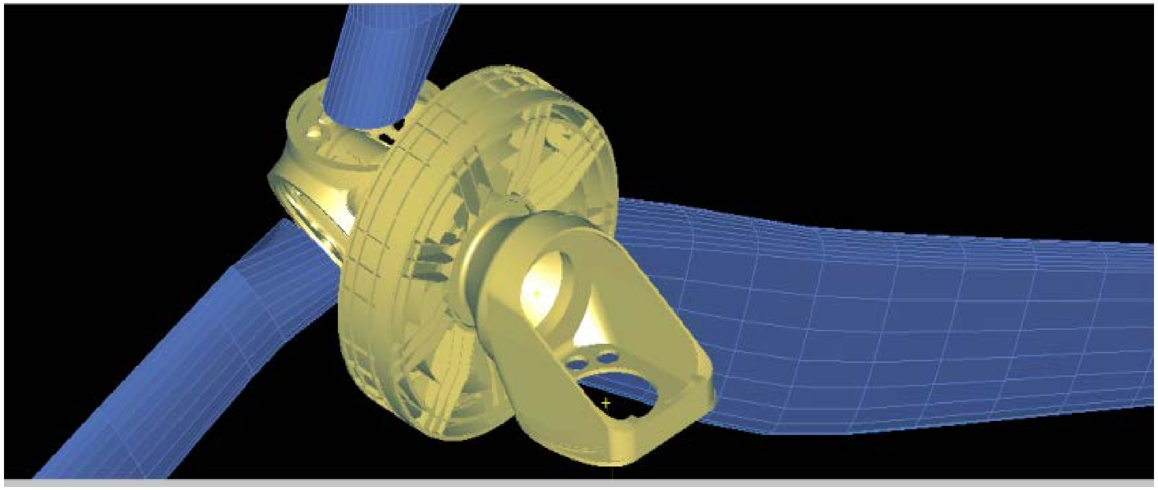
Drive train – Component/Turbine Design Level

Alstom uses SWT - Samcef Wind Turbines

- Global analyses of complete machines or local analyses of single components available in the same environment
- Also use Samcef Field for PRE and POST-Processing.

Modules that are called from SWT or Samcef Field:

- Samcef Dynam: Solver for modal analysis, superelement creation.
- Samcef Mecano: Solver for time-domain analysis.
- Samcef Nonlinear Motion Analysis: to simulate flexible dynamics with high accuracy.



Integrated aero/hydrodynamic loads and FEA.

Tower and Substructure

Tower & Substructure - Integrated System Design

- Integrated structural dynamics:
  - Accurate structural dynamics
  - Accurate load response
  - Accurate numerical integration
  - Accurate extreme and fatigue structural design

- What we have in-house:
  - Know-how on complex sub-systems (SSI, WSI, Structural Analysis, and SAMCEF knowledge)
  - SAMCEF Multibody code → combines the aero-servo-hydro-elastic + FEA capabilities into 1 code.
  - modeFRONTIER → Software manager & optimization platform. Able to couple input-output codes in a single workflow.

Tower and Substructure

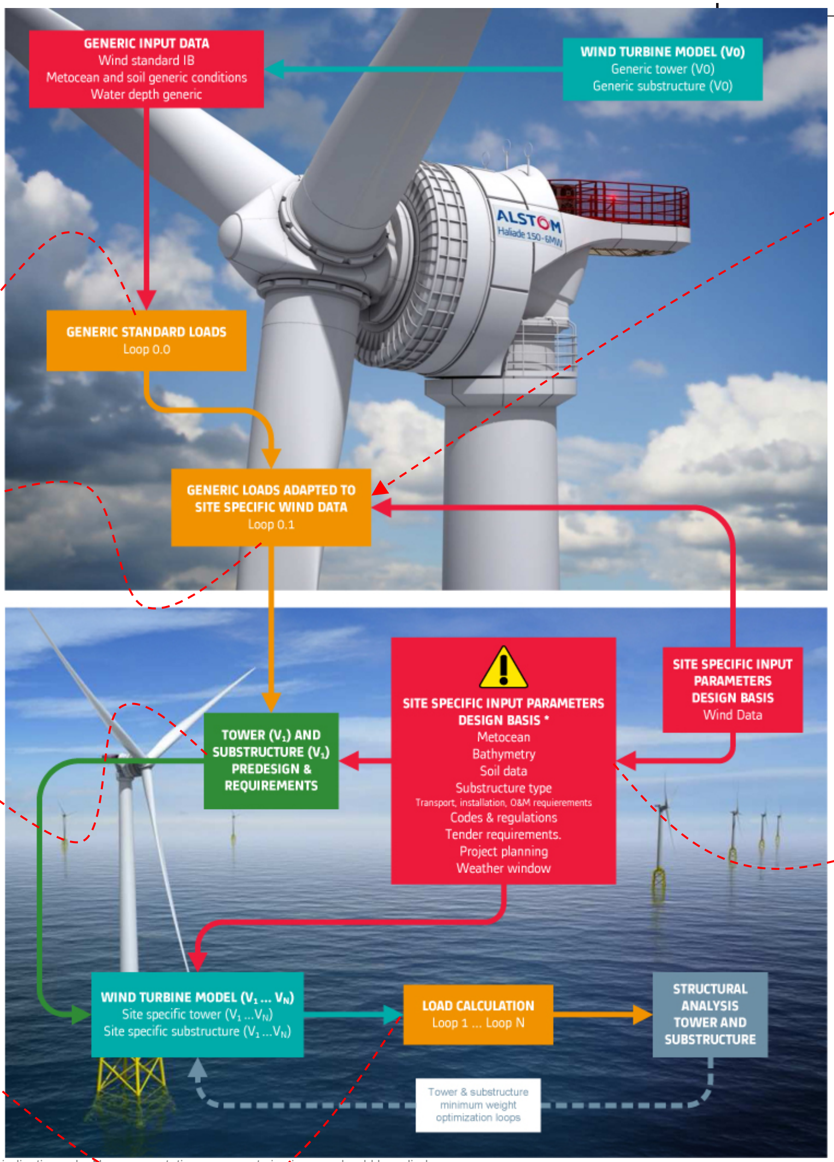
Project integrated load & structural analysis - **Iteration Process**

Loop 0.0
Loads for Generic Wind Conditions & Substructure

Loop 0.1
Generic Substructure & Site Specific Wind Conditions

Substructure
Preliminary Substructure & Tower design (V1)

Load Loops
Substructure and Tower Designs (V2..Vn)



Site Assessment - Wind

Hub Height

Substructure Concept

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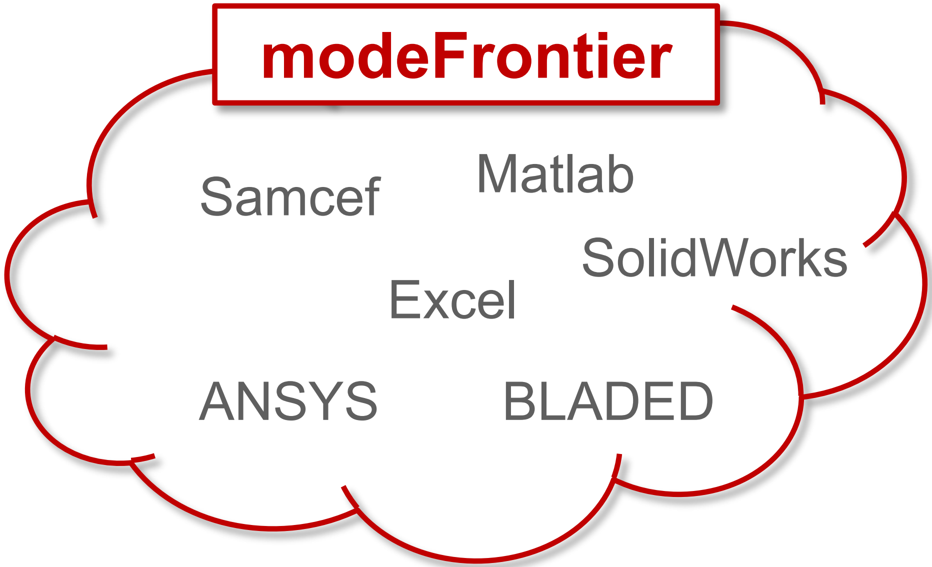
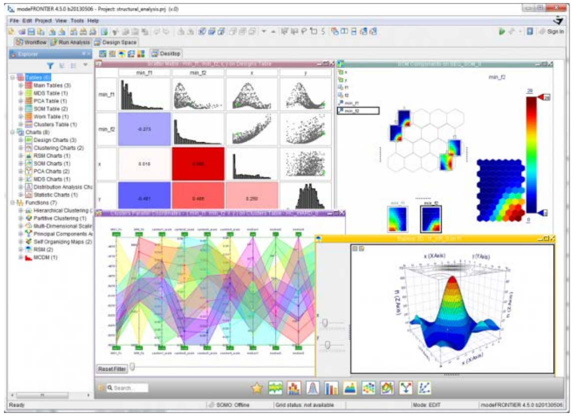
Optimization with modeFrontier



Key Features:
- Allows for integration of various simulation tools
- Design of Experiments
- ~30 types of optimization algorithms
- User interface – GUI driven
- Analysis “wizard”

To optimize 1 tower:
- 17K – 20K cases
- ~ 15.5 hours of runtime
- Runs on a dual core mobile workstation



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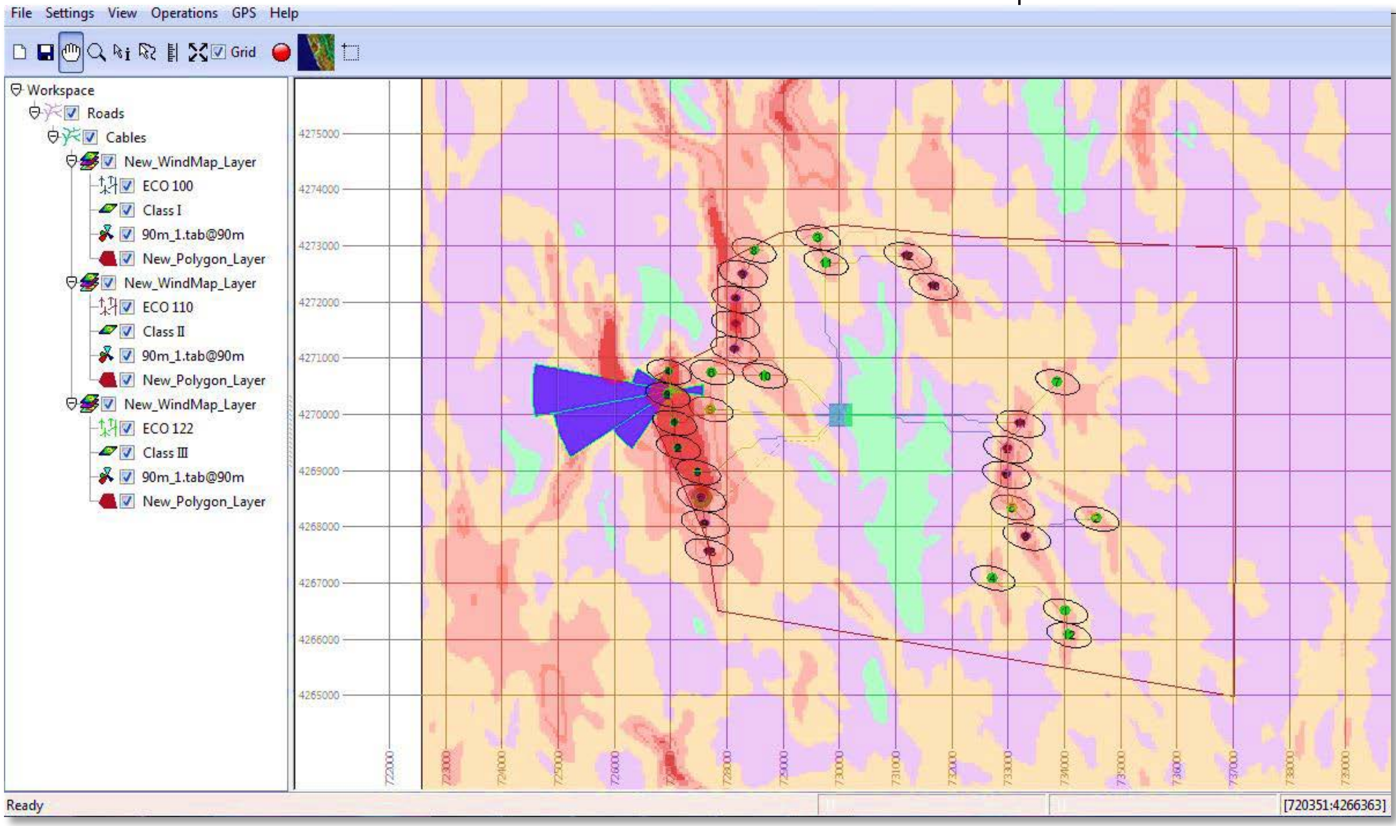
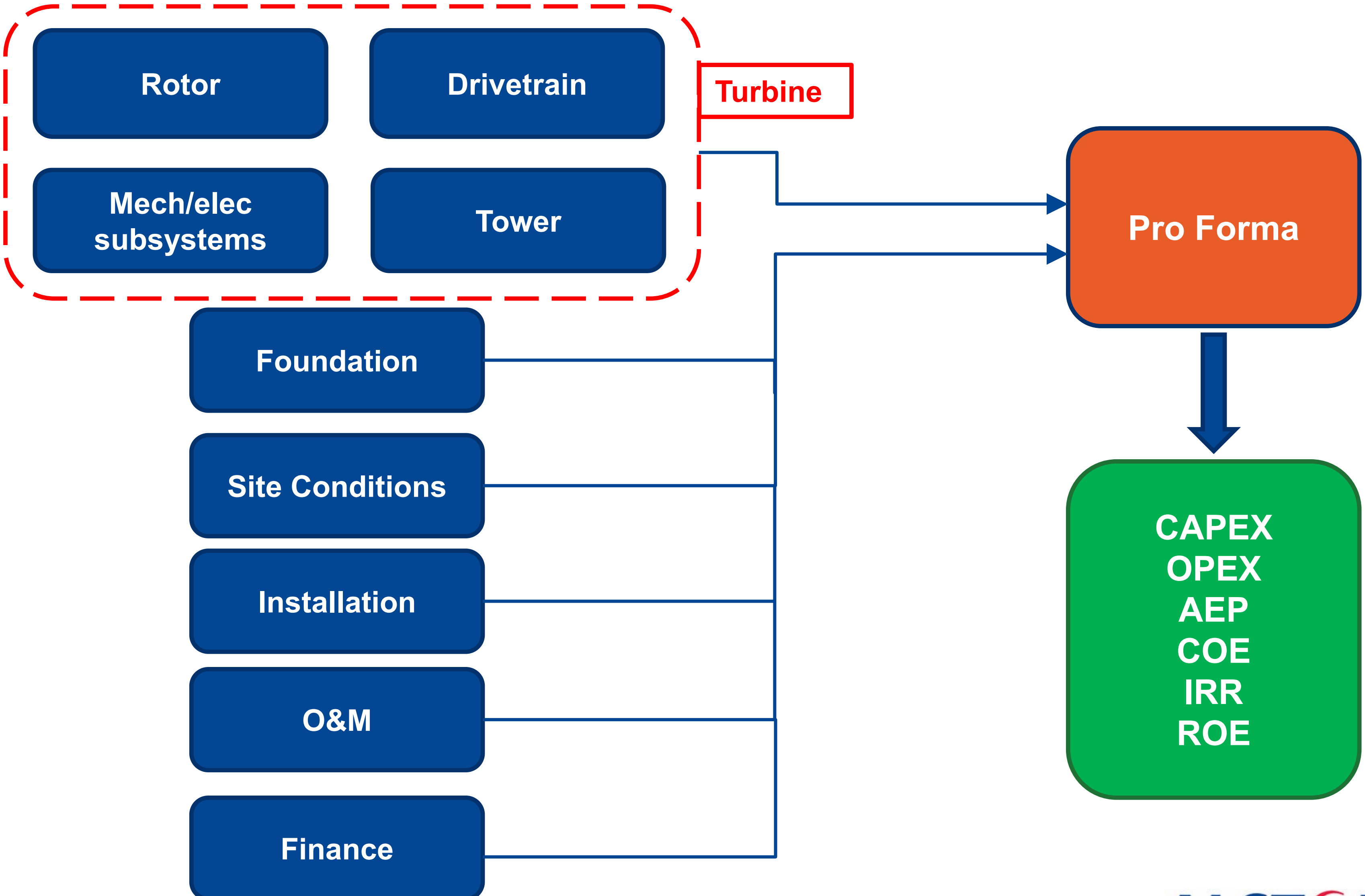
Wind Farm Level

Farm-Level Analysis and Optimization



- Alstom uses **Openwind** for farm layout optimization – turbine location and spacing; model different turbine configurations in a single farm.
- COE: maximize production, minimize installation and BOP costs.
- Used in conjunction with our Pro Forma analysis tool.

Economic Value Analysis – “Pro Forma”



Economic Value Analysis – “Pro Forma”

Results of component / subsystem analysis are inputs into a detailed technical and financial model.

- Inputs owned by specialist in area (WTG subsystems, O&M, finance, etc.)
- Multiple scenario comparison
- Comparison to market

Pros

- Excel-based
- Low licensing cost
- No specialized knowledge required (programming)
- Flexible, varying levels of complexity, analysis toolkits.

Cons

- Limited number of scenarios
- Low level of integration – currently not set up for parametric studies.
- “Manual interface” with other tools

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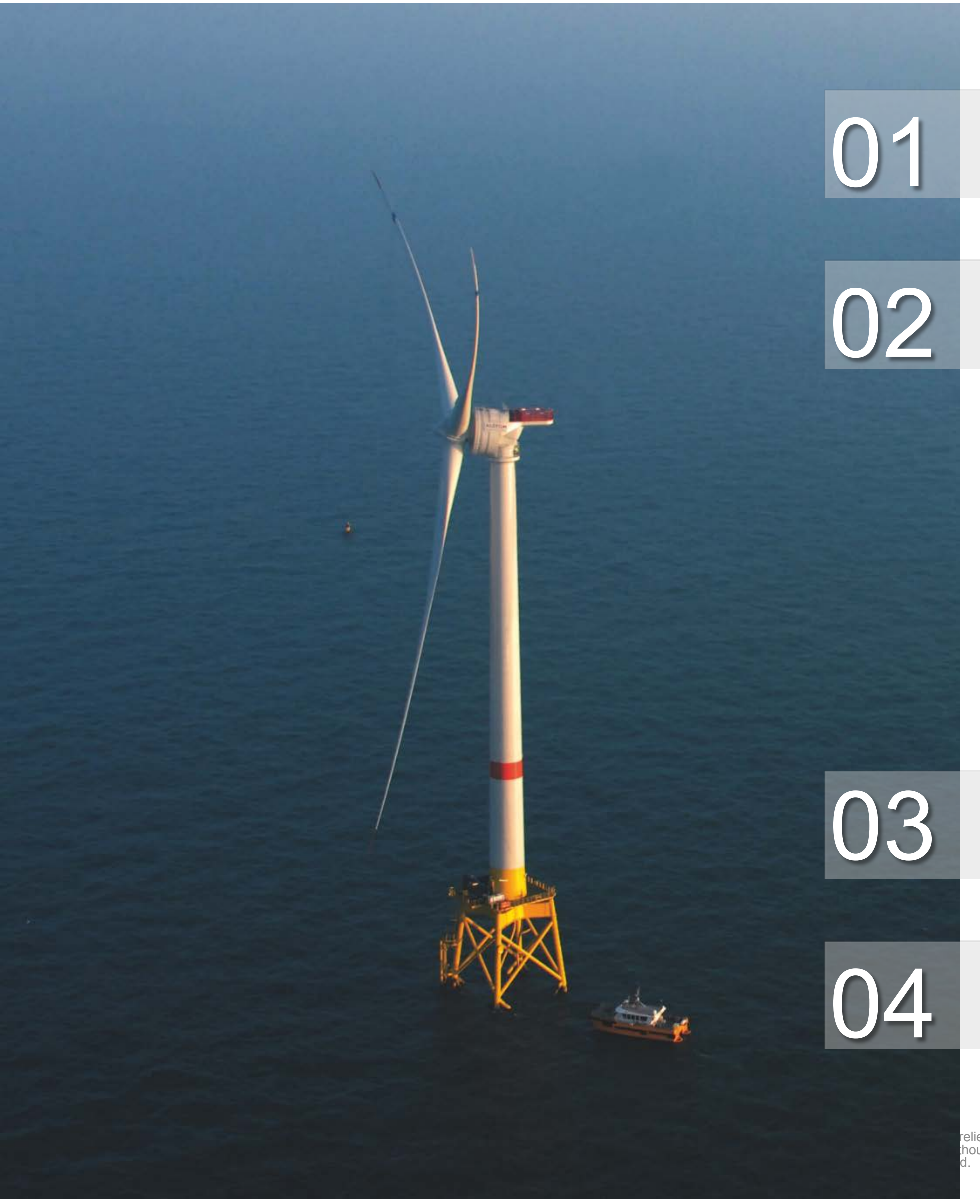

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Future Work – Platform Evolution

Investigating expanded Integrated System Design capabilities

- Revised Pro Forma with integrated transfer functions
  - Expanded conceptual design tool
  - Improved fidelity in COE optimization

- LMS Boss Quattro for LMS SAMCEF optimization
  - Parametric studies
  - Monte Carlo method
  - Optimization and updating
  - Design of experiments methods

- Integrating economic value analysis and additional subsystems into modeFrontier®.

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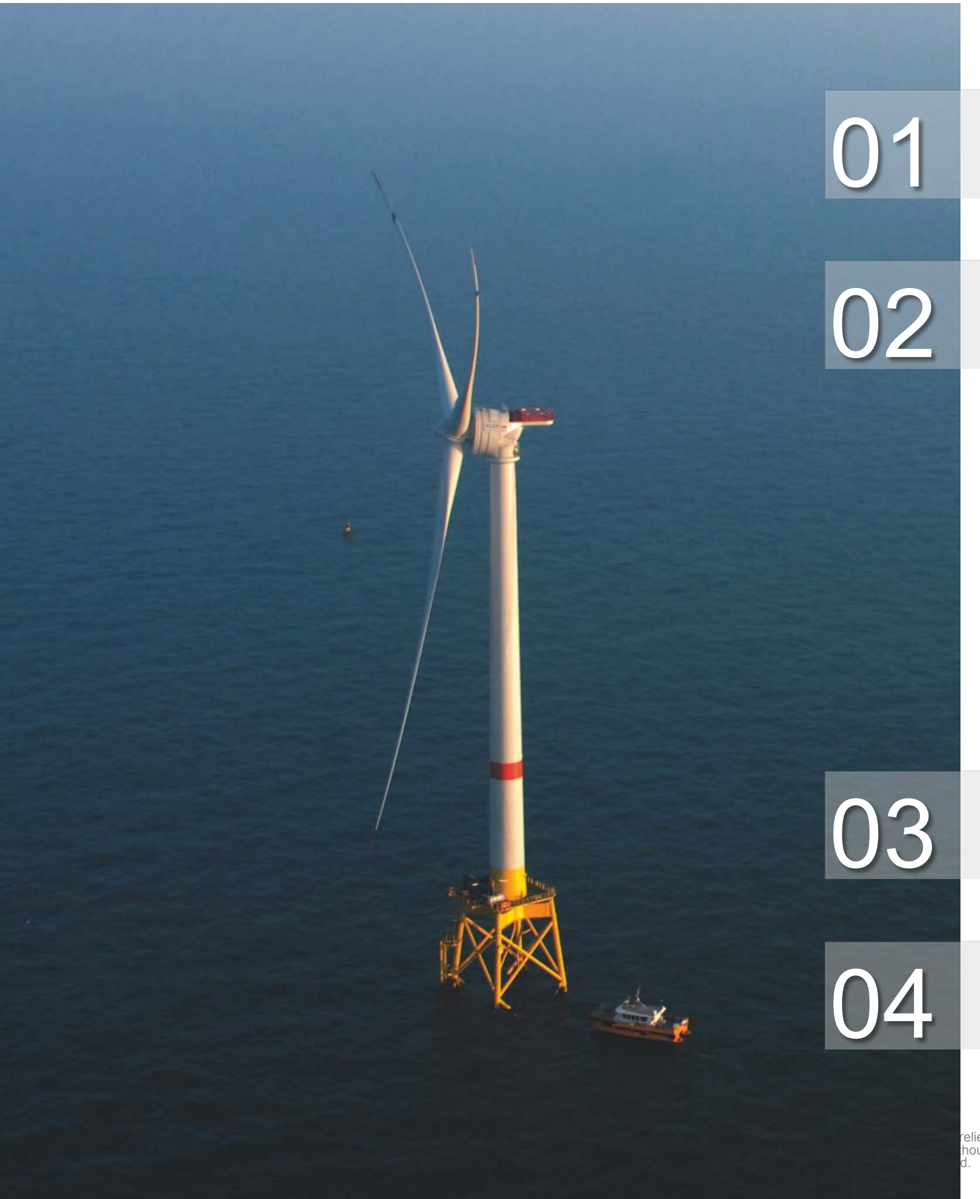

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Management Considerations

Factors for ISD platform selection, design and use

Goals

- Conceptual design
- Marketing strategy
- Product specification
- Detailed design
- Plant optimization

Cost

- Features/capabilities
- Cost of implementing
- Cost of maintaining
- Complexity

Resources

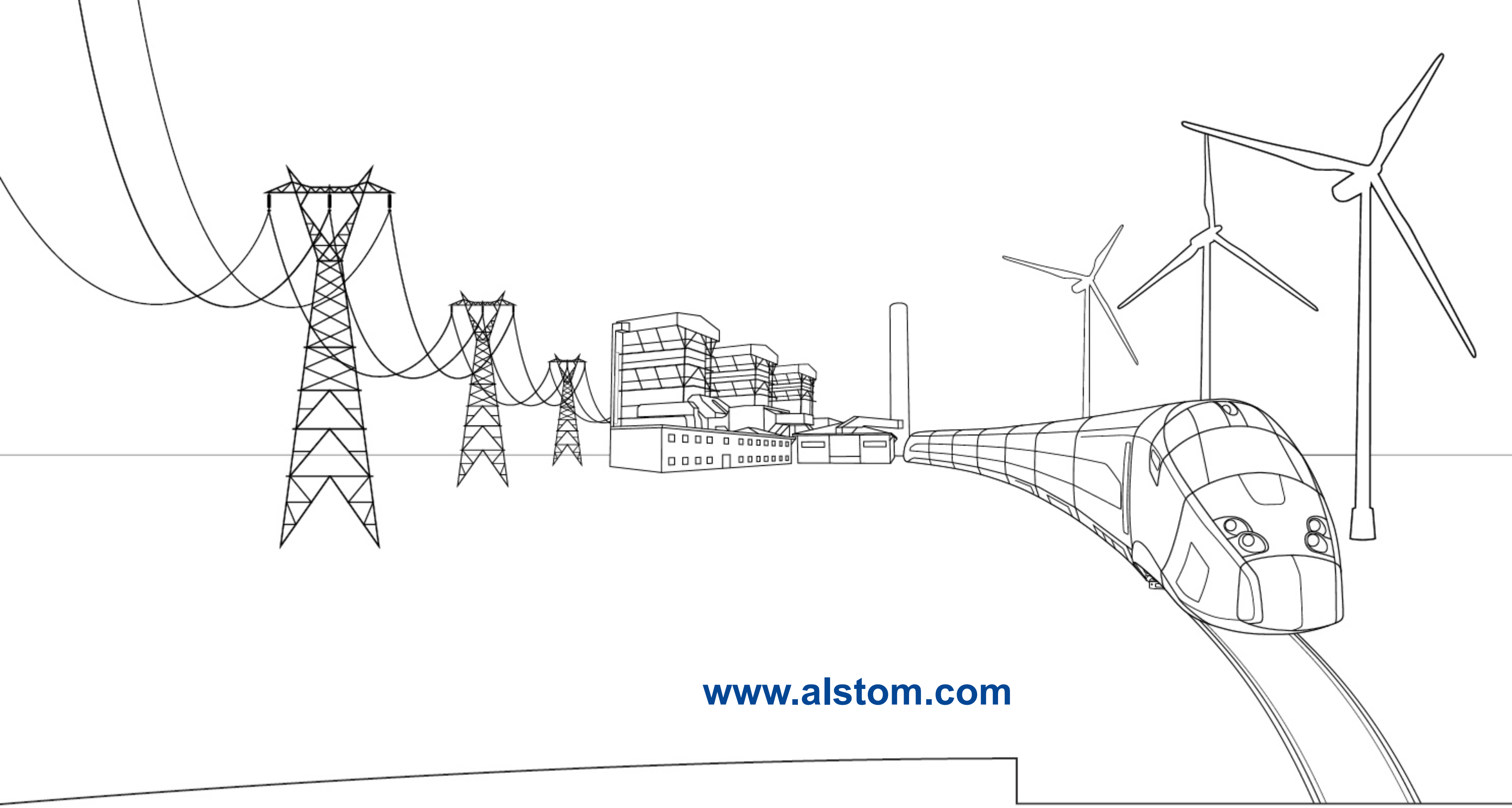
- Size of team
- Skill level of team members
  - User interface
  - Programming needs
- Computing system requirements

Execution

- Ownership/champion
- Communication between user groups
- Internal/external marketing
- Demonstrate value, quantify benefits.

Conclusion

- Integrated systems-level design is needed to compete in the marketplace and deliver optimized wind farm solutions.
- Alstom methodology currently uses a variety of tools at the component, turbine and wind farm levels.
- Tools and methods continue to evolve into a more integrated platform.
- Select the platform/tools appropriate for organizational goals.
- Intuitive user interface will increase accessibility/usage.
- "Sell it" internally and externally, demonstrate the value of new system design capabilities.
- ISD serves as a differentiator and increases an OEM's competitive advantage.



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