Du côté des industriels

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MATHEMATICAL TOOLS IN ENERGY INDUSTRY (MINI SYMPOSIUM AT THE NINTH INT. CONFERENCE CURVES AND SURFACES, ARCACHON, 2018)

In this contribution, we give an overview of the mini symposium (MS) “mathematical tools in energy industry” organized at Arcachon during the 9th International conference Curves and Surfaces (Dassault Systèmes, EDF, IRSN, Siemens Gamesa renewable energy and Total were the participants of this MS). A specific focus on EDF R&D activities is also provided. Let us note that several contributions linked to this MS have been submitted to SMAI Journal of Computational Mathematics in 2019.

Introduction

This contribution is linked to a mini symposium (MS) organized during the 9th international conference Curves and Surfaces (Arcachon, june-july 2018). The MS was oriented toward math modelling and simulations with industrial applications to energy[1].

France has leading international companies in energy domain including Adwen, Areva, EDF, Engie, Total, etc. The links between these companies and academic sector representing mathematics teams like academic laboratories (in universities and school of engineers), organisms (CNRS, INRIA) and national structures like CEA, IFPEN, IRSN, etc. are of course very strong. In this paper, we focus on a general survey of mathematical tools used in the following TSO (Technical Safety Organization) or companies : IRSN, TOTAL, Dassault Systèmes, EDF and Siemens Gamesa renewable energy. Concerning the contributions that were presented during the MS, three different articles have been submitted to SMAI JCM : the first one written by IRSN is devoted to the design of experiments for the approximation of complex system behaviors with applications

1. http://lmi.insa-rouen.fr/88.html

to nuclear challenging problems, in the second one TOTAL R&D addresses recent advances in numerical methods for solving the wave equation in the context of seismic depth imaging and finally in the third one, Siemens-Gamesa renewable energy focuses on exact and efficient computations for Galerkin Boundary Element Methods. We give below a short introduction to each contributor involved in this MS with a special attention to activities in mathematics. A more detailed description of EDF activities is also provided at the end of this paper

INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE (IRSN)

IRSN[2] is the French public service expert in nuclear and radiation risks. Activities include all the related scientic and technical issues :

- Nuclear safety
- Safety of transport of radioactive and fissile materials
- Protection of man and the environment against ionizing radiation
- Protection and control of nuclear materials
- Protection of nuclear facilities and transport of radioactive and fissile materials against malicious acts.

As in all industrial fields, mathematical methods play a key role in the analysis of nuclear problems. IRSN activities in mathematics concern two main interacting topics.

The first one deals with computational and applied mathematics, essentially for the development of softwares dedicated to specific risks : fracture mechanics for the failure of structures, fires, explosion...As far as these latter issues are concerned, IRSN is currently developping a library of components for turbulent reactive flows named CALIF^{3}S (for Components Adaptive Library For Fluid Flows Simulation), for Mach numbers ranging from values close to zero (incompressible or quasi-incompressible flows encountered in fire simulations) to values greater than one (deflagration and detonation). Consequently, significant efforts have been devoted in the last ten years to develop a family of schemes addressing incompressible Navier-Stokes equations as well as compressible Euler equations and based to a common "numerical technology" : staggered finite volumes and fractional step time discretization, with, for hydrodynamics, different variants of pressure correction schemes. In particular, the latest developement yielded staggered schemes on grids or unstructured meshes able to compute shock solutions, with very simple fluxes (not needing the solution of any Riemann problem), unconditionally stable and entropy preserving for the implicit variants, and naturally boiling down to standard projection schemes in the limit of vanishing Mach numbers.

The second topic is data science. It naturally arises in risk studies where phenomena of interest are often known through a set of experimental observations or numerical

2. https://www.irsn.fr/EN

simulations. Dedicated analysis requires the development of various techniques depending on the objective and on the amount of available data. For instance, IRSN activities involving large data sets are often related to image processing where the application of wavelets and other mathematical morphology tools can extract structural features of heterogeneous materials. Large data sets are also encountered in decision-aid problems handled with expert systems based on Bayesian networks. The IRSN contribution is focused on the situation where few data is available due to time or budget constraints. It is the case in uncertainty analysis of complex computer codes where the computational cost reduces the number of simulations. To circumvent this limitation, Design of Experiment (DoE) approach can be exploited to efficiently select the simulations to perform. **J. Baccou (IRSN)** gave a talk on this topic entitled *On the construction of adaptive Design of Experiments for the approximation of complex computer code behaviors*. After an overview on existing approaches for DoE construction, J. Baccou presented two recent developments related to optimization and analysis of data exhibiting heterogeneous behaviors. All these developments were illustrated on several test cases coming from IRSN nuclear studies.

TOTAL

Total[3] and its 98,000 employees around the world live out their commitment to better energy while relying on cutting-edge expertise that spans the entire energy chain. They are not only oil and gas producers, refiners, distributors and petrochemical specialists, they are also the world's second largest solar energy company. This global vision and interdisciplinary expertise allows Total to work towards a responsible energy future in many fields :

Explore and produce : To meet the energy needs of a burgeoning global population while preparing for the future, Total continually innovate to produce sustainable and responsible solutions in oil and gas, solar energy, and bioenergies.

Transform and develop : You already know Total through their network of service stations. Their industrial expertise in transforming oil and gas helps to produce a wide range of everyday items such as cars, packaging and household appliances in :

- Refining petro chemicals
- Polymers
- Hutchinson : Leading affiliate in processing elastomers.

Ship and market : We all require energy for heat, transportation, light in our homes and so much more. Total serves our needs worldwide each and every day. They bring energy from producing regions all the way to consumer hubs, working across a long, complex logistics chain.

Their projects worldwide : From oil exploration to refining operations and investment in renewable energy, Total operates in over 130 countries across all 5 continents. Here are a few of their most noteworthy projects.

Polylactic acid (PLA) :

3. http://www.total.com

- Developing a renewable plastic
- West of Shetland : an innovative underwater facility in the North Sea[4].

As a global energy operator, they have made their commitments to the environment and community engagement an integral part of their strategy. From ensuring people's safety and security to meeting the challenges of climate change and strengthening their integration into local communities, they act in a sustainable and responsible manner every day. This is what being committed to better energy is all about.

Becoming the responsible energy major : Total is committed to finding solutions to the challenge of climate change, while also supporting social and economic development around the world by providing energy that is affordable and sustainable.

Committed to better energy : The world needs better energy to ensure sustainable, responsible growth. Because their ambition is to become the responsible energy major, they are committed to providing safer, cleaner and more affordable energy that creates value.

The **CSTJF** (Centre Scientifique et Technique Jean Feger) in Pau (southwest France) is the nerve center of R&D for Total's Exploration & Production (E&P) branch. This world-class facility is a hub of technological excellence, staffed by some 2,500 employees of some 35 different nationalities. It is home to a large share of the E&P branch's scientific expertise and research facilities. A few kilometers away is the PERL (Platform for Experimental Research at Lacq), one of the focal research centers of our multi-site R&D network. Not only has the PERL earned a global reputation for expertise in acid gas processing, it also excels in the field of physical chemistry. Its achievements include formulating the first polymer used in offshore enhanced recovery applications. On the strength of this expertise, the PERL recently established a joint laboratory devoted to the physical chemistry of complex interfaces with École Supérieure de Physique et de Chimie Industrielles de la Ville de Paris (ESPCI-Paris Tech). Thanks to their worldwide locations, Total can take advantage of leading-edge academic and industrial know-how wherever it may be, either through dedicated R&D centers or through more streamlined entities that maintain close ties with top-flight public or private research bodies. Today stretching from the United States to Russia and from Britain to the Middle East, their network is destined to further extend its reach to other countries, such as Brazil.

H. Calandra (TOTAL) gave a talk entitled *Recent advances in numerical methods for solving the wave equation in the context of seismic depth imaging* where he presented recent advances in using Discontinuous Galerkin Methods for solving wave equation in the context of seismic depth imaging.

4. Access their projects and achievements at https://www.total.com/en/projects

DASSAULT SYSTEMES - The 3DExperience Company

Dassault Systèmes[5] (DS) is the world leader in 3D with its products CATIA, SOLIDWORKS, ENOVIA, DELMIA, SIMULIA, GEOVIA, EXALEAD, 3DVIA, BIOVIA, NETVIBES, 3DEXCITE, with many applications in domains like Aerospace and Defense, Architecture, Engineering and Construction, Consumer Goods and Retail, Consumer Packaged Goods and Retail, Energy, Process and Utilities, Financial and Business, Services, High-Tech, Industrial Equipment, Life Sciences, Marine and Offshore, Natural Resources, Transportation and Mobility.

D. Bonner (DS) presented the different products of the company and many applications. He also showed applications to wind turbine energy. Wind turbines are one of the most important sources of renewable energy in the world. As of the end of 2016, 340000 units were installed worldwide, totaling half a terawatt of generating capacity. A typical medium sized turbine is capable of producing 2 megawatts, with a rotor diameter of 90 meters, and each of its three composite blades weighs 7 tons. Price is critical, as is performance. Blade shape must be optimized so that the turbine produces the most useful power over its entire service life, subject to expected wind conditions in situ ; but also, it must be structurally optimized to survive a complex set of loadings, while using the least resources and time possible in its manufacture. For these reasons, wind turbine aerodynamic and structural analysis has received much attention. The purpose of this talk was twofold : to give an overall view of the state of the art in turbine optimization, and to illustrate the role of curves and surfaces in blade modeling using Dassault Systèmes tools.

EDF R&D

EDF[6] is the world's No. 1 electricity company, particularly well established in Europe, especially France, the United Kingdom, Italy and Belgium. The Group's energy production, marked by the rise in renewable energy, relies on a diversified low-carbon energy mix based on nuclear power. EDF is also a leader in low carbon production. EDF covers all electricity activities : generation, transmission and distribution, Supply and energy services.

An industrial utility like EDF needs to better understand the behavior of energy infrastructures like power plants (nuclear, thermal, renewable,...), electrical networks, but also energy management. The objective is to increase safety, performance, lifetime, and optimize processes. To reach these goals, it is necessary to better understand various phenomena met inside the infrastructures, for example : nuclear components (containment building, PWR vessel, steam generator, fuel rods), networks (electrical grids) or energy management (quality of electricity), in order to win margins. This is done using

5. https://www.3ds.com
6. https://www.edf.fr/en/meta-home

various numerical softwares developed at EDF R&D. The use of intensive simulation allows new approaches and new perspectives. On the other hand, due to the significant increase of data produced by our production systems, our electrical infrastructures and our commercial activities, and the progress of IT solutions, more and more problems can be handled by disruptive approaches, such as Data Science, Data Analytics, Artificial Intelligence, Virtual and Augmented reality. Here again, the use of the new computing powers allows new possibilities previously underutilized, complementary to physical modeling approaches. **A. Caruso (EDF R&D)** gives in the following a general presentation of *Modelling and Simulation Issues at EDF enabling Energy Challenges* corresponding to his talk at the MS.

SIEMENS-GAMESA renewable energy

The new Siemens Gamesa Renewable Energy Group (SGRE)[7] was born in April 2017, with the merger of Gamesa Corporación Tecnológica and Siemens Wind Power.

Gamesa's history is marked by a spirit of innovation and successful expansion into new markets. What started as a small machining workshop in northern Spain quickly grew into a global Company focused on industrial facility management, the automotive industry, and new technology development.

In 1995, Gamesa expanded into wind power, installing the first wind turbine in the hills of El Perdón, in Spain, and just four years later the Company had grown into the leading manufacturer of wind turbines in the country. International expansion quickly followed as the Company opened production centers in the U.S., China, India and Brazil. The history of Siemens Wind Power is equally impressive.

The Company has been directly involved in the wind power industry since 2004, when it acquired the Danish wind turbine manufacturer Bonus Energy. With the acquisition of Bonus, Siemens gained a wealth of technology and proven experience stretching back to 1980. This history includes providing turbines for the world's first offshore wind farm located in Vindeby off the coast of Denmark, in 1991. The Company grew into the global market leader for offshore wind turbines, earning a reputation for technological leadership, strong customer service, and for offering fully integrated end-to-end energy solutions. Siemens Gamesa Renewable Energy brings these many qualities together under one roof : an innovative spirit, dedication to technological excellence, and a determination to provide real and lasting value to all stakeholders and customers.

Today, Siemens Gamesa Renewable Energy is a respected industry leader committed to providing innovative and effective solutions to the energy challenges of tomorrow. Siemens Gamesa Renewable Energy came into being ready to address the challenges and seize the opportunities that the wind business offers in the short, medium and long term, to create value for all stakeholders. In a changing environment with increasingly demanding wind markets, the merger's strategic rationale is even more compelling. Global scale and reach have become essential to compete profitably. Meanwhile, the combined Company's diversification and balance and its leading position in emerging and offshore markets provide resilience and above-average growth potential.

7. https://www.siemensgamesa.com

N. Warncke (Siemens-Gamesa Renewable Energy) gave a talk entitled *Exact and efficient computations for Galerkin Boundary Element Methods (BEM)*, BEM have recently had a renewed interest in the field of wind energy as they allow to model more of the unsteady flow phenomena around wind turbine airfoils than Blade Element Momentum theory. Though being computationally more complex, their costs are still significantly lower than CFD methods, placing them in a sweet-spot for the validation of turbine designs under various conditions (yaw, turbulent wind).

Mini symposium program

Short talks introducing labex AMIES[8], M2NUM project[9] and Pole AVENIA (competitiveness cluster)[10] were given by C. Gout. The complete program of this MS is given below :

Labex amies — Agence pour les mathématiques en interaction avec l'entreprise et la société

Competitiveness cluster : AVENIA — POLE AVENIA Geosciences Innovation Valley

Jean Baccou *On the construction of adaptive design of experiments for the approximation of complex computer code behaviors*	IRSN — Institut de Radioprotection et de Sûreté Nucléaire
Henri Calandra *Recent advances in numerical methods for solving the wave equation in the context of seismic depth imaging*	TOTAL
David Bonner *Wind Turbine Optimization*	Dassault Systèmes — The 3DEXPERIENCE Company
Ange Caruso *Modeling and simulation issues at EDF enabling energy challenges*	EDF
Norbert Warncke *Exact and efficient computations for Galerkin Boundary Element Methods*	SIEMENS Gamesa RENEWABLE ENERGY

RÉGION NORMANDIE

8. https://www.agence-maths-entreprises.fr/a/
9. lmi2.insa-rouen.fr/~m2num/
10. http://www.pole-avenia.com/

Modelling and Simulation Issues at EDF enabling Energy Challenges

EDF Group presentation

EDF is the world's No. 1 electricity company, particularly well established in Europe, especially France, the United Kingdom, Italy and Belgium, the Groups energy production, marked by the rise in renewable energy, relies on a diversified low-carbon energy mix based on nuclear power. It is also a leader in low carbon production :

- No. 1 producer of nuclear electricity in the world
- No. 1 producer of renewables in Europe
- No. 3 European operator of energy services.

EDF covers all electricity activities : generation, transmission and distribution, Supply and energy services.

EDF R&D focus

The mission of EDF R&D is to prepare for the energy scenarios of the future by working on disruptive technologies, following two ways :

- Improve the EDF Group's performance in all of its current ventures and enable customers to benefit
- Carry out research for external commissioning bodies within the framework of partnerships or orders.

Four main strategic priorities drive the activity, in line with the EDF Group's CAP 2030 project :

- Develop and test new energy services for customers
- Prepare the electrical systems and networks of the future
- Consolidate and develop competitive zero-carbon production mixes
- Support the Group's international growth by developing research partnerships.

With four main disruptive projects :

- Local systems and energy services
- Digital technologies supporting relations with clients and for our industry
- Storage, photovoltaic and electric mobility item Small modular reactor.

And three main areas of research :

- The electricity transition
- The climate transition
- The digital and societal transition.

Anyway, an industrial utility like EDF needs to better understand the behaviour of energy infrastructures like power plants (nuclear, thermal, renewable...), electrical networks, but also energy management. The objective is to increase safety, performance, lifetime, and optimize processes. To reach these goals, it is necessary to better understand various phenomena met inside the infrastructures, for example : nuclear components (containment building, PWR vessel, steam generator, fuel rods), networks (electrical grids) or energy management (quality of electricity), in order to win margins. This is done using various numerical softwares developed at EDF R&D. The use of intensive simulation allows new approaches and new perspectives. On the other hand, due to the significant increase of data produced by our production systems, our electrical infrastructures and our commercial activities, and the progress of IT solutions, more and more problems can be handled by disruptive approaches, such as Data Science, Data Analytics, Artificial Intelligence, Virtual and Augmented Reality. Here again, the use of the new computing powers allows new possibilities previously underutilized, complementary to physical modelling approaches.

Some contextual elements

Many power plants (nuclear power plants, hydraulic power plants, ...) have to be operated over 40 to 100 years in order to guarantee safety, minimize the environmental footprint, to maintain assets in a good state of exploitation. At the same time, the operating conditions are changing very fast (more competitive markets, tougher regulations, ageing, environment) and new business models, services and capabilities appear (smart meters, cloud computing, data science, artificial intelligence, blockchain...). Energy transition has also a real impact on the way to manage power plants, electrical networks and business : diversified energy mix (nuclear, renewables), products and services, energy-saving solutions, help customers to manage their consumption, dual digital and energy transition for both society and the economy. One way to study problems generated by these challenges is the use of High Performance Computing, which is a great help to understand complex phenomena.

The use of HPC at EDF R&D

The three reasons of HPC at EDF

For an industrial like EDF, High Performance Computing (HPC) enables 3 kinds of studies :

- **To simulate and then to understand**. The goal is to have a better understanding of system's complexity in order to comply to new regulations and to find optimization opportunities
- **To simulate and then to decide**. The goal is to obtain more predictive, more reliable & more trusted simulations of complex real systems in order to find new margins, to help for decision making & business value)

- **To simulate and then to innovate**. The goal is to get more and more refined information in order to open up new areas, new products and services, to improve methods and methodologies (studies), to improve our in-house tools (most of them are Open-Source) : numerical methods, algorithms, models.

Main domains of HPC Applications

To make short, **every fields of activity is concerned**! The most important one is the domain of **Energy Production** :

- Nuclear (for examples : Lifespan of power plants, Safety studies, Fuel management),
- Hydraulic (for examples : Behaviour of engineering structures, Optimisation of operations, Sediment transport)
- Thermal (for examples : Environmental performance, Modelisation of combustion)
- Renewables (for examples : Wind power potential (Inshore, Offshore), Photovoltaic process)
- Environment (for examples : Quality of water, Quality of air, Natural risks management).

The other fields of uses concern **Network** (Smart Grids : Impact of distributed and intermittent power generation on our network, Smart-Cities : Optimization of power resources, water, waste, ...), **Marketing** (Knowledge of the load curve, Customer behaviour simulation, Analysis of customer data), **Energy Management** (Generation / consumption balance, Weekly forecast, European Electrical System for 2020, 2030, Weather and climate forecast adjustments).

Main in-house codes developed at EDF R&D

In order to master the quality of its studies, the strategy of EDF is to develop its own codes, mainly to modelize physical phenomena met in its assets. Main of these codes are open source. One can list some of the codes used for the studies devoted to energy production (not exhaustive list) :

- Code_Saturne and NEPTUNE_CFD (single and multiphase CFD codes)
- SYRTHES (thermal diffusion in solid and radiative transfer)
- Code_Aster (general usage structure mechanics)
- TELEMAC system (free surface flows)
- Open TURNS (tool for uncertainty treatment and reliability analysis)
- SALOME Platform (integration platform : CAD, meshing, post-processing, code coupling)
- ... and many others (neutronics, electromagnetism, component codes, system codes, optimization codes,...)

But what do we do exactly with HPC? The answer is : Intensive Numerical Simulations! Because an experimental mock up is not always easy/feasible (due to technical problems, metrology difficulties, scale effect, high cost); another reason is that we cannot measure everything we want/need. However, one important thing to say is that we absolutely need to validate and qualify our codes in order to trust them (physical models, numerical algorithms, methodologies of study). One way to do is comparing numerical simulations with experimental data to define the domain of trust of the codes. But we have to keep in mind : numerical simulation and experimental simulation are today always complementary!

Today, we consider that EDF R&D has a maturity model for HPC usages. EDF R&D road map is based on three different forecasts of usage of HPC :

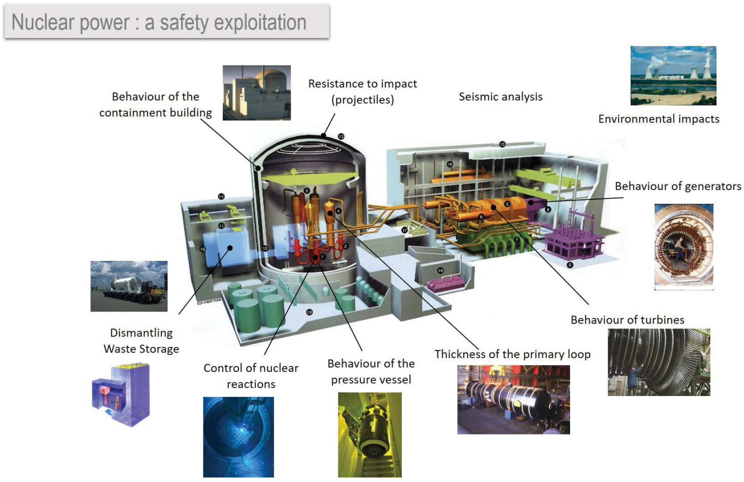
- **Planned usages : Simulation for daily studies**. Projects have already secured the use of HPC. **HPC is required as a necessary step** of the project (Ex : Safety studies, process qualification of non-destructive control, CFD : 50 Million cells calculation for a mixing grid of a fuel assembly)
- **Opportunities : Simulation to prepare for tomorrow**. HPC is part of the experimental framework of the project, **and HPC is contributing to short term or middle terms benefits** (Ex : Microscopic scale simulation of materials, CFD : 1 Billion cells calculation for a whole fuel assembly)
- **Challenges : Simulation to explore new frontiers. HPC is part of a scientific research** and should contribute to make major breakthroughs (Ex : CFD- 100 Billion cells calculation of a PWR reactor).

Exemples of HPC applications

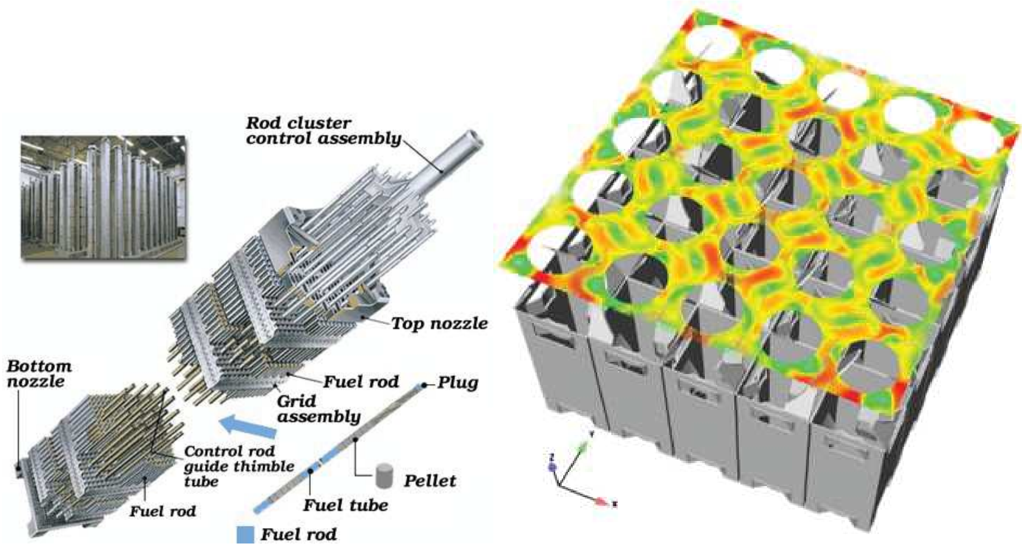
Nuclear

Every component of a nuclear power plant is concerned by numerical studies. The objectives are to understand the phenomenum met inside these components in order to increase safety (the most important one), performance, lifetime and to optimize processes.

This example illustrate the complexity of the different phenomena met inside this component : CFD, Thermal, Neutronics, Mechanics. All these phenomena are coupled. Geometry is very complex : 157 to 241 fuel assemblies in a PWR (Pressurized Water Reactor). Each fuel assembly has 17×17 fuel rods or guide tubes and 8 to 10 grids (complex, non-symmetrical geometry, different vendors and models), many constraints / stakes (if head loss/lift too high, stronger springs needed to keep FA down, leading to possible bowing and deformation), good heat exchange : need mixing grids to generate turbulence, avoid DNB (de-nucleate boiling), low vibration : loss of cladding integrity may result from vibration induced fretting.

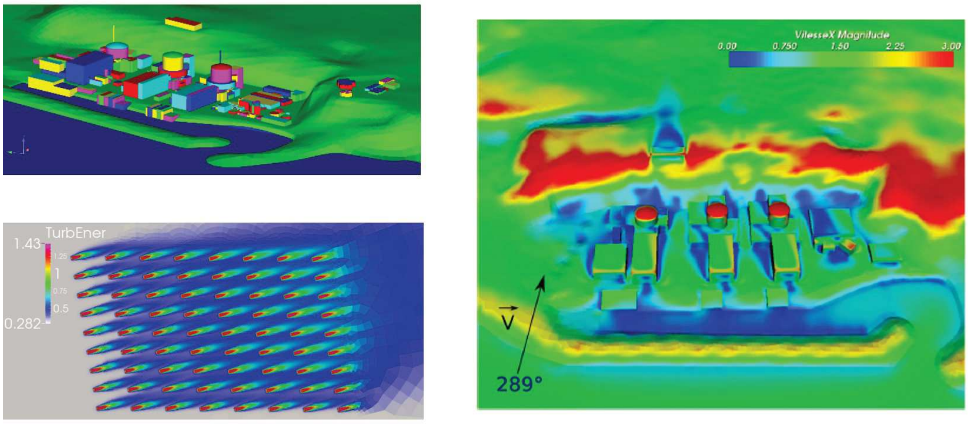


Modelling of Fuel Assemblies



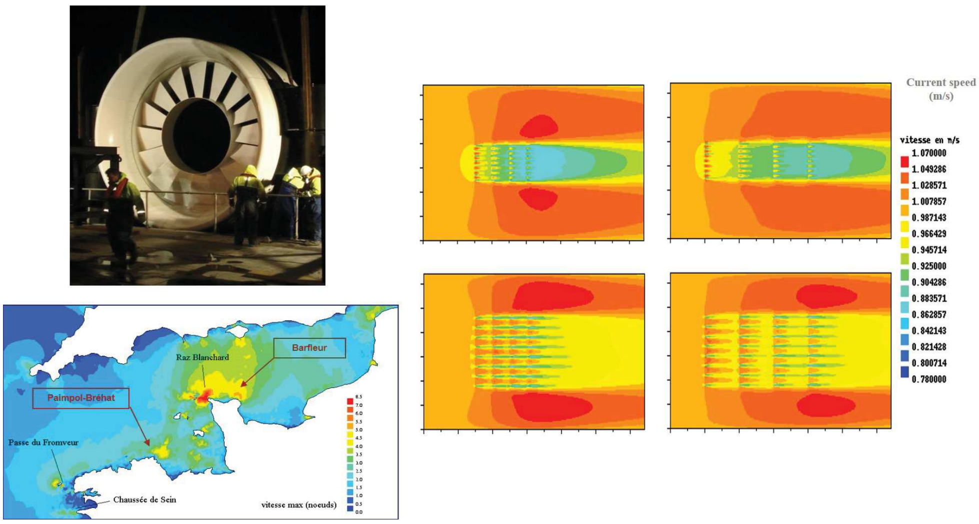
Environment

The objective of this study is to simulate the atmospheric environment at the local and micro-scale (a few tens of meters to 20 km), taking into account for terrain, building (environmental impact of industrial sources, of road traffic...). We look for all pollutant types : radionuclides, chemical or biological pollutants, heavy gases), the environmental impact on energy production with renewables (estimation of wind production, wake effects, model energy exchanges and pollution in urban areas), environment impact on plants (wind and turbulence on buildings, HT lines), impact of external aggressions (rupture of gas tank near a power plant).



Hydraulic

The objective of this study is to optimize the placement of offshore marine current turbines for an improved power production : evaluate the currents, determine the space between turbines.

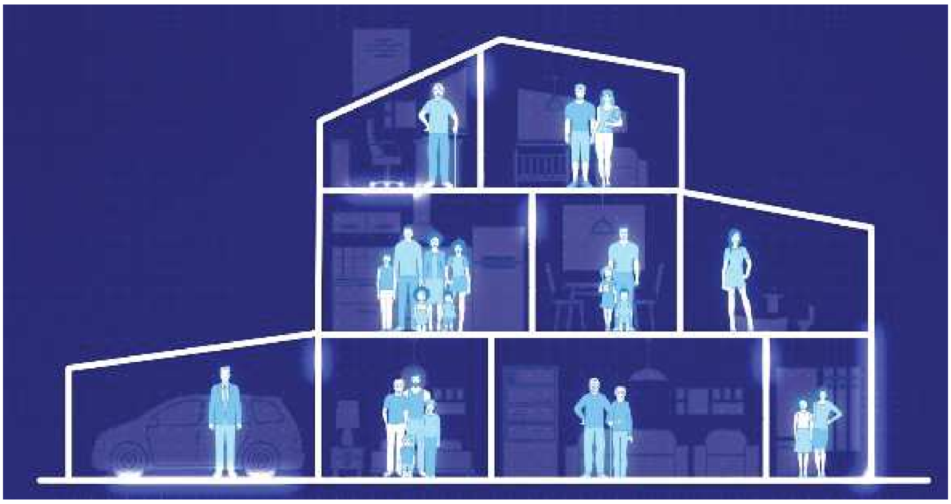


Simulation of the human activity

The objective of this study is to simulate the behavior of human beings related to their use of energy (mainly electricity), in order to best evaluate auto-consumption, inclusion of electric vehicles regarding to electrical networks, define new rate offers...This is done using a multi system agent modelling with code SMACH, using the composition of the family, the nature of the household and its electrical equipment, the geographical location.

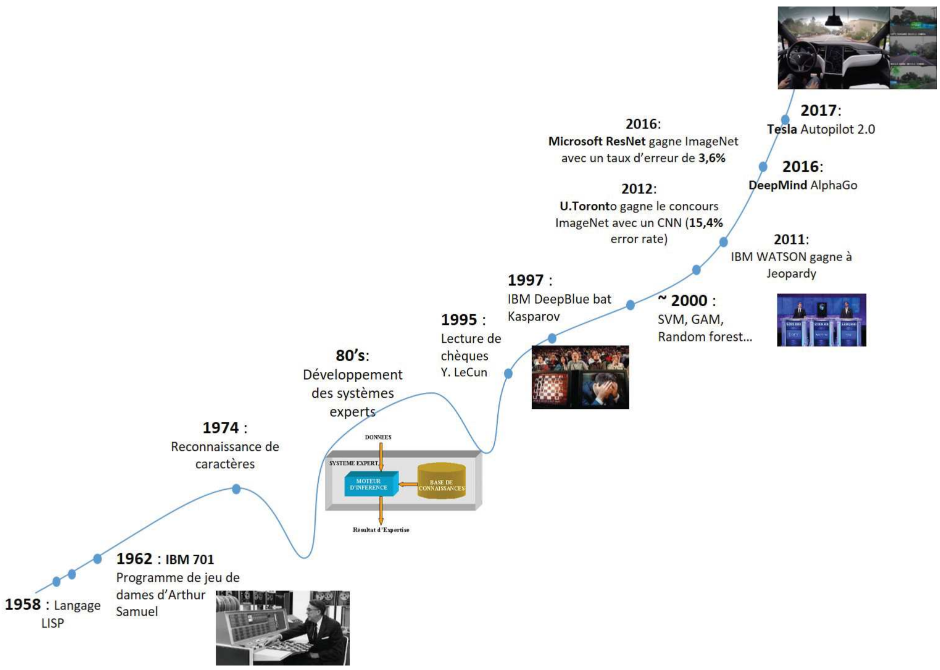
SMACH is used to describe family profiles in order to evaluate their electricity consumption (individual or collective actions of daily life). The tool then produces load curves and activity diagrams that can be used free from any regulatory constraints.

Examples of applications : simulate the overall energy performance of à building, assess the effects of public energy policies on consumption, simulate the impact of external events on power consumption.

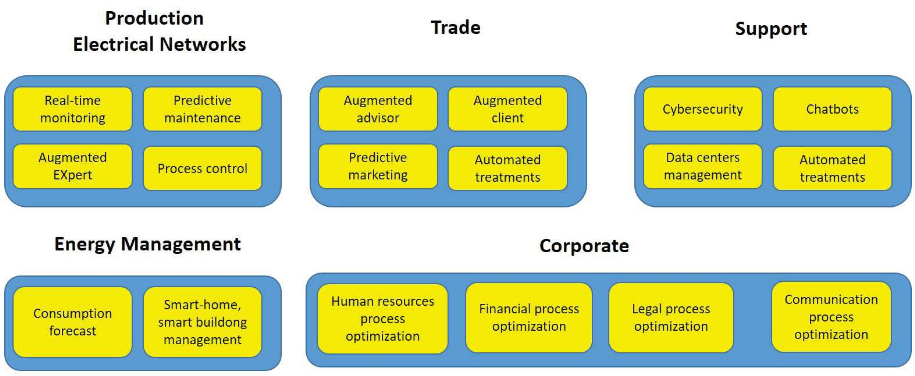


Artificial Intelligence VS Simulation

A new boom of artificial intelligence has appeared some years ago, mainly due to the increasing capabilities of supercomputers.



Viewed from EDF, artificial Intelligence is a complementary tool to simulation, used for all areas of activity at EDF, as shown in the following figure :



Some future challenges

Many challenges of interest for EDF are still ahead of us. One can list some of them :

- Simulation of multi-scales and/or multi-physics phenomena (Ex : how to simulate of a whole energy system (power plant, networks, buildings) ?)
- Probabilistic simulations : the use of uncertainties / calibration / assimilation method (Ex : evaluate the impact of intermittency on the electrical network). These methodologies can lead to a factor 10 to 1000 of needed computing resources
- Pre-processing of input data and post-processing of simulation results (Ex : what efficient tools to mesh complex geometries and vizualize a deluge of results (including uncertainties) in a simple way ?)
- Connection between HPC and ROM (Reduction Of Model) / Modelization of complex and heterogeneous systems
- Connection between HPC and Data Science / Data Analytics / Artificial Intelligence (Ex : Real time calculation and analysis, Analysis of significant data, Validation and qualification of codes, Improvement of Security / Cybersecurity)
- (For much later) Impact of quantum computers (Ex : How to re-write existing codes ?)

Conclusion

All the fields of activity of EDF are today concerned with intensive simulation, data analysis and artificial intelligence. The combination of these approaches helps to better understand how its systems work. New opportunities are now available; they allow to increase safety, performance, lifetime, and optimize processes. To summarise, we are absolutely convinced that Energy needs Modelization, Simulation, and now Artificial Intelligence.

Acknowledgements

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11. http://www.pole-avenia.com/
12. https://www.agence-maths-entreprises.fr/a/