WELCOME

www.ozeninc.com
WHAT DO WE DO? WE SOLVE PROBLEMS

• Ozen Engineering, Inc. helps solving challenging and **multidisciplinary engineering problems** with industry leading computational simulation technologies

• We provide advanced **multi-physics FEA, Computational Fluid Dynamics analysis**

• We specialize in **Mechanical Structures, Design Optimization, Failure Analysis, Testing** and **R&D**

We are passionate about developing accurate simulation and realistic modeling as core competencies within client companies and helping them realize unparalleled results from their FEA and CFD investments.
AN EXAMPLE OF MULTI-DISCIPLINARY APPROACH

Meshing

Tet/Prism
Hex/Hex Core
Structured
Unstructured
Multi-zone
Body-fitted Cartesian
Patch Independent
More...

Structural
Large Displacements
Finite Strain
Contact
Multibody Dynamics
Random Vibration
Implicit & Explicit
More...

Fluids
Compressible
Incompressible
Laminar Flow
Turbulence
Multiphase Flow
Non-Newtonian Fluids
More...

Thermal
Conduction
Convection
Radiation
Phase Change
Mass Transport
More...

Electromagnetics
Quasi static (Low Freq)
Full Wave
Joule Heating
Eddy currents
Current flow
Circuit Coupling
More...

Steady-State, Transient, Harmonic & Modal
Linear & Nonlinear

Technical Depth

OZEN ENGINEERING
INDUSTRY SPECIFIC EXPERTISE - SEMICONDUCTOR

Example of analysis we can perform:

- Multi-physics simulations of Semiconductor chambers
- BGA Solder Joint Reliability Optimization
- Thermal-Stress
- Seismic vibration of chamber design
- MEMS
- High and Low Frequency Electromagnetics
Example of analysis we can perform:

- Multi-physics simulations of solar panel and support
- Electrical, thermal, mechanical and structural analysis
- Solar panel design optimization
- Modal analysis
- Virtual Prototyping

Example of case studies:

- Maximize the solar flux through a surface
- Structural optimization of the pole mount supports of a solar panel in a wind load case study
- Hail Impact on a solar panel
INDUSTRY SPECIFIC EXPERTISE – DOE AND DESIGN OF EXPERIMENT

Capabilities:

- Designs Exploration
- Mono and Multi-Objective Design Optimization (MDO)
- Process Integration
- Sensitivity Analysis
- Robust Design
- Decision Making Criteria and Tools

Efficiency maximization of a hydraulic pump

Pressure plots

Initial Design  Intermediate Design  Optimal Design

Efficiency Improvement of 43% from the Initial design
Example of analysis we can perform:

- BGA Solder Joint Reliability
- Theta Jc Thermal Characterization
- Thermal-Stress
- Fracture Mechanics & Fatigue
- Board & System Level CHT
Example of analysis we can perform:

- Drop test
- Impact analysis
- Failure testing
- Reliability Simulation

Example of case studies:
- Drop test for cell phone
- ...
INDUSTRY SPECIFIC EXPERTISE – BIOMEDICAL INDUSTRY

Capabilities:

• Simulating how the human body performs when interacting with the environment

• Model the body, but also the objects it interfaces with

• Optimization of movement patterns

• Analysis of working movements and postures, scale results to population or subject anthropometric data

• Virtually assessing the exertion requirements of a new product or process

• Implant virtual prototyping

• Perform computational assessments and quantitatively investigate ergonomic consequences related to changes in design parameters.
INDUSTRY SPECIFIC EXPERTISE – ACOUSTICS

Capabilities:

• Acoustics simulation for development of robust product
• Optimization of acoustic pressure distribution for maximizing product performance
• High frequency analysis of large scale acoustic models (400,000 + DOFs)
• Coupled structural-acoustic modeling for flexible resonant structures
• Prediction of acoustic pressure fields from machinery to musical instruments
SIMULATIONS FOR SOLAR POWER TECHNOLOGIES

PV Solar Radiation (Flat Plate, Facing South, Latitude Tilt) Annual

Model estimate of monthly average global horizontal irradiation, using inputs derived from satellite and/or surface observation of cloud cover, solar zenith angle, terrestrial radiation, aerosol optical depth, and geocentric pressure and geolocation data. See https://www1.eere.energy.gov/solar/policy_documentation for more details.
ROLE OF SIMULATION IN SOLAR TECHNOLOGIES

**Solar Materials**
- Metallurgical grade to solar grade silicon purification is mainly achieved through gas phase precipitation processes
  - Fluidized Bed Reactors (FBR), Chemical Vapor Deposition (CVD), Physical Vapor Deposition (PVD)
  - complex, nonlinear physics and chemistry
    - Multiple reaction pathways
    - Consistency, uniformity, scalability for CVD and allied processes
- Productization
  - Structural performance, formability, shaping
  - Specular performance, interface details for efficiency issues

**Solar System Design**
- Manufacturing costs
  - Traditional silicon
  - Thin film
  - Nanostructures
- Safety assurance
  - Seismic safety
  - Reliability in high wind conditions
- Performance

**System Support Structures**
- Basic integrity of structural supports for large solar panels
  - Seismic stability
  - Wind loading
  - Fatigue
SOLAR PV SIMULATIONS

- **Wafer/film level**
  - Manufacturing processes, breakthrough improvements in cell technologies
    - Si-based: CVD innovations, SG-Si-production, grain-structure control,
    - CIGs, Cd-Te and A-Si based: cell design, thin film technologies

- **Cell level**
  - Electrical designs
    - Circuit optimization, efficiency improvements
  - Optical designs
    - Coating, texture, reflection and refraction management
  - Thermal designs
    - Enclosure, connector and support organization, support insulations
  - Structural designs
    - Thermal stress, fatigue, cracks

- **Panel level**
  - Construction, installation, life and maintenance
  - Simulation is matured and similarities with other metal fabrication
SOLAR SILICON MANUFACTURING
EQUIPMENT & PROCESS MODELING

- Multi-disciplinary effort
- Gas/mixture flow
- Conjugate heat transfer and radiation
- Complex chemistry
  - Stiff gas phase and surface reactions
- Electrostatics and electromagnetics
- Fluid-structure interactions
- Free surface and multi-phase flows
- Engineering equipment design

Need to simulate interactions between various physico-chemical processes
SIMULATION OF CONCENTRATED SOLAR POWER SYSTEMS

- Cooling for concentrating photovoltaic modules
- Heat transfer in novel heat exchangers and hybrid heat pipe designs
- Temperature profiles in thermal energy storage tanks – thermal stratification essential
- Wind loads on concentrator structures

Computed airflow over a multi-faceted heliostat structure
Source: NREL
The wind loading on the solar panel can cause significant stress on the structure.

Thermal cycling also would lead to material fatigue.

- 90 MPH stream lines
- 90 MPH pressure distribution
- Structural Deformation Due to wind loading
- Stress due to wind loading
- Pre-stressed Natural frequencies and mode shapes
- Random Vibrations Analysis
For cases where silicon is involved, crystal growth simulations can be performed to analyze different techniques used.

Simulation of Czochralski crystal growth

- Computational fluid dynamics enables a detailed view of the process and the impact of varying input parameters
For thin film depositions, CFD coupled with chemistry can be used to analyze and optimize the chamber designs as well as deposition.
SOLAR SIMULATIONS

- For solar panel farms where they may be subjected to high winds, coupled Fluid-Structure Interaction (FSI) simulations are required to design the support structure for these large panels.
The PV panels have copper wires that connect to each other by solder joints. As the panels expand and contract, the solder joint reliability becomes an issue. Simulations are required to characterize and identify the causes of failure, predict different solder joint material performance, and optimize (maximize) the fatigue lives of these solder joints.
The solar cell consists of many different layers as well as different materials. When these materials expand and contract due to heating during the day and cooling during the night, the difference in coefficient of thermal expansion create high stresses at the interfaces where these different materials meet. Minimization of the stresses require temperature cycling simulations to understand the failure modes and then to correct for the failure by making design changes (optimizing) the way these components interact with each other.
SOLAR SIMULATIONS

- Joule heating due to the generated electric current can also be simulated in these solar cells. This type of simulation can be performed in conjunction with the thermal cycling simulations to determine the thermal loads.
Hail impact simulations can be performed to determine if the panels will fracture. These types of simulations are classified under “explicit” simulations since the dynamic loads take place under extremely short transient time.

In addition, a random vibration load simulation can be performed for these solar panel assemblies to predict the stresses created during the transportation of these panels.
All the simulations that are discussed above can be performed to address the following business issues:

- Decrease time to market
- Accelerate testing and certification
- Optimize performance (electrical, heat, reliability, etc.)
- Increase reliability and quality
- Decrease prototyping as well as manufacturing costs
- Manage financial risk
SOLAR SIMULATIONS

Simulations today can be performed to address the business issues as well as the technical (engineering) issues such as:

• Production and manufacturability of solar panels
• System design issues
• Design of system support structures
• Solar cell electrical designs for circuit optimization
• Solar cell thermal designs
• Solar cell structural designs for thermal stress, fatigue/reliability, cracks
• Solar panel system design for construction, transportation, installation, fatigue life, and maintenance.
DEMO CASE #1

- In order to simulate the robustness and the thermal behaviour of a solar panel, a parametric model has been generated.
DEMO CASE #1

- UL/IEC test requirements: Steel ball impact (51 inch, 1.18lb)
DEMO CASE #1

- UL/IEC test requirements: Steel ball impact (51 inch, 1.18lb)

```
/PREP7 ETCHG,ITE

/MASS_SCALING
/EDCTS,-5E-6,0.9 ! (-1E-6 ORIGINAL)

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/EDST,50
/EDHTIME,50

/HISTORY FILE
/EDHIST,DELE
/EDHIST,KEY_NODES

!EXTRA OUTPUT FILES
EDOUT,GLSTAT !GLOBAL DATA
EDOUT,BNDOUT !BOUNDARY CONDITIONS AND ENERGY
EDOUT,NCFORC !NODAL INTERFACE FORCES
EDOUT,RCFORC !RESULTANT INTERFACE FORCE DATA
EDOUT,NODOUT !NODAL DATA

! SIMULATION TIME
SIMULATION_END_TIME=1.0 ! 0.5
TIME,SIGNALATION_END_TIME
FINISH
```
DEMO CASE #1

- UL/IEC test requirements: Steel ball impact (51 inch, 1.18lb)
DEMO CASE #1

- UL/IEC test requirements: 400 pound weight loading (Static and Transient Dynamic)
- Modal analysis is request to better investigate the dynamic behaviour

\[ T = \frac{1}{f} \]

\[ 0.015 = \frac{1}{70} \]
DEMO CASE #1

- UL/IEC test requirements: 400 pound weight loading (Transient Dynamic)

<table>
<thead>
<tr>
<th>Details of &quot;Force&quot;</th>
</tr>
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<tbody>
<tr>
<td>Scope</td>
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<tr>
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<tr>
<td>Definition</td>
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<td>Z Component</td>
</tr>
<tr>
<td>Function Unit System</td>
</tr>
<tr>
<td>Suppressed</td>
</tr>
</tbody>
</table>

![Graph](image-url)
A complete characterisation of dynamic behaviour is also possible by means of an harmonic response analysis...

An harmonic response analysis is very easily setting in WorkBench and give an essential deep understanding of the dynamic behaviour of the structures undergoing a periodic load. The designer can probe the stress and strain levels on each specific part of the solar panel.
DEMO CASE #1

...and a Random Vibration Analysis.

An Random Vibration analysis is very easily setting in WorkBench and is the best way to test any kind of structure undergoing a random load like for instance vibrations induced during the transport.

An equivalent stress
Equivalent Stress 2
Equivalent Stress Frame

Details of "Equivalent Stress Frame"

Scope
Geometry 7 Bodies

Definition
Type Equivalent Stress
Scale Factor 3 Sigma
Probability 99.737 %

Results
Minimum 0.0 MPa
Maximum 0.99058 MPa
Minimum Occurs On Surface Body
Maximum Occurs On Surface Body

Information
DEM0 CASE #1

- EC 61646 test requirements: Thermal Cycling
DEMO CASE #2

- As more deeply we need to investigate the behaviour of our solar panel as more accurate have to be the model we generate...
DEMO CASE #2

- Each specific detail insert on a real solar panel can be taken into account and parametrized.
DEMO CASE #2

• The tests required by Standard UL/IEC have also been simulated on this model (since the increased number of elements the analysis are computationally more expensive, but perfectly manageable by a normal dual core workstation)
DEMO CASE #2

• A simulation coupling thermal-mechanical field has also been performed in order to determine the stress on the layers close to the conductors.
DEMO CASE #2

• A simulation coupling thermal-electric field has also been performed in order to determine the joule heating
DEMO CASE #2

• A simulation coupling thermal-electric field has also been performed in order to determine the joule heating
POWERFUL SOFTWARE TOOLS

• All the simulations performed can be handle in one main page
In order to use the cells in practical applications, they must be:

• Connected electrically to one another and to the rest of the system
• Protected from mechanical damage during manufacture, transport and installation and use (in particular against hail impact, wind and snow loads). This is especially important for wafer-based silicon cells which are brittle.
• Electrically insulated including under rainy conditions
• Mountable on a substructure or building integrated.

Source: Wikipedia (Photovoltaic module)
• Diodes are included to avoid overheating of cells in case of partial shading. Since cell heating reduces the operating efficiency it is desirable to minimize the heating. Very few modules incorporate any design features to decrease temperature, however installers try to provide good ventilation behind the module.

Source: Wikipedia (Photovoltaic module)

“The battle is going to be won on the manufacturing floor.”
David Pearce, CEO of CIGS manufacturer Miasolé
Why to optimize a design?

Parameter 1 → th1
Parameter 2 → w1
Parameter 3 → l1
Parameter 4 → E1
OPTIMIZATION

- What we want to optimize

**Modal Analysis**

- WE WANT TO Increase frequency

**Thermal Cycling**

- WE WANT TO Reduce Max Displacement

**Geometry**

- WE WANT TO Increase Area

**TEST REQUIREMENT**

- UL/ICE 400 Lb
- WE WANT TO Reduce Max Displacement
How to optimize a design?

**PARAMETERS TO MODIFY**

- Thickness
- Length
- Width
- Young Modulus

**OBJECTIVES TO OPTIMIZE**

- Increase frequency
- Reduce Max Displacement
- Thermal Cycling

**OPTIMIZATION**
What does optimization do?

1) Optimization performs a Design of Experiments (DOE)

2) Optimization starting from the data acquired from the DOE explore all the domain of the parameters searching the maximum or minimum of the objective function(s)
What does optimization give?

Basically optimization gives several different combinations of the parameters we chose to optimise...

...among them there is/are the best one(s)!
OPTIMIZATION

• How can we choose the best solution(s)?
• How can we choose the best solution(s)?
**OPTIMIZATION**

- **Improvement after optimisation**

<table>
<thead>
<tr>
<th>Original Parameter Value</th>
<th>Optimised Parameter Value</th>
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<tbody>
<tr>
<td>(Area) 1,244 m²</td>
<td>(Area) 1,284 m²</td>
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<tr>
<td>(Frequency) 70 Hz</td>
<td>(Frequency) 73 Hz</td>
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<tr>
<td>(Displacement_1) 0,42 mm</td>
<td>(Displacement_1) 0,31 mm</td>
<td>35.5</td>
</tr>
<tr>
<td>(Displacement_2) -0,19 mm</td>
<td>(Displacement_2) -0,18 mm</td>
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</tr>
<tr>
<td>(Displacement_3) -0,20 mm</td>
<td>(Displacement_3) -0,19 mm</td>
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</tbody>
</table>

**WARNING**

This test case optimisation has taken into account only 4 geometric parameters to improve the mechanical robustness of solar panel **BUT** several different parameters can also be optimise simultaneously to improve, for instance, the thermal efficiency and/or the electric performance and everything else the designers need to improve.
HOT STUFF

NEM reduces cost and improves efficiency for concentrated solar power generation.

By Ingrid van DJB, Solar Team, NEM Energy B.V., Leiden, The Netherlands

Advanced technology is playing an important role as the world looks for efficient and cost-effective sources of energy. Solar energy generation is growing, especially in sunny areas such as Africa, the Middle East, the Mediterranean and the southwestern United States. Photovoltaic (PV) energy has been a long-time leader in this field, but concentrated solar power (CSP) systems (which use mirrors or lenses to concentrate a large area of sunlight onto a small area to drive a heat engine connected to an electrical power generator) have been used for a long time and have now started to pick up steam. The U.S. Department of Energy (DOE) has offered roughly $1.5 billion in loans to four CSP projects, an amount greater than what it has offered to develop photovoltaic projects.

CSP is experiencing rapid growth, with about 700 MW of new generating capacity added between 2007 and the end of 2010, bringing the total installed capacity to 1.955 MW. NEM Energy B.V. is developing a power tower concept type of CSP that uses a field of sun-tracking mirrors called heliostats to concentrate light onto a receiver on top of a tower. The difference between CSP and the more widely known photovoltaic form of solar power is that PV converts sunlight directly to electricity using the photovoltaic effect, while in CSP, concentrated sunlight is converted to heat. The heat can be used to power a steam turbine to generate electricity. A key design challenge for NEM is increasing the stiffness of the mirrors to put as much reflected light as possible onto the target, called a receiver, without paying a cost premium. The company uses ANSYS mechanical software within the ANSYS Workbench environment to evaluate the stiffness of the mirrors and other components of the heliostats. The results are fed into a ray tracing program that simulates the energy generated by the design. This makes it possible to determine the performance-to-cost ratio of each design alternative without having to build physical prototypes. NEM is one of the top five producers of mirrors generating equipment in the world.
Blending Solar Panels with Roof Profiles

Simulation guides the design of innovative solar panel frames, reducing molding time, material and cost.

By Matthew Stel, President, Stel Design, California, U.S.A.

One of the most efficient sources of renewable energy is rooftop photovoltaic (PV) solar cells, which convert sunlight into electricity for homes and business. Use is hampered, however, by high upfront costs as well as aesthetics, with most solar panels mounted on unsightly brackets that do not blend well with house and building designs.

Open Energy Corp. of Sylmar, California, has overcome these drawbacks with SolarSaw™ panels — a solar roof solution unlike anything previously available in the industry. Panels are designed to integrate and interweave with standard roofing tiles so as to blend in with the roof, an important consideration in subdivisions with strict homeowner bylaws pertaining to roof profiles and solar panel installations. These integrated panels are also cost-effective, as they are installed on lipping over part of the roof rather than as an add-on above traditional coverings. The lightweight panels are warranted for 25 years, are easily handled, and can be walked on, simplifying installation for roofing contractors and solar integrators.

In their continuing efforts to improve the cost-effectiveness and performance of these solar panels, Open Energy commissioned Stein Design to complete a redesign of the panel with the goal of reducing unit cost while improving strength and reliability. The new design was to be a four-foot-long PV panel to replace existing three-foot models, cutting square footage costs by reducing the number of electrical connections, melted junction boxes and other hardware. Analysis work was done exclusively using ANSYS DesignSpace software.

Stein Design started the redesign by first evaluating the existing three-foot panel product. Three-dimensional solid CAD model assemblies were generated in SolidWorks® and then imported into the ANSYS DesignSpace tool to perform the stress analysis. Two load cases were considered: (1) a 300-pound per-square-foot pressure, satisfying at least 98 percent of structural building code requirements across the United States and Canada for snow loads; and (2) a 400-pound load concentrated in a three-inch (76-mm) Stabilitrue area, representing a concentrated 2x2 foot load of an installer on the
DEMO CASE #3
DEMO CASE #3

CHT temperature and streamlines

Pressure profile
DEMO CASE #3

Imported Temperature

Imported Pressure

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DEMO CASE #3
DEMO CASE #3

Pressure and streamline

Wind induced deformation
DEMO CASE #3
## DEMO CASE #3

<table>
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<th>Optimization Study</th>
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### Candidate Points

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<tr>
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<th>P1 - ForceAngle</th>
<th>P2 - SupportSize</th>
<th>P3 - AirSpeed (m s⁻¹)</th>
<th>P4 - HeatLoad (W m⁻²)</th>
<th>P5 - Temperature Maximum (°C)</th>
<th>P6 - Total Deformation Maximum (m)</th>
<th>P7 - Equivalent Stress Maximum (Pa)</th>
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</table>

![Graph showing data points and trends](image)
Problem
Increase the stiffness of the mirrors for a concentrated solar power system so that as much reflected light as possible is directed onto the target.

Solution
- Use ANSYS Workbench to automatically add more than 1,000 contacts using a 5 mm tolerance value.
- Employ ANSYS Mechanical plastic deformation calculations on small sections of the model to account for permanent deformations of the structure.
- Use ANSYS Parametric Design Language (APDL) command snippets to evaluate the model at different angles and wind speeds as part of a batch process.

Result
Simulation helps NEM to quickly improve performance and reduce the cost of heliostat designs.

“With simulation we can improve performance and reduce cost of our heliostat designs at a much faster pace than could be accomplished solely by building and testing prototypes.”
ANSYS IN ENERGY

Problem
Design the foundation for a concentrated solar thermal project with thermal storage facilities. The foundation must satisfy all the stringent design criteria stipulated by the equipment manufacturer on a tight project schedule and budget.

Solution
Use ANSYS Structural software to design a complex 3-D model of the foundation and perform dynamic analysis. The complete dynamic behaviour of the foundation was obtained using ANSYS software.

Using ANSYS, the design cycle time was reduced, resulting in higher efficiency and better manpower utilization.
CONCLUSIONS

• Finite element analysis program can simulate almost all the physical phenomenon experienced during the solar panels operational life

• Numerical simulation focussed on process manufacturing can also be performed

• DesignXplorer can optimize all kind of parameter defining the solar panel or solar cell project, respecting all the constrains imposed by the designers

Significant improvement of the efficiency and reliability of solar panels can be achieved by coupling numerical simulations and optimization techniques.
THANK YOU FOR YOUR ATTENTION!

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