Solar Industry - Numerical Simulation and Optimization

1. Introduction

Nowadays, the renewable energies attract a lot of attention from politicians and the public. On the one hand, this is a consequence of an increased environmental awareness all over the world. On the other hand, new technologies can become the best strategy to face and overcome the global economic slump. A loan of hundreds of millions of dollars provided by the U.S. Department of Energy to a solar panel company based in Silicon Valley, California, is another clear proof of the commitment and investments made in this field.

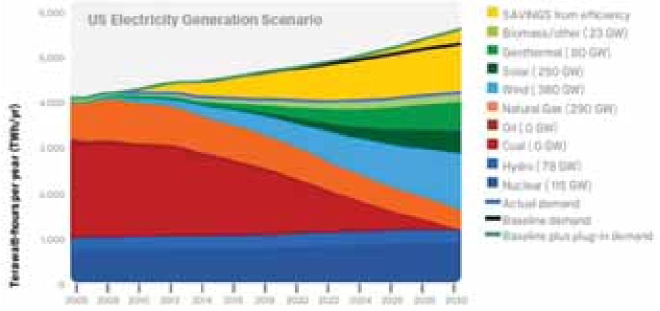


Figure 1: US Expected electricity generation scenario

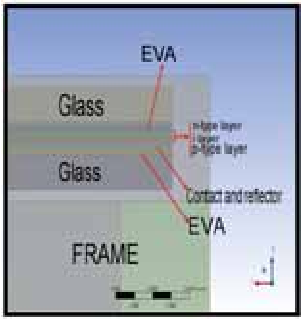
Also, financial institutions and banks are ready and eager to invest in a promising sector with expectations for growing revenues. For instance, the fourth largest bank in the US, signed an agreement to fund SunPower, one of the most important solar panel manufacturers in the United States.
Figure 1 illustrates the expected electricity generation scenario in the USA.

The main goal of the companies involved in this business is to develop new technologies to improve the efficiency and reliability of solar panels. This task is not at all trivial, since there is a relevant amount of parameters that affect the performances and the costs of the solar modules. Despite the fact that efficiency is crucial and that the multi-junction technology should reach a remarkable value of 40.8%, there are other very important factors needed to guarantee the commercial success of solar panels. Under this point of view, reliability, robustness, operational life, manufacturing processes and the use of materials can not be considered less important than the conversion efficiency. All these factors could dramatically affect the future of solar technology compared to others. In this context, only optimized solutions can stand out and survive.

2. Numerical simulations

In order to reach the optimum result, the first step is to acquire a deep understanding of the behavior of the solar panel. Numerical simulations are by definition tools devoted to investigate and evaluate the behavior of systems or their functional parts, allowing in this way, to improve the efficiency and to tremendously decrease the cost of the prototypes. This article describes a demo case, mainly focussed on the evaluation of the mechanical performance of a solar panel. Some of the simulations executed have been performed in order to verify if the analyzed solar panels comply with EC Standard. A better understanding of the solar panel behavior has been achieved by performing not only mechanical analysis, but also fluid dynamics and thermal-electric simulations.
The EC Standard requires that solar panels are robust enough to resist hail impact. Following the standardized test, if a steel ball (1.18lb) was dropped from 51 inches, an approved panel will not crack. Since ANSYS WorkBench R11.0 has been used to simulate the drop test, a command snippet was inserted in the GUI to set the explicit solution. Maximum principal stress, evaluated at the impact point on the glass layer, was 43MPa (see figure 2), lower than the breaking limit value. The new Release 12.0 does not need scripts for explicit analysis because of the new capabilities.

The second analysis evaluated the effect of a static load (400lb) applied on the top layer (glass) of the solar panel. In addition, a transient dynamic analysis has been performed to gain a deeper understanding of the structural behavior. The dynamic load has been applied as a transient sine function with a period equal to the first natural frequency of the panel.
In some particular cases, transportation may be a matter of concern because of the vibrations induced in this phase. This also pushed to evaluate the suitability of the modules to support random vibration loads.



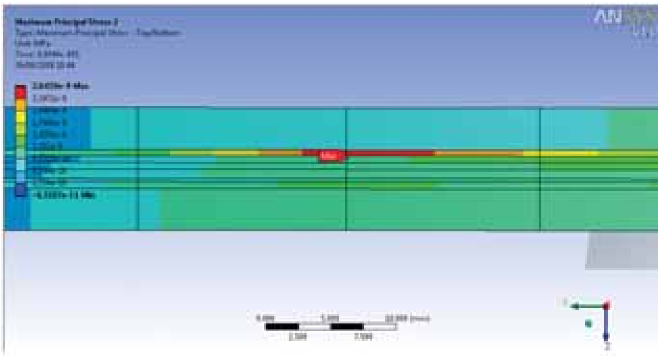


Figure 2: Solar panel cross section - Principal stress

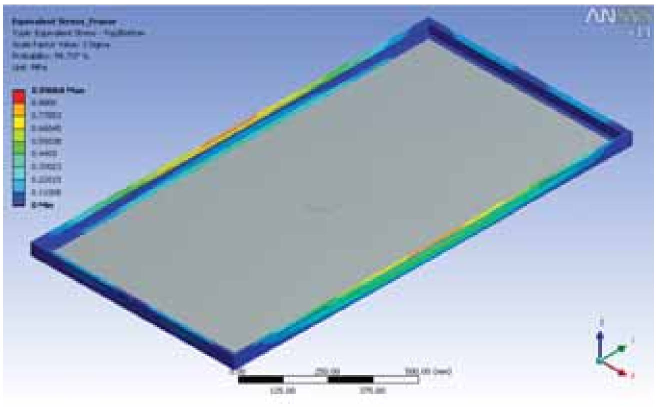


Figure 3: von Mises stress induced by PSD

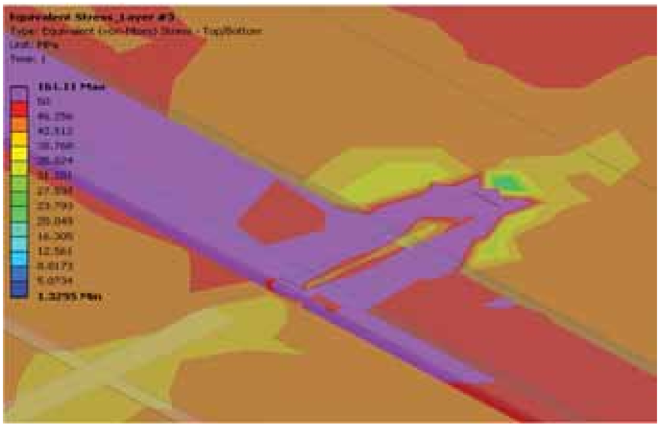


Figure 4: von Mises stress induced by thermal cycling test

The analysis performed revealed that in all cases considered, stress levels are lower than the admissible values.
After installation of the solar panel, thermal conditions become a severe cause for mechanical stress, mainly on the solder connections. Because of the relevance of this issue, a thermal cycle test is required based on the EC standard. The standard test requires the sample to undergo thermal cycles from a low temperature of -40 °C, to high temperatures equal to +85 °C with a dwell time equal to 10 minutes at both higher and lower temperatures.

As expected, the junctions between cell and connector are the most sensitive parts with respect to the thermal cycle test. The following figure reports a detailed view of the stress spot.

High temperature is not only challenging from a mechanical point of view, but also considerably affects the electrical performance. It has been determined that the decrease in efficiency can beat 0.5%/°C (depending on the technology used), as high temperatures reduce the open-circuit voltage. Consequently, under severe sun irradiation conditions during the operational phase, the negative effects of high temperatures can result in bad performances. Because of the importance of this issue, a thermal-electric simulation on a single cell has been performed to analyze the temperature field triggered by the Joule heating induced by the current collected by the cell. Moreover, a fluid dynamic analysis has been performed in order to take into account the air flux around the solar panel to evaluate both the ventilation around the panel and the stress on the support frame induced by the wind pressure (see figure 5).

The analysis revealed that under a structural point of view, the frame support is properly designed to resist the standard code wind. From a fluid dynamic aspect, as expected, a low pressure zone was detected on the back side of the panel causing inefficient heat dissipation.

3.Optimization

Numerical simulations are a powerful tool to evaluate the performance of a design, but in a market where only the best technologies can survive, the optimization process plays a crucial role and is as important as numerical simulations. As explained above, the goal for manufacturers and researchers is not only to increase performances, but also to reduce cost and time of production, so that significant optimization can be achieved, from the early design stages to the final product manufacturing processes.
The original design has been optimized by modeFRONTIER, a multi-objective optimization software tailored to be coupled with other programs, such as, for example, Finite Element Methods or Computational Fluid Dynamics software (not only engineering software though). The main task of the optimizer is to drive the initial set of parameters that define the model, to the/an final optimized set of parameters which define a new better performing model. Basically, the optimization process is made by modifying the input variables, using mathematical algorithms, and analyzing the outputs in accordance with the objectives and constraints of the design.
The first phase of the process starts with the Design of Experiments (DOE) to generate an initial population of possible designs. Starting from the initial population, modeFRONTIER explores all parameter domains. It searches for the maximum or minimum of the objective function(s) using a variety of state-of-the-art optimization techniques.
An Optimization process, with many and conflicting objective functions, cannot deliver "the" optimal solution as a result, but rather a "full set" of optimal solutions called Pareto frontier. Each solution of the Pareto frontier maximizes/minimizes at least one of the objective functions, but none of them maximizes/minimizes all objective

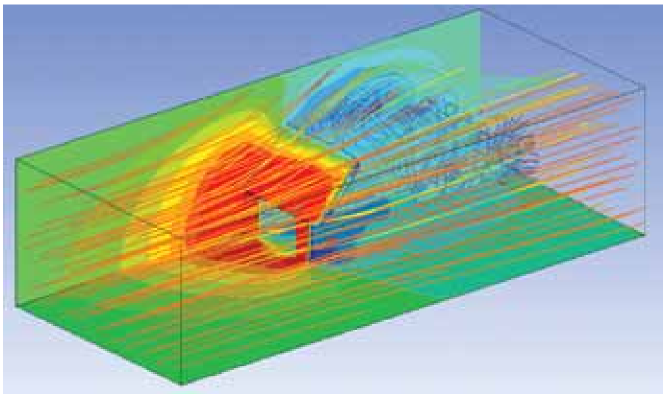


Figure 5: Pressure Distribution and Velocity Streamlines.

functions. This article presents two case studies. The first one is a multi-objective and multi-disciplinary optimization; the second one is a mono-objective structural rigidity of a solar panel mount optimization.

3.1 Solar panel case study. Multi Objective Optimization

3.1.2 Optimization Problem and Objectives

The structural and thermal behavior of the solar panel during the operational phase is determined by the geometric and material characteristics. Hence by modifying the geometric and material parameters, an optimum solution can be achieved.

We have searched for an optimum solution by maximizing/minimizing the following objectives:

- Maximize the exposure area to sunlight;
- Maximize the first frequency of the solar panel;
- Minimize the displacements due to thermal cycling;

The input parameters and their variability range which have been used in the optimization problem, are shown in Figure 6. Since the defined objectives are conflicting, a certain trade-off will be accepted. The finite element model has been generated and parametrized in Workbench R11 and the Optimization "Workflow" has been defined in the modeFRONTIER Graphical User Interface (GUI), as shown in figure 7. The GUI allows to control any process setting included in the optimization algorithm.

PARAMETER	VARIABILITY RANGE
Young's Modulus	6.0e+10 – 7.0e+10 [Pa]
Length	1300 – 1900 [mm]
Width	400 – 1500 [mm]
Thickness	-4.5 – -1.5 [mm]

Figure 6: Input parameters and variability range.

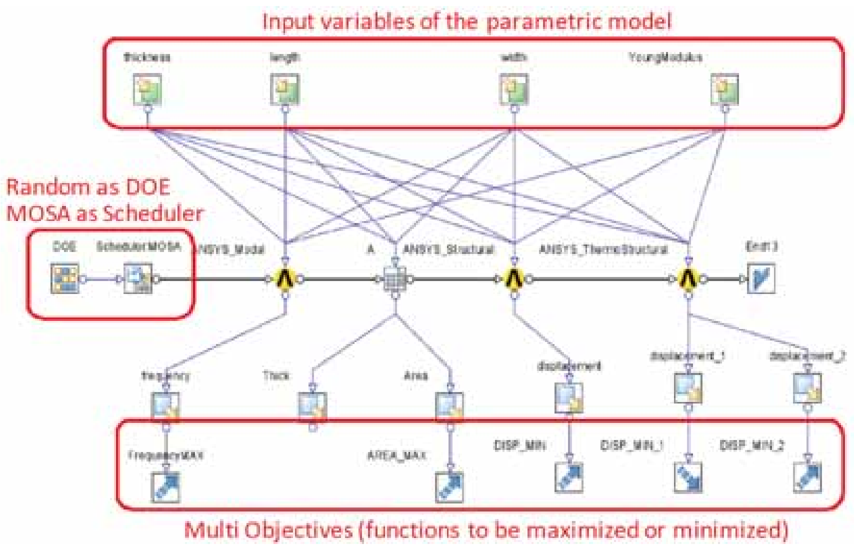


Figure 7: modeFRONTIER Workflow

3.2.Evaluation of the optimization results

After the optimization algorithm has completed its process, due to the many objectives, several optimum solutions have been generated. At this point, a careful evaluation of the results is indispensable. Despite the fact that a "design table" provides all input and output parameters of the process, a comparison of the designs is necessary in order to understand the effectiveness of the optimization. A parallel chart can be used for this task. To speed up the post-processing, it is possible to work on the parallel chart output ranges, in such a way that a reduced subset of optimized designs can be obtained (see figure 8).

To focus on the most relevant output parameters, a bubble plot has been used (see figure 9).

Finally, by merging the information provided by the parallel chart and the bubble chart, an optimum design has been selected. The improvements achieved are reported below:

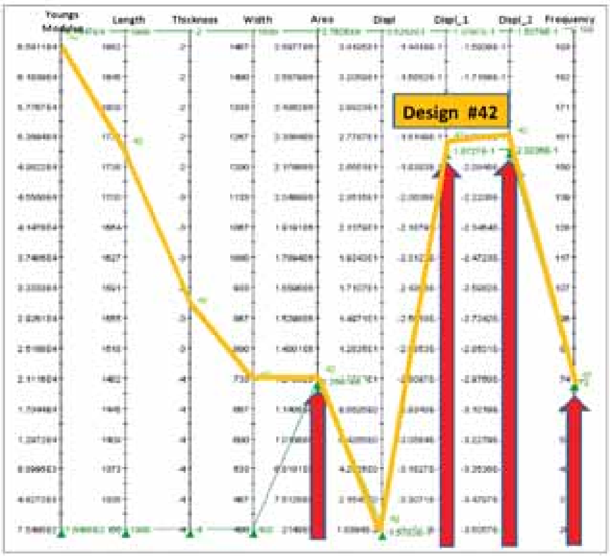


Figure 8: Parallel chart

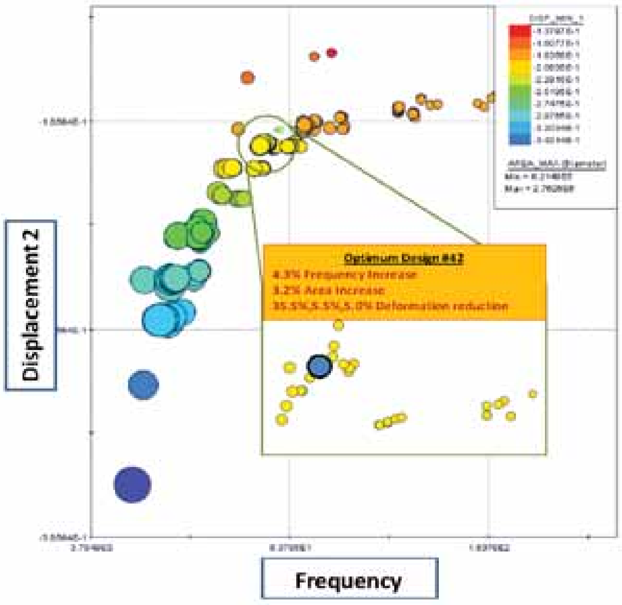


Figure 9: Bubble chart

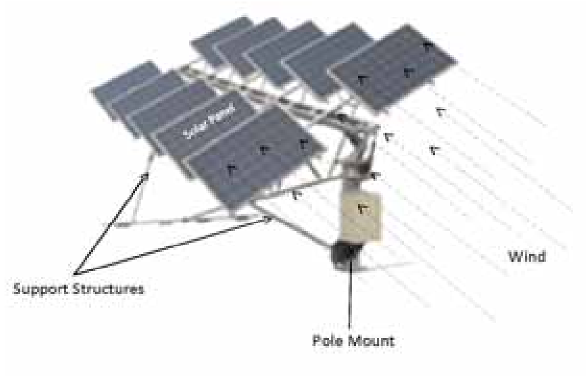


Figure 10: Solar Panel with Pole Mounts Schematic Diagram

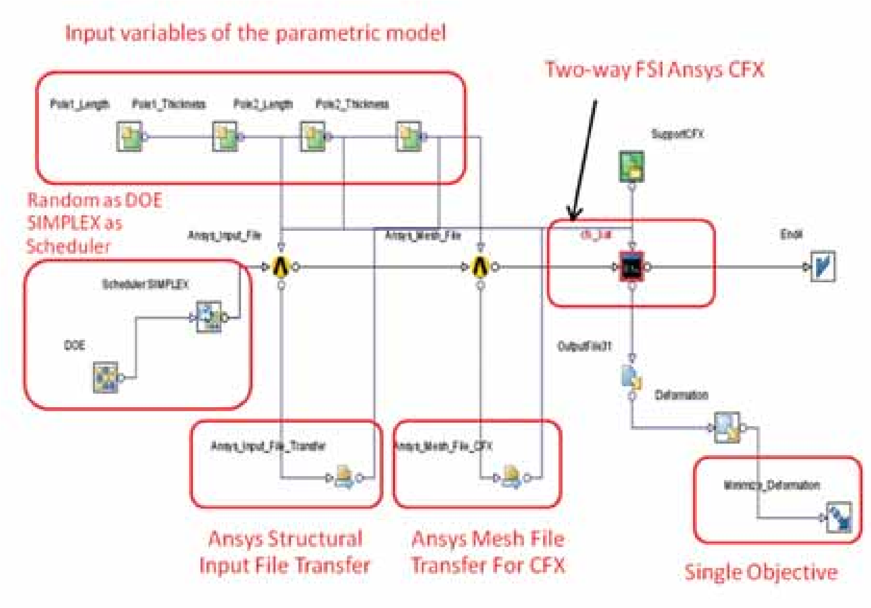


Figure 11: modeFRONTIER Workflow

- maximized power output (+3.2%)
- maximized robustness (+4.3% first frequency; -35.5% displacement)

4. Solar panel case study. Structural Optimization of the pole mount supports

The second case study analyzed has been focussed on the structural optimization of the solar panel pole mount supports (see figure 10). The goal of this optimization case study has been to identify the best geometric configuration of the pole mount support structure when subjected to a wind load equal to 5 m/s. The analysis was performed with the aim to find the maximum displacement of the solar panel. Since the problem involved only one objective function, the optimization process is defined mono- objective. In order to generate the optimization workflow, ANSYS Structural has been coupled with ANSYS CFX. Consequently, a Two-way Fluid Structure Interface analysis needed to be performed. In figure 12, the optimization workflow is shown. The improvements achieved on the structural rigidity are equal to 56%.

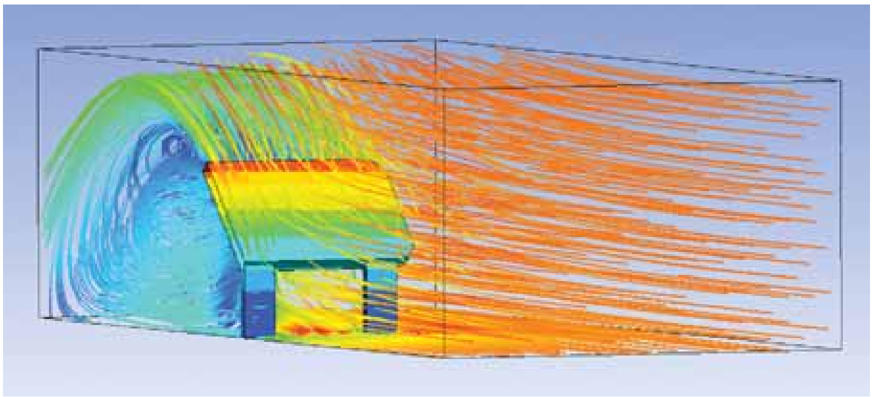


Figure 12: Deformation and Air-flux Streamlines

5. Conclusions

In recent years, the interest in the solar industry, its developments and advancements, has been growing steadily; economic, scientific and technical sectors have contributed to this trend and process.

In this context, numerical simulations have proved to be mature, powerful and reliable technologies whose capabilities can be exploited to reduce cost related to test phases, to gain a better understanding of the behavior of solar panel systems, and to prevent possible causes for failure or low efficiency.

Furthermore, since the solar sector is expected to assume a major role in the global energy market, and specifically in domestic energy demands, the primary objective is to guarantee that solar panels deliver best performances in costs, efficiency, reliability, robustness, safety, durability and aesthetics. Existing difficulties for designers are linked to the huge number of parameters and the conflicting ways in which they affect the final results. In order to overcome these difficulties and to reach the targets, design processes have to take into account multi-disciplinary and multi-objective optimization techniques to achieve optimum results.

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