Final Report
of the
STSM at RWTH Aachen University

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Purpose of the STSM

This Short Term Scientific Meeting was a visit whose main aim was to collaborate with Professor Martin Frank and with his Phd student Pascal Richter at the MATHCCES department of RWTH Aachen University, Germany, on the optimization of the heliostats field design. We had been working in collaboration with the solar thermal energy research group (STERG) at Stellenbosch University on one specific topic related with this technology during the past months. The scientific plan was to continue working on the previously studied topic and also to start exploring new methods to improve the designs obtained so far. An abstract was submitted to publication on SolarPaces 2015 proceedings and hopefully will be completed for publication with the results obtained during this stay.

Description of the work carried out during the STSM

A Solar Power system comprises basically a tower with a receiver on the top and a field of mirrors called heliostats. Each heliostat has two axis movement which allow to follow the sun at each time instant and reflect the sunlight into the receiver. The heliostats location problem deals with a black-box objective function and nonconvex constraints, as collisions between heliostats must be avoided. The study of optimization techniques to solve the heliostats location is an active field nowadays. A greedy-based heuristic algorithm and a genetic-based algorithm had been proposed by the Seville group and the MATHCCES group respectively.

The problem proposed by the STERG group was the optimization of the field design using triangular pods instead of standard heliostats. A triangular pod is a structure where six heliostats are placed together, three in the vertices and three in the middle points. The final goal was to construct a small-scale solar power plant using the triangular pod prototypes. Both algorithms were already adapted to address the heliostats location problem when considering triangular pod systems.

In the previous studies the side length of the triangles were fixed. We wanted to study the optimal size for the triangular pod system and to adapt the greedy-based location algorithm to deal with the location problem including the optimization of the triangle side length. Also, we wanted to explore new optimization techniques to improve the heliostats field layouts obtained so far with both algorithms.

Description of the main results obtained

We have first worked on the triangular pods location problem when the side of the triangle is considered as an optimization variable. For simplicity, we consider that the triangles are equilateral. We adapted the greedy algorithm to solve this problem. The three optimization variables considered are: the coordinates of one vertex (x, y), the inclination of the triangle α and the side length of the triangle l. New constraints had to be included because the combination of different triangle lengths lead to solutions with overlapping effects between the pods and therefore unfeasible configurations. In order to check if any of the vertices of the new pod is inside the already located triangles and vice versa we have used the Surveryor's formula, which gives us the triangle signed area. Feasible configurations are obtained where can be appreciated that the side length varies with respect the distance to the sweet point.

Secondly, we seek to improve the field design obtained so far with our algorithms. We proposed an optimization strategy using derivatives to locally improve the heliostats locations. The final idea is to optimize the whole field by iterative optimizing the positions of a small number of heliostats. As we deal with a blackbox objective function automatic differentiation softwares offer the possibility to compute directly the derivatives of the objective function. We started working with Automatic Differentiation for Matlab (ADiMat) which is a software for the computation of precise and efficient derivatives of Matlab programs. The ADiMat software was started and developed by André Vehreschild and Johannes Willkomm among others, at the Institute for Scientific Computing, TU Darmstadt, Germany and formerly the Institute for Scientific Computing, RWTH Aachen University, Germany. ADiMat transforms a given MATLAB code for the evaluation of some mathematical function into a new MATLAB code for the evaluation of user-specified derivatives of that function.

The code used to compute the objective function is going to be adapted to deal with the ADiMat requirements. The first tested cases has been done considering only one of the factor involved into the objective function (annual thermal energy) calculations, the cosine efficiency. The code has been adapted and the same results are obtained computing the derivative function obtained with ADiMat and the exact derivative.

Future collaboration with the host institution

The first point will be to finish the research topics already open. The objective function has to be fully adapted to apply the ADiMat software successfully. One of the functions involved in the annual energy calculation is even not continuous are therefore the calculation of the derivatives has to be carefully studied. I am optimistic about future cooperation with Martin Frank in order to study, not only this type of problems, but also others related with solar tower plants optimization.

Foreseen publications resulting from the STSM

It is my hope that, the research done during my stay leads at least one paper in the SolarPaces 2015 conference proceedings.

Aachen, 19th of June, 2015.

Carmen-Ana Domínguez Bravo
Visitor, University of Seville

Confirmation by the host institution of the successful execution of the STSM

I have read the final report written by Carmen-Ana Dominguez Bravo describing her STSM visit to RWTH Aachen University to collaborate with my research group. I am extremely satisfied with the results of the visit. We have successfully deepened a cooperation that we had started at the ECMI 2014 conference. We developed optimization techniques for a heliostat field of a solar tower power plant, which is planned in South Africa, and consists not of individual heliostats, but pod systems. The result was an abstract that was accepted at SolarPACES, the most important international conference in the solar industry.

I hope this fruitful cooperation will continue in the future as well.

Aachen, 19th of June, 2015.

Martin Frank
Host, RWTH Aachen University