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Improving shadows detection for solar radiation numerical models

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Solar radiation numerical models need the implementation of an accurate method for determining cast shadows on the terrain or on solar collectors. The aim of this work is the development of a new methodology to detect the shadows on a particular terrain. The paper addresses the detection of self and cast shadows produced by the orography as well as those caused by clouds. The paper presents important enhancements on the methodology proposed by the authors in previous works, to detect the shadows caused by the orography. The domain is the terrain surface discretised using an adaptive mesh of triangles. A triangle of terrain will be under cast shadows when, looking at the mesh from the Sun, you can find another triangle that covers all or partially the first one. For each time step, all the triangles should be checked to see if there are cast or self shadows on it. The computational cost of this procedure eventually resulted unaffordable when dealing with complex topography such as that in Canary Islands thus, a new methodology was developed. This one includes a filtering system to identify which triangles are those likely to be shadowed. If there are no self shadowed triangles, the entire mesh will be illuminated and there will not be any shadows. Only triangles that have their backs towards the Sun will be able to cast shadows on other triangles. Detection of shadows generated by clouds is achieved by a shadow algorithm using satellite images. In this paper, Landsat 8 images have been used. The code was done in python programming language. Finally, the outputs of both approaches, shadows generated by the topography and generated by clouds, can be combined in one map. The whole problem has been tested in Gran Canaria and Tenerife Island (Canary Islands – Spain), and in the Tatra Mountains (Poland and Slovakia).

1. Introduction

As it is well known, renewable energies have increased their importance in power systems during the last decades. According to European Photovoltaic Industry Association [1], the global solar photovoltaic cumulative installed capacity for 2014, is 178 GW. This power is expected to be increased up to, around, 470 GW in 2019. Again, European Photovoltaic Industry Association [1] estimates that PV penetration in Europe in 2030 could be between 10% and 15% of the electricity demand, against the 3.5% of 2014.

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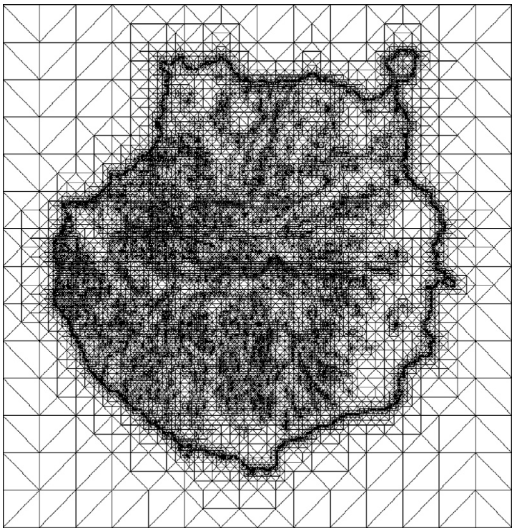

Fig. 1. Adaptive mesh for Gran Canaria Island.

The conclusion is clear, power systems will have to, increasingly, take into account solar power generated by means of photovoltaics or solar thermal electric facilities. In all of them the key parameter is solar radiation, either global or direct, and an accurate estimation of those variables needs a good knowledge about the spatiotemporal evolution of shadows over the whole analysis domain.

The solar radiation computation on the different parts of the terrain is based on the Šúri and Hofierka [2] model. This one uses geometrical, astrophysical and atmospheric considerations. In previous works of our research group we have introduced the use of triangle meshes adapted to both, elevation and albedo to analyse the solar radiation on the terrain [3,4]. This model has been applied in tasks of solar radiation and power forecasting too [5]. Shadows effects on surfaces have been studied by many authors because of its importance when estimating solar radiation [6,7]. In fact, we worked on a shadows model in [3], however its computational cost was quite high so a new methodology has been developed and presented in this paper. It includes a double filtering system to identify which triangles are those likely to be shadowed using adaptive meshes of triangles to describe the shapes of the terrain as solid surfaces. These ones can produce shadows because they are surfaces, not points.

In the other hand, the need of detecting the presence of clouds and their cast shadows, arises as an important problem to take into account, especially when you want to make a short term solar radiation forecasting. In this sense, clouds shadows detection is incorporated in the general shadows modelling, so that the new model greatly improves the predictive ability of our forecasting one. Clouds detection through satellite images has been studied by many authors. Statella and da Silva [8] proposed the application of Mathematical Morphology (MM) in shadow and clouds detection in high resolution images. Fisher [9] developed a method for masking clouds and shadows from clouds, in SPOT5 HRG Imagery. Semitransparent thin clouds detection can be done using Advanced Very High Resolution Radiometers (AVHRR) and Moderate Resolution Imaging Spectroradiometers (MODIS) [10]. Some researchers have analysed the use of the Landsat dataset [11] for these purposes, and this imagery will be used by the authors in this paper.

2. Adaptive mesh for topography and albedo

The chacterisation of the topography and the albedo is done using an adaptive method for refining and derefining a triangular mesh [3,4]. We will obtain a 2D mesh adapted to the altitude and albedo (if needed) variability. The first step is building a regular mesh τ_1 of the domain starting from the Digital Elevation Map (DEM). Then, a sequence of nested meshes $\Gamma = \{\tau_1 < \tau_2 < \cdots < \tau_m\}$ will be obtained in a way that level τ_j is built through a global refinement of the previous level τ_{j-1} with the 4-T Rivara's algorithm [12]. When the refinement is done, a new sequence $\Gamma' = \{\tau_1 < \tau_2' < \cdots < \tau_{m'}'\}, m' \le m$, is defined derefining the mesh [13]. In case that we want a mesh adapted to both surface (topography) and albedo, two derefinement parameters are needed, one for elevation, ε_h, and one for albedo, ε_a. These two parameters will give the accuracy of the mesh.

Once the process is finished, we obtain an adaptive mesh that characterise the topography and the albedo, if necessary. Fig. 1 shows a fine adaptive mesh for Gran Canaria Island adapted to topography. To get good results for solar radiation purposes, a coarser mesh is needed. In fact, a mesh with 5866 nodes and 11,683 triangles is enough for Gran Canaria Island (Canary Islands – Spain), which has an area of 1560 km^2.

Using the same methodology we have studied a very different place, the Tatra Mountains placed between Poland and Slovakia. These mountains are part of the Carpathian Mountains, and have an area of 785 km^2. The whole landscape