CityGML and Solar Potential Analysis for Buildings in Singapore

Dr. XU Le, Dr. Martin REED, Dr. Thomas REINDL
Solar Energy System Cluster

Solar Energy Research Institute of Singapore (SERIS)
National University of Singapore (NUS)

6th Workshop CityGML Energy ADE, Ferrara, Italy
25 November 2016
Overview

- Introduction of SERIS
- Capabilities from SES cluster
- Motivation and Background
- Methodology

Case studies
- Rooftop PV potential
- Solar Insolation for Buildings with full 3D implementation
- Automatically Modelling LoD from 2 to 3
SERIS
Solar Energy Research Institute of Singapore

- Founded in 2008; focuses on applied solar energy research
- Part of the National University of Singapore (NUS)
- Rapid growth (now ~160 people and > 6000 m² of space)
- > USD 30 million investments for labs
- R&D focus is on PV (cells, modules, systems) and solar energy efficient buildings
- Specialised in professional services for the PV industry
- ISO 9001 & ISO 17025* certified (* PV Module Testing Lab)
Overview

- Introduction of SERIS

- Capabilities from SES cluster
SES cluster
Research Groups

Solar Potential & Energy Meteorology Group
- Solar potential analysis for buildings
- Solar Irradiance forecasting: short, medium and long term time scales
- Sky image and GPS acquisition
- Weather Research and Forecasting
- Cloud analysis and forecasting

PV System Technology Group
- Long-term PV module performance testing and monitoring
- PV system optimization
- First floating PV test bedding in Singapore

PV Grid Integration
- Power grid operations and regulations
- Multiple levels of interdependencies between the distributed generation
- Variability of the resource and demand
- Integrations between grid control, PV systems and energy storage solutions

Asia PV Quality Assurance Center
- Third part evaluation of system design, implementation and economic variability
- Feasibility studies and full due diligence evaluations
- National Solarisation Center (NSC)
National Solar Repository (NSR)

One-step information for solar PV in Singapore

http://www.solar-repository.sg
National Solar Repository (NSR)

LCOE calculator

LEVELISED COST OF ENERGY (LCOE) CALCULATOR

This LCOE calculator is simplified. It does not include the depreciation period aligned to operational life. It is also a decision.

Disclaimer, limitation of liability

This calculation tool represents the personal opinions of SERIS and the National University of Singapore (NUS), and NUS of any tier liable in contract, tort, strict liability.

CO₂ savings over the lifetime of the system (tonnes)

Levelised cost of electricity, LCOE (SG$ cents per kWh)

How does your LCOE compare to your current electricity price?
Overview

- Introduction of SERIS
- Capabilities from SES cluster
- Background and Motivation
Vision
Deploying Solar Energy in Singapore

- Adopting of solar power from 87.8 MWp in Q3-2016 to 350 MWp by 2020
- Reducing greenhouse gas emissions by 16% by 2020
- Reducing the ratio of carbon emissions to each dollar of the GDP by 36% from 2005 levels by 2030
PV Energy Harvesting

Process

Sun Position

DNI

DHI

In-plane Irradiance

Rooftop size, Inclination, and Orientation

Solar power generation

Nearby Shading

Time series data

Spatial data
Challenging Issues
Solar Potential Analysis for Urban Environment

- Limited rooftops for PV installation
- Variability of Solar Irradiance
- Complexity of building geometry
- Shading impacts on solar irradiation
- PV system performance
Solar Radiation in Singapore

Using SERIS’ 25 irradiance stations, assessing time-spatial variability

Year-on-year comparison of the monthly solar irradiance

Spatial distribution of the solar irradiance across Singapore
In-Plane Solar Irradiation Variability

Impact factors: surface inclination and orientation

Irradiance distributions for a typical day in Singapore from June 2011 to May 2012

Highest annual irradiation is 1562 kWh/m² when a surface facing 97°SE with tilt angle of around 26°

Key Indicators

Solar Potential Analysis

- Solar Irradiation
  - Direct, diffuse and ground reflected irradiation
  - Able to represent weather (clear sky, cloudy and heavy sky)

- Rooftop profile
  - Size, shape, inclination and orientation

- Shading from near by buildings
  - Irradiation reduction due to shading effect

- PV system performance
  - Suitable area
  - PV technology
  - Performance Ratio
  - Solar power generation
Overview

- Introduction of SERIS
- Capabilities from SES cluster
- Motivation and Background
- Methodology
Solar Potential Analysis for Buildings

Procedure

- Quantify solar irradiation received by Buildings
- Identify suitable Building area
- Estimate PV potential

Solar Potential Analysis for Buildings

Quantify Solar Irradiation Received by Buildings

1. 3D building models (Sample data from SLA)

2. Shading analysis at spatial and temporal scales

3. Measurement Data from SERIS Stations

4. Calibrated Perez diffuse irradiance model to transpose measurement data to any inclined surface

5. In-plane solar insolation for any surface using four input
Mapping Singapore in 3D
Technology of Reconstructing Singapore in 3D

Airborne Laser Scanning & Imaging

Mobile Laser Scanning & Imaging

Mapping Singapore in 3D

Demo of 3D Singapore in Downtown Delivered by SLA

Overview

- Introduction of SERIS
- Capabilities from SES cluster
- Project Objectives
- Methodology
- Case studies
Case Study I
Rooftop PV Potential

SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore’s National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).
**Case Study I**

**Rooftop analysis – inclinations and orientations**

- **Total rooftop size**
  - 36,645 m²

- **Inclination distribution**
  - Flat surfaces: 40.4%
  - Slope ≤ 10° (59.1%) 

- **Orientation distribution**
  - N0~NE45: 24.3% 

---

**Inclination**

- 59.1% rooftops have the tilt angle is smaller than 10°

**Orientation**

- 24.3% rooftops have the orientation angle facing North (0°) to East (45°)
Case Study I
Shading analysis – annual shaded hours for rooftops

- **Simulation period**
  - From 7.00 am to 7.00 pm, 1st Jan – 31st Dec. 2015, UT+8
  - 4380 hours in total
  - Rooftop colored dark blue: no shading over a whole year

- **Shading pattern**
  - Fisheye images for every square meter

---

Annual shaded hours (hrs)

0 876 1752 2628 3504 4380

SERIS 25 Weather Stations

Data acquisition

Sensors: irradiance, temperature, humidity, pressure, wind speed, sky image
Solar Radiation Modelling

Perez Diffuse Irradiance Model

- Well represent different sky conditions
  - Circumsolar
  - Isotropic background
  - Horizon brightening

- Adapted Perez model to tropic weather
Case Study I
Solar Insolation map for rooftops

- Simulation configuration
  - Considered **rooftop profiles** (inclination, orientation and shading)
  - Applied **Perez diffuse irradiance model** for in-plane global, direct, diffuse and reflected irradiation
  - Simulated **hourly in-plane irradiances** over a whole year for every square meter based on measured irradiance data

- Significant Irradiance loss caused by nearby shading

Solar Insolation (kWh/m²) 0 200 400 600 800 1000 1200 1400 1600

Case Study I

Classify suitable rooftop area

- Classify suitable rooftop area
  - Annual solar irradiation
    - >= 1000 kWh/m²

- Suitable rooftop area
  - 13,323 m²

High: 1617 kWh/m²
Low: 1000 kWh/m²

Case Study I
PV potential analysis for suitable rooftop area

- **PV assumptions**
  - PV configuration: follow rooftop structure
  - Area factor: 126 Wp/m² (260Wp PV, 1.65 m × 1 m)
  - Average Performance Ratio (PR): 80% for unshaded rooftop area, linear response to the irradiance loss
  - CO₂ grid emission factor: 0.4313 kg/kWh

<table>
<thead>
<tr>
<th>Summary of results</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total rooftop area (km²)</td>
<td>0.037</td>
</tr>
<tr>
<td>Suitable rooftop area (km²)</td>
<td>0.013</td>
</tr>
<tr>
<td>Installed capacity potential (MWp)</td>
<td>1.72</td>
</tr>
<tr>
<td>Annual electricity generation (GWh)</td>
<td>1.65</td>
</tr>
<tr>
<td>Annual CO₂ emission savings (Ton)</td>
<td>710</td>
</tr>
</tbody>
</table>

Case Study I
Strengths and Weakness

Strengths

- Solving 3D problem by 2D graphics (like DEM, fish-eye photography)
- Modelling solar potential analysis for LoD2 Buildings
- 1 spare meter for spatial resolution
- Minutely or hourly temporal resolution
- 3D building model could be CityGML, .shp, .sketchup, .obj.
- Could be applied in other countries.

Weakness

- Lost details in facades during meshing buildings as square meter
- Only good for Rooftop PV analysis
Case Study II
Solar Potential Analysis for Buildings with full 3D implementation

- Visualization of 3D buildings in CBD.
Case Study II

3D computer graphics modelling

- Mesh a building into pixels representing a small surface area (e.g. 1 square metre)
- Represent a sky dome that becomes the source of incident radiation
- Mesh the sky dome into pixels
- Ray tracing is implemented for each building pixel and sky pixel

Case Study II

Full solar insolation profile of a downtown area in Singapore

Case Study II

Strengths and Weakness

- **Strengths**
  - Perfect solution to mesh LoD3 buildings in 3D
  - Analysing building geometries through vertices, e.g. surface normal, surface area, surface tilt and surface orientation
  - Well rendering each surface based on weights
  - 3D building model could be CityGML, .shp, .sketchup, .obj.
  - Could be applied in other countries.

- **Weakness**
  - Time-consuming
  - Over-meshing issue
  - Need to use HPC for speeding up computation
  - Need to find a online solution
Case Study III
Automatically Modelling LoD from 2 to 3

- Computer generated architecture (CGA)
  - Texture 3D buildings

Before

After
Thank you for your attention!

serxule@nus.edu.sg

More information at www.seris.sg