Evaluation of the plane of array irradiance for a photovoltaic installation equipped with flat reflectors in different geographical locations

Christine Abdel Nour[a,b,d], Anne Migan-Dubois[a], Jordi Badosa[b], Vincent Bourdin[c], Claude Marchand[a], Tilda Akiki[d]

[a] GeePs, UMR 8507 CNRS ; CentraleSupelec, UPMC Sorbonne Universités, Université Paris-Sud ; 11 rue Joliot-Curie, Plateau de Moulon, 1192 Gif-sur-Yvette Cedex, France
[b] LMD, Institut Pierre-Simon Laplace, École Polytechnique, 91128 Palaiseau Cedex,France.
[c] LIMSI, UPR 3251 CNRS, Bâtiment 508, Rue John von Neumann, 91405 Orsay Cedex, France
[d] Université Saint Esprit de Kaslik, USEK, Département de génie électrique et électronique, BP446 Jounieh, Liban

Introduction

The irradiance in the plane of array (GPOA) assessment is an approach requiring calculations based on several parameters and measurements and it becomes more complex when adding planar reflectors in front of the panels [1]. Several optical, geometrical and solar data must be taken into account for that purpose. On the other hand, the plane of array irradiance of a PV-Reflector system will be highly affected by the longitude, latitude and weather conditions. In this work, six different locations will be studied in this paper: Oslo, Palaiseau, Chicago, Athens, Ouarzazat and New Delhi (Table I) over a five years period (2012-2016). The irradiance data (horizontal beam and diffuse) were taken from PVGIS (Photovoltaic Geographical Information System) dataset [2], [3].

Table 1 : Different geographical locations studied

Country	Location	Latitude	Longitude
Norway	*Oslo*	59.9	10.73
France	*Palaiseau*	48.71	2.24
USA	*Chicago*	41.87	-87.62
Greece	*Athens*	37.98	23.72
Morocco	*Ouarzazat*	30.92	-6.91
India	*New Delhi*	28.61	77.2

Fig. 1. Photovoltaic system equipped with mirrors

Objectives

- Describing a plane of array irradiance (GPOA) estimation study performed for a PV system equipped with flat reflectors.
- The work presented focuses on the evaluation of GPOA for a PV-Reflector system architecture in six different geographical locations and under various weather conditions.
- Performing an architectural optimization approach by considering several geometrical variations in order to achieve the highest plane of array irradiance.

Model and Methodology

A- System's description

- BNI: The beam normal irradiance (W/m²).
- DHI:The diffuse horizontal irradiance (W/m²).
- DRBI: The direct radiation reaching the reflector to be then absorbed by the PV array (W/m²)
- DRSR: The diffuse radiation reaching the reflector to be then absorbed by the PV array (W/m²)
- Lr: The planar reflector Length (m)
- Lpv: The photovoltaic panel length (m)
- Otilt: The inclination angle of the PV module to the horizontal plane (°)
- OR: The angle between reflector and the horizontal plane (°)

- $GPOA_{Mir}$: The plane of array irradiance for a PV-Reflector installation (W/m²)

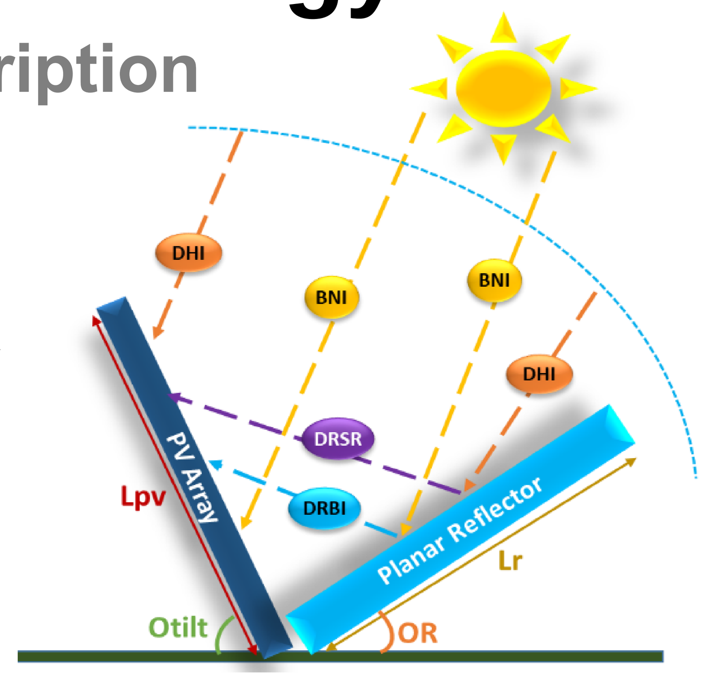

Fig. 2. PV-Reflector system architecture

$$GPOA_{Mir} = \underbrace{\frac{GHI - DHI}{\sin(O\ SunEl)} \times \cos(AOI)}_{Direct} + \underbrace{DHI \times \frac{1+\cos(Otilt(pv))}{2}}_{Diffuse} + \underbrace{GHI \times Albedo \times \left(\frac{1-\cos(Otilt(pv))}{2} - VF_{PV_R}\right)}_{Reflected} + DRBI + DRSR \quad [4]$$

B- Analytical Model

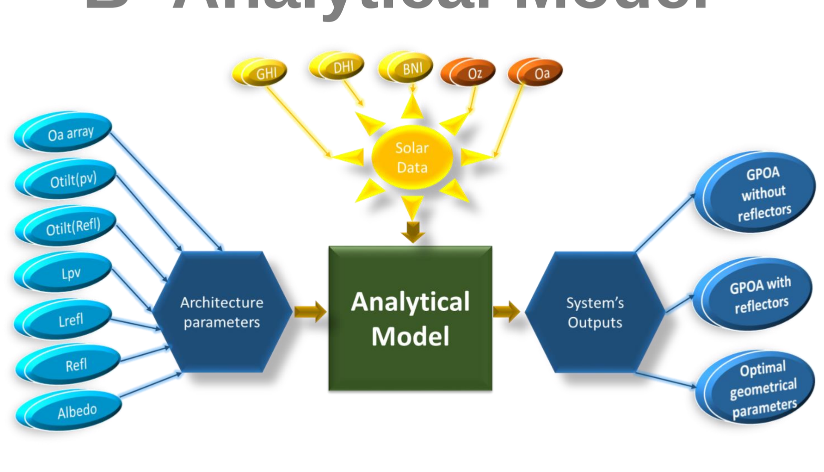

Fig. 3. GPOA estimation and optimization model

C- Geometrical optimization process

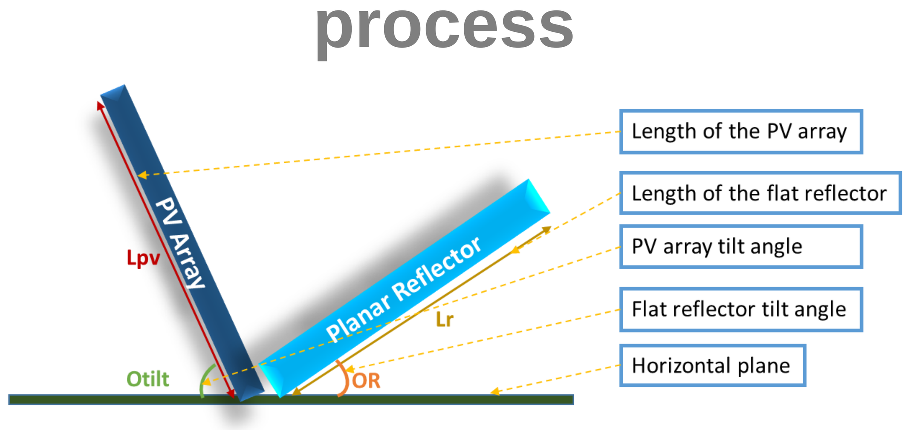

Fig. 4. Geometrical optimization parameters

Optimization strategy:

- Three possibilities for the reflector's length (Lr) were considered : Lpv/2, Lpv and 2Lpv.
- Three architectural possibilities affecting Ɵtilt and ƟR: a fixed configuration, a seasonal adjustment and a monthly adjustment.

$$G_A = 1 - \frac{\sum GPOA_{mir}(\theta tilt_{mir,optimum}, \theta R_{optimum})}{\sum GPOA\ \ (\theta tilt_{optimum})} \times 100$$

- G_A: Gain in GPOA added by the reflectors over the entire period (%).
- Ɵtiltoptimum: Optimal Otilt value obtained for the architecture without mirrors.
- Ɵtiltmir,optimum : Optimal Otilt value obtained for the architecture with mirrors.
- ƟRoptimum : Optimal OR value obtained.

C- Geometrical optimization process

Case study: Athens

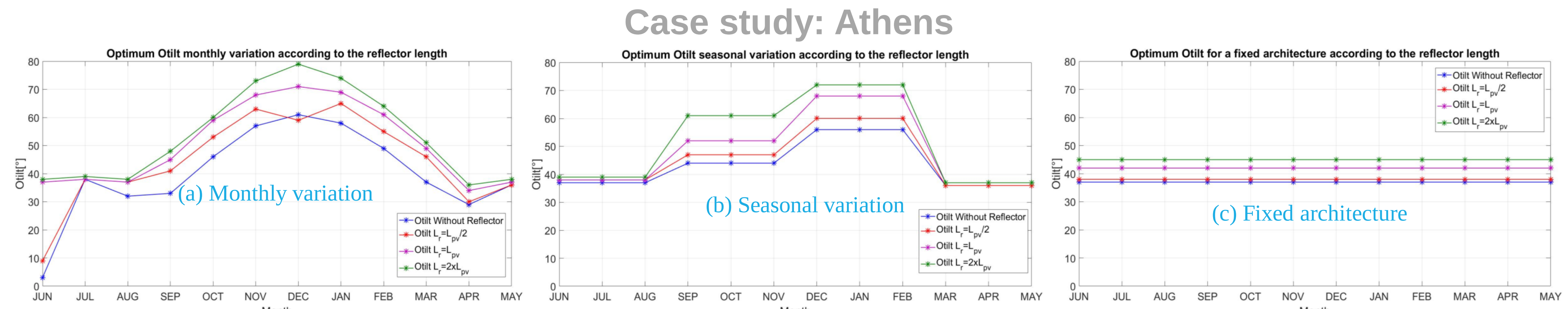

Fig. 5. Optimum Ɵtilt for Athens according to the reflector's length for monthly varied (a) seasonal varied (b) and fixed architectures (c)

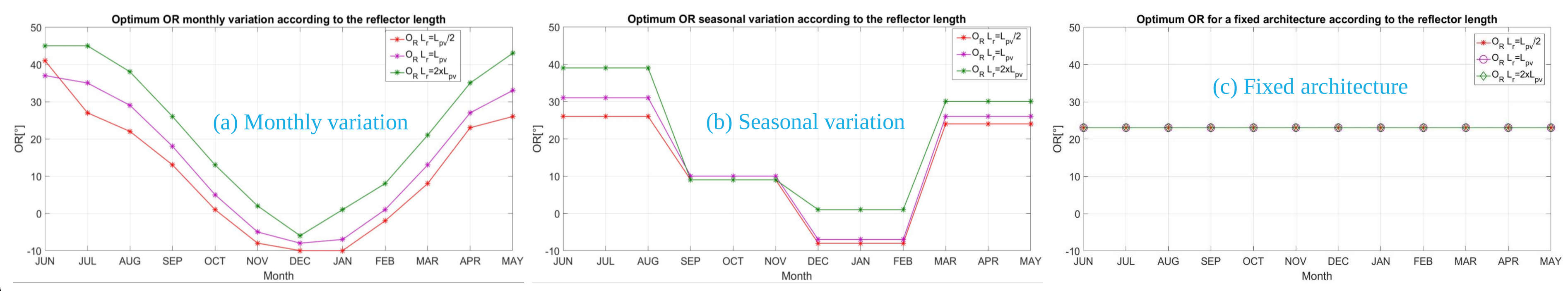

Fig. 6. Optimum ƟR for Athens according to the reflector's length for monthly varied (a) seasonal varied (b) and fixed architectures (c)

Results

A- Geometrical optimization results for Athens case study

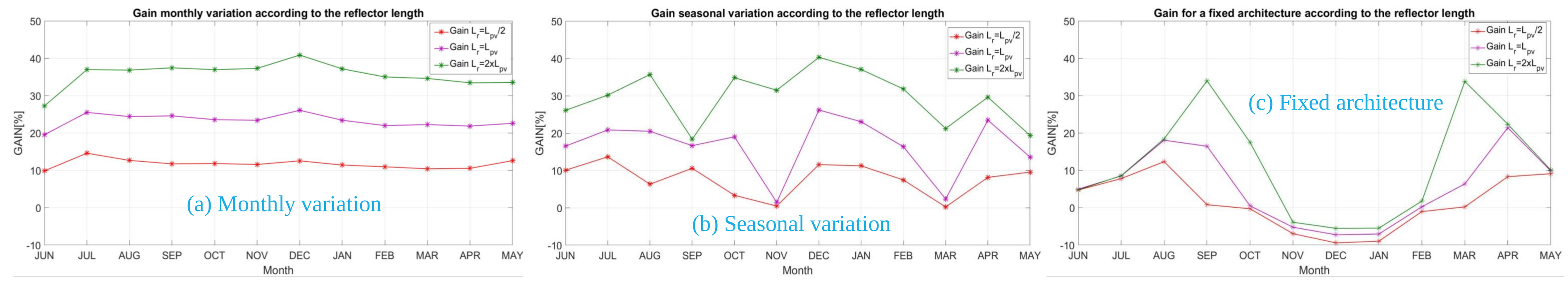

Fig. 7. Gain in GPOA for Athens according to the reflector's length for monthly varied (a) seasonal varied (b) and fixed architectures (c)

B- Computing the plane of array irradiance gain

Table 2: Gain for the optimized architectures obtained for the entire studied period (2012-2016)

Location	*Reflector's Length*	*Monthly variation*	*Seasonal variation*	*Fixed architecture*
		Gain (%)		
Oslo	Lr=Lpv/2	7.7	5.1	3.3
	Lr=Lpv	17.6	12.2	8.2
	Lr=2∗Lpv	32.0	24.3	16.1
Palaiseau	Lr=Lpv/2	7.9	5.3	2.6
	Lr=Lpv	17.1	12.0	6.9
	Lr=2∗Lpv	28.1	21.7	12.6
Chicago	Lr=Lpv/2	9.9	6.1	2.0
	Lr=Lpv	20.1	13.7	6.5
	Lr=2∗Lpv	31.7	25.1	12.4
Athens	Lr=Lpv/2	11.8	7.9	2.5
	Lr=Lpv	23.2	16.7	6.9
	Lr=2∗Lpv	35.4	29.2	12.7
Ouarzazat	Lr=Lpv/2	10.8	6.6	2.7
	Lr=Lpv	20.6	15.0	6.7
	Lr=2∗Lpv	30.5	26.3	13.9
New Delhi	Lr=Lpv/2	9.1	6.0	2.8
	Lr=Lpv	17.5	13.1	6.9
	Lr=2∗Lpv	26.7	23.2	14.9

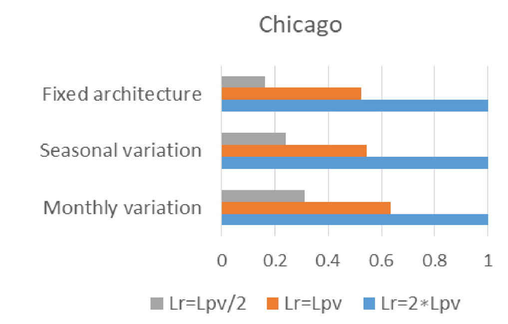

Fig. 9. Gain comparison according to the reflector's length

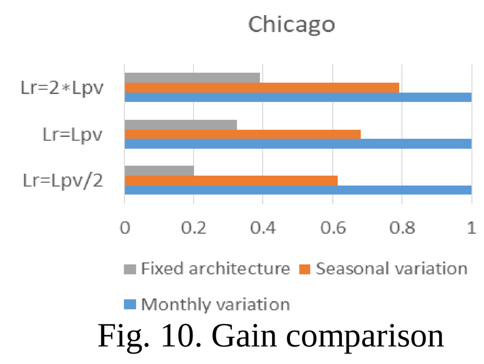

Fig. 10. Gain comparison according to the angular variation

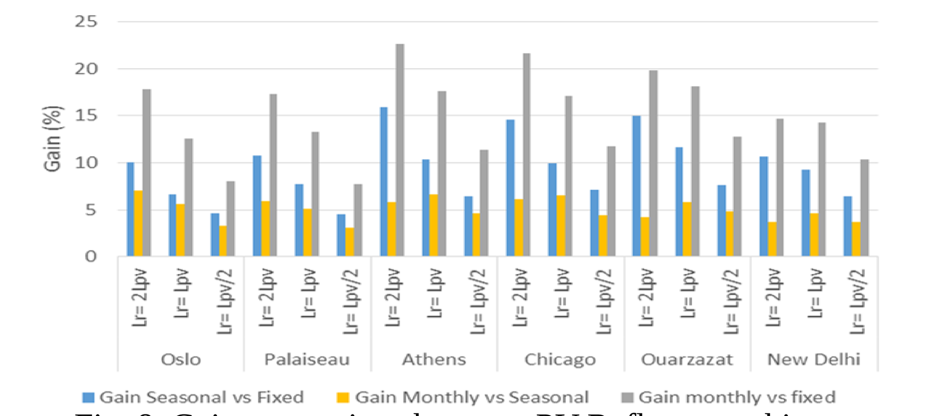

Fig. 8. Gain comparison between PV-Reflector architectures according to angular variation frequency

Conclusion

- The optimization results showed that each region requires specific considerations.
- GPOA gain doubles or triples from Lr=Lpv/2 to Lr=Lpv in monthly and seasonal variations.
- The gain does not increase similarly going from Lr=Lpv to Lr=2Lpv where the increasing ratio is lower (shading effect).
- Regions with close latitudes showed quite similar results in terms of geometrical optimization.
- The highest gain was achieved was 35% considering a monthly varied architecture with Lr=2Lpv in Athens
- Oslo presented the highest gains in fixed architectures because of its geographical location.
- A power production gain assessment will be conducted using a MPPT model developed in a previous work [1].

References

[1] Abdel Nour C., et al, "Photovoltaic system equipped with flat reflectors: new MPPT model in case of non-uniform illumination on PV modules". ", 35th European PV Solar Energy Conference and Exhibition (Eu-PVSEC), Brussels (Belgium), September 2018.
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[3] Suri, M., Huld, T., Dunlop, E. D., & Cebecauer, T. (2008). Geographic aspects of photovoltaics in Europe: contribution of the PVGIS website. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 1(1), 34-41.
[4] Gelegenis, John & Axaopoulos, Petros & Misailidis, Stavros & Giannakidis, George & Samarakou, Maria & Bonaros, Bassilios. (2015). Feasibility for the use of Flat Booster Reflectors in Various Photovoltaic Installations. International Journal of Renewable Energy Research. 5. 82-98.

Corresponding author
Christine.abdelnour@geeps.centralesupelec.fr