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Web tools concerning performance analysis and planning support for solar energy plants starting from remotely sensed optical images

Marco Morelli [a,*], Andrea Masini [b], Fabrizio Ruffini [c], Marco Alberto Carlo Potenza [a]

[a] Department of Physics, University of Milano, Via Celoria 16, 20133 Milano, Italy
[b] Flyby S.r.l., Via Puini 97, 57128 Livorno, Italy
[c] i-EM S.r.l., Via Lampredi 45, 57121 Livorno, Italy

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ABSTRACT

We present innovative web tools, developed also in the frame of the FP7 ENDORSE (ENergy DOwnstReam SErvices) project, for the performance analysis and the support in planning of solar energy plants (PV, CSP, CPV). These services are based on the combination between the detailed physical model of each part of the plants and the near real-time satellite remote sensing of incident solar irradiance.

Starting from the solar Global Horizontal Irradiance (GHI) data provided by the Monitoring Atmospheric Composition and Climate (GMES-MACC) Core Service and based on the elaboration of Meteosat Second Generation (MSG) satellite optical imagery, the Global Tilted Irradiance (GTI) or the Beam Normal Irradiance (BNI) incident on plant's solar PV panels (or solar receivers for CSP or CPV) is calculated. Combining these parameters with the model of the solar power plant, using also air temperature values, we can assess in near-real-time the daily evolution of the alternate current (AC) power produced by the plant. We are therefore able to compare this satellite-based AC power yield with the actually measured one and, consequently, to readily detect any possible malfunctions and to evaluate the performances of the plant (so-called "Controller" service). Besides, the same method can be applied to satellite-based averaged environmental data (solar irradiance and air temperature) in order to provide a Return on Investment analysis in support to the planning of new solar energy plants (so-called "Planner" service).

This method has been successfully applied to three test solar plants (in North, Centre and South Italy respectively) and it has been validated by comparing satellite-based and in-situ measured hourly AC power data for several months in 2013 and 2014. The results show a good accuracy: the overall Normalized Bias (NB) is −0.41%, the overall Normalized Mean Absolute Error (NMAE) is 4.90%, the Normalized Root Mean Square Error (NRMSE) is 7.66% and the overall Correlation Coefficient (CC) is 0.9538. The maximum value of the Normalized Absolute Error (NAE) is about 30% and occurs for time periods with highly variable meteorological conditions.

Introduction

Context

One of the major global challenges in the near future is how to provide energy in abundance, and to be able to provide this energy from sources with a limited impact on the environment. The electricity consumption in the European Union has been estimated to rise by 50% from 2000 to 2020 (Eicker, 2003) and the exploitation of renewable energy in an efficient as possible way is fundamental to face the energy demand avoiding a strong increase of air pollution.

An effective and tangible approach to solve the energy production problem, used in Italy and in other countries, involves an improvement of the use of the solar energy solution. This could be also favoured by the introduction of specific laws. The solar energy production potentialities are well known, but they have begun to be fully developed only in recent years. Given the large variability, non-easily predictable, of the solar source, the planning and installation of new power plants require a careful a priori analysis. Therefore, the presence of services able to provide an accurate estimation of available energy sources is extremely important for the investors, that are given the possibility to evaluate the repayment plan when planning new plants. A service providing this kind of information can use standard techniques, such as in-situ measurements of the solar energy available in a certain location, but this kind of approach can be significantly expensive. On the contrary, cost reductions can be the strength of alternative approaches, such as planning support systems using data remotely sensed by satellites (Mueller et al., 2009).

* Corresponding author. Tel.: +39 0586 505016.
E-mail addresses: marco.morelli1@unimi.it (M. Morelli), andrea.masini@flyby.it (A. Masini), fabrizio.ruffini@i-em.eu (F. Ruffini), marco.potenza@unimi.it (M.A.C. Potenza).

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Furthermore, when the energy plant begins its activity, a service able to monitor the productivity of the plant so to improve it and increase the efficiency is necessary for cost reductions. An effective and low-cost approach is to use a service able to compare the power actual produced with the power predicted by a model. The model uses data from satellite to evaluate the environmental parameters needed to calculate the expected power production in well-functioning conditions.

"Planner" and "Controller" web tools

In order to face the problems related to planning and monitoring of solar energy plants described before, we developed two innovative web tools based on Earth Observation (EO) optical imagery: the "Planner" and the "Controller" services.

Both the services start from temporal series of solar GHI provided by the MACC Core Service, that is calculated from Meteosat Second Generation (MSG) optical imagery by means of the Heliosat-2 algorithm (Cano et al., 1986) and the ESRA model for clear-sky solar irradiance (Rigollier, 2000).

The "Planner" service consists of a web-GIS map showing average solar irradiance (Beam Normal Irradiance for CSP or CPV plants; Global Horizontal Irradiance for PV plants) and average air temperature, both obtained from historical satellite optical imagery archive (air temperature data lacks are filled by a spatial interpolation of the data provided by the meteorological stations of the Italian AirForce). The service shows the monthly averaged expected energy yield starting from site selection and planned plant technical features, providing also an estimate of the Return on Investment (break-even point and cumulative cash-flow).

The "Controller" service, instead, is in practice of an active solar plant production monitoring web-service that, starting from the near real-time calculation of the expected energy yield based on satellite-based incident solar irradiance, can provide a malfunctioning daily detection with an embedded email/SMS alerting system.

These services are currently available for PV, CSP and CPV plants. The spatial coverage comprises Italy, North-Africa and Qatar but it's going to be extended also to other regions (such as Brazil).

Methods

Both the "Planner" and the "Controller" web services are based on a similar scheme (as shown in Fig. 1): satellite-based irradiance data and air temperature data are set as inputs to a detailed physical model of the solar energy plant (PV, CPV or CSP) and of the inverters to calculate the expected AC power yield. The solar irradiance data have 4 km spatial resolution (in Italy) and 15 minute time resolution (following the MSG satellite resolution), whilst the air temperature data could have the same resolution if obtained from MSG or 30 km of spatial resolution and 3-hourly temporal resolution if obtained from Italian AirForce measured data.

The same scheme can be applied in the frame of the "Planner" service by using environmental data retrieved from historical long time-series of satellite imagery, whilst in the "Controller" service case the satellite-based data are elaborated in near real-time (i.e. with a maximum 24 hour delay and 15-min temporal resolution) to calculate the plant's performances for monitoring purposes. The plant's modelling part of the method, of course, is different depending on the type of solar energy plant of interest.

The interfaces of both services are based on web-GIS standards (such as GeoTIFF) and data are elaborated using also the PostgreSQL database with PostGIS extension.

CSP plants

A thermodynamic solar plant uses the direct solar radiation by reflecting it towards a concentrating point where a fluid is heated. The radiation intensity is hence a fundamental parameter for the plant planning and for its financial evaluation, but it is also a critical information in the operational mode of the plant, since it allows an accurate analysis of the plant performances.

The model has been developed in the frame of the FP7-ENDORSE project (Morelli et al., 2012) adapting existing approaches both for the modelling of the irradiance incident in the one-axis sun-tracking solar receivers (Perez et al., 1990) and for the performance analysis of CSP parabolic-trough plants (Qu et al., 2010; Powell and Edgar, 2012).

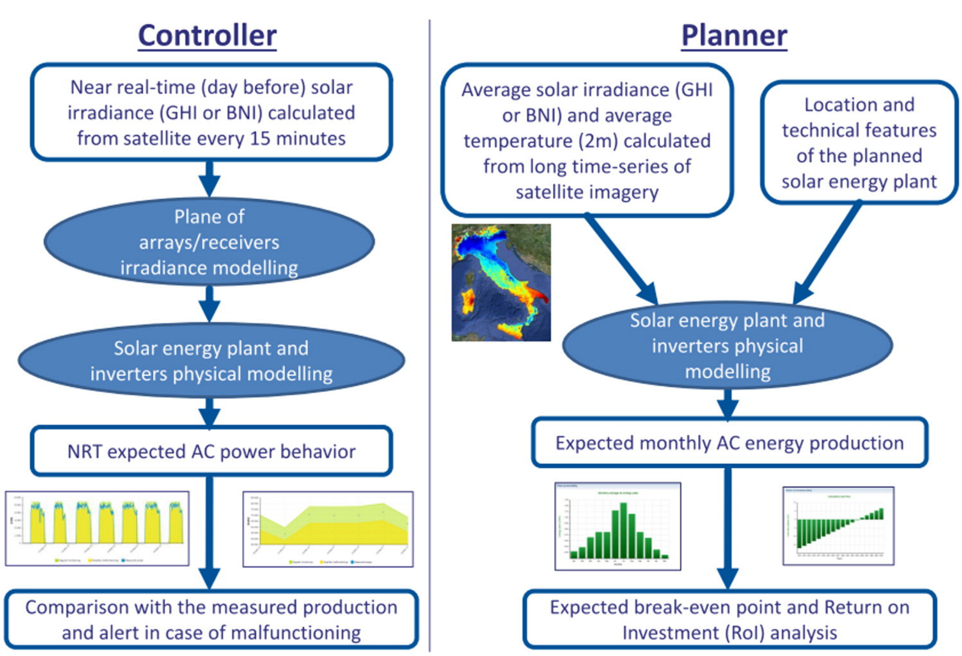

Fig. 1. General scheme of the "Controller" and "Planner" services dedicated to solar energy plants.

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