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WAVELET SYSTEM FOR INTELLIGENT MEASURING, DESIGNED TO ENHANCE THE MANUFACTURING PROCESS OF A PHOTOVOLTAIC MODULE. PRELIMINARY RESULTS

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Abstract: Intelligent measuring is related to smart systems and automated measurements of weather conditions or solar irradiance, to help the manufacturer to optimize solar cell features. Technology should strive to minimize the impact of human activity upon the environment, developing greener solutions for energy consumption. In this paper, we propose a prototype for a wavelet based system, which should analyze several parameters collected by a photovoltaic system - using the Stationary Wavelet Transform. We aim to develop a general mathematical model, which should allow us to improve the manufacturing process of the solar modules. The Stationary Wavelet Transform and several mother wavelets families were tested. The most accurate results were obtained with the Daubechies mother wavelets.

Keywords: intelligent measuring, intelligent control, smart systems, wavelet, software.

1. PROBLEM DESCRIPTION

An intelligent system aims at monitoring several parameters, which are analyzed in order to develop a product with optimal characteristics and reduced risk assessment based on the provided information. Usually, optimal metering depends on exact measured values [1, 2].

An intelligent measuring system is a modern metering device, connected to a communication unit. Intelligent control occurs through software analysis, which allows making the necessary changes and adjustments before finalizing and manufacturing the product [3, 4]. Products go through several stages before reaching the manufacturing stage:

- Development of the idea of a product;
- Research of the usefulness of the idea;
- Design of the product;
- Making of a prototype;
- Manufacture of the product.

Photovoltaics (PV) has been developed in the late 20th century, based on the principle of the photoelectric effect (electrons are loosening, when the grid is being hit a light photon) [5]. The electrons are directed and used as energy sources, generating electricity. Contrary to fossil

energy, such a source is considered a renewable energy source and is accepted globally as one of the best solutions for clean energy sources. Shortages of fossil fuel and negative impacts of their exploitation on the environment have led to an increased interest in alternative power systems, such as solar power. Time-series generated by PV systems are non-stationary due to the chaotic fluctuations of the cloud coverage and changing weather conditions. The design and manufacture of photovoltaic systems must meet specific energy needs and preferences [6]. Solar forecasting is critical for an efficient operation of solar PV systems. In this paper, we aimed to develop and test a software system based on wavelets, which should analyze the parameters of the PV system and thus help to optimize the final manufacturing process (helping the selection of the optimal materials, for example). Recent forecasting models in literature are based on data mining, artificial neural networks or machine learning models [7]. Compared to the other methods, wavelets are based on an easy to implement bank-filtering system, which does not require the adjustment of many parameters. The paper is structured in seven chapters, as follows: problem description,

application field, research stages, methods used, results, conclusions and further research, references.

2. APPLICATION FIELD

Solar cells' ability to capture the sunlight is increased through the texturing of silicon wafers, reducing the reflection of the light and maximizing the light absorption.

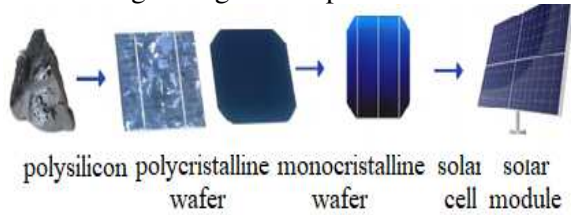


Fig. 1. Photovoltaic system.

Typically, a silicon nitride coating provides the antireflective characteristics. Metal conductors, which allow the collection of the cells' produced energy are printed onto the wafer (Figure 1). As a last manufacturing step, a precise slicing of the wafers and cell aligning is necessary as even slight variations or damages to the cells' surface can reduce the solar panel efficiency [8]. The photovoltaic modules were studied at the research institute of the West University Timisoara: the Solar Platform was built in the frame of the PN II Project PASOR 21039/2007 [9]. The PV platform is equipped with DeltaOHM first class pyranometers (LP PYRA02AC, LP PYRA12AC), measuring the global solar irradiance, the reflected solar irradiance, temperature, air pressure and relative humidity. It is generally assumed that the clouds movements across the PV system mostly cause the variable power production [10].

Unexpected changes of these parameters generate variations on the PV output power. All these parameters must be measured, as the drawbacks can be managed with several solutions (better energy storage equipment, larger capacity for power reserve [11, 12]).

We focused in this paper on developing an intelligent measuring software, using wavelets. An analysis step of the collected data is performed, the main parameters taken into consideration being: air temperature, humidity, wind speed, solar irradiance.

3. RESEARCH STAGES

Wavelets are a powerful mathematical tool for analyzing a signal at different resolutions. For example, an individual event might be outlined and zoomed to see what other details it might contain. Thus, wavelet analysis can be used to decompose the signal into several time-scale parameters, such as solar fluctuations to measure the variability at that time-scale [13]. Wavelets can be seen as waves with different amplitudes and frequencies which oscillate around a median value, so they add to zero.

Considering linear algebra, we might decompose a signal $s(t)$ into a linear combination of waves, which belong to the space spanned by the basis signal (Equation 1).

$$s(t) = \sum_n c_n \cdot \Psi_n(t) \quad (1)$$

where c_n is an expansion coefficient computed at different resolutions and frequencies (given by the index n) and $\Psi_n(t)$ is the basis function. This basis function is a flexible function called „mother wavelet“ (MW) $\Psi_{a,b}$ (Equation 2):

$$\Psi(t) = \langle s, \Psi_{a,b} \rangle = \frac{1}{|a|^{1/2}} \cdot \int_{-\infty}^{\infty} s(t) \cdot \Psi\left(\frac{t-b}{a}\right) dt \quad (2)$$

where a is a space localization parameter describing the signal in the frequency domain and b is a time localization parameter defining the signal. Any signal can be constructed through stretching and dilating the MW applied [14]. A challenge for engineers is the identification of the MW most suited for a specific task: researches have shown that the shape of the MW should be adapted to the studied event. Wavelet Transforms can also evaluate the surface roughness [15] or can be used for forecasting algorithms [16]. A specific challenge for solar systems is to correlate the irradiance values with the approximation and

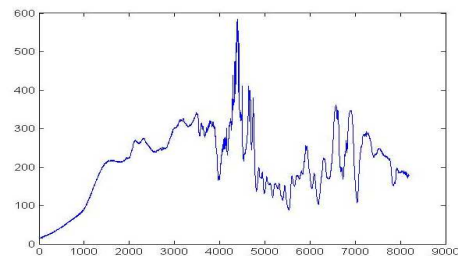


Fig. 2. SWT applied on the daily irradiance. Sample taken on 27.03.2021.

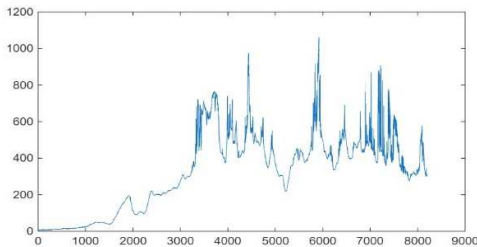


Fig. 3. SWT applied on the daily irradiance. Sample taken on 28.03.2021.

detail coefficients given by wavelet decomposition. The variations and fluctuations of the daily solar irradiance are significant to the weather condition. Sunny days display high irradiance values and smooth curves, while cloudy days show small irradiance values and more fluctuations on the irradiance curves (Figure 2, Figure 3).

4. METHODS USED

We propose a PV analysis software of solar parameters based on wavelet decomposition. The Stationary Wavelet Transform (SWT) is a transform invariant to translation, based on a filter decomposition scheme (Figure 4) – the use of decimators at each iteration level being avoided. We present some preliminary researches, the first step of our research done on PV panels. We focused on providing an analysis of the parameters measured by the PV module, so we can analyze its performance and draw some conclusions related to improvements that can be done when manufacturing the PV modules. Wavelet decomposition allows us to envisage the general tendency of a signal (through the approximation coefficients) and therefore, we can use this information to check whether various types of solar wafer reflect the same parameters under the same conditions. The wavelet decomposition has been done using Matlab2025a and the Wavelet Toolbox.

We notice that the irradiance presents great fluctuations, which may indicate changing wind or cloud movements during the day (Figure 2, Figure 3). As a comparison, the temperature is more stable and increases and decreases with the setting sun, indicating that the studied polycrystalline wafers store shortly the energy. This can be regarded as a drawback, as the performance of the solar cells decreases with increasing temperature [17]. The resistance

within the solar cells increases with higher temperature, which decreases the cells efficiency in converting sunlight into electricity. For the weather forecasting algorithm, the solar irradiance should be taken more into consideration, as it reflects more accurately the weather's changes.

5. RESULTS

The proposed algorithm was tested on real data, collected by the West University Timisoara, publicly available online [18] to enable viable comparisons between software developers. We have used the SWT, with the Daubechies (Db) mother wavelet, applied on up to 4 (four) decomposition levels, which gives us the resolution level of the signal. A value too high will produce the attenuation of the waveform, while a value too small will distort the useful signal. In Figure 4 is represented the SWT applied on the solar irradiance, to allow us to separate the signal into approximation and detail wavelet coefficients. Thus, at each iteration, different low-pass and high-pass filters are used. Their impulse responses are constructed through interpolation (Equation 3):

$$h \text{ or } g_{k+1}[n] = \begin{cases} h \text{ or } g_k \left[\frac{n}{2} \right], & n : 2 \\ 0, & \text{else} \end{cases} \quad (3)$$

where, k is the number of iteration level and n the length of the input signal.

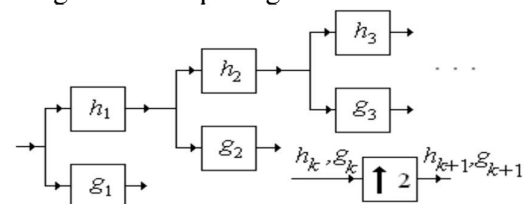


Fig. 4. Filter bank decomposition for the Stationary Wavelet Transform.

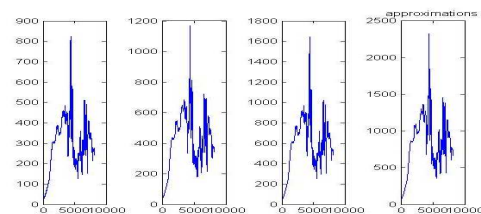


Fig. 5. Wavelet approximation coefficients of the daily irradiance. Sample taken on 27.03.2021.

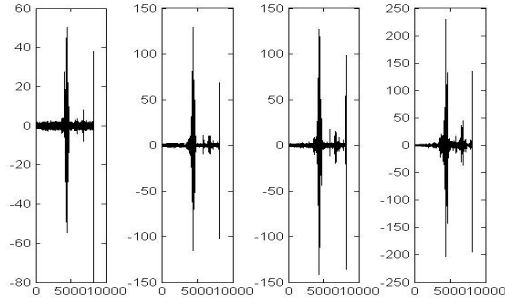


Fig. 6. Wavelet detail coefficients of the daily irradiance. Sample taken on 27.03.2021.

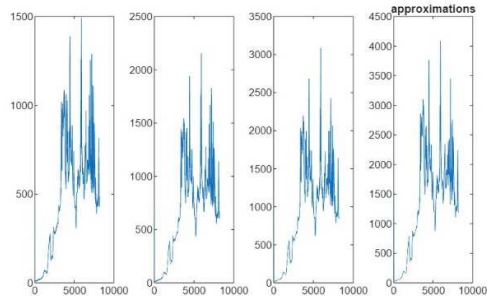


Fig. 7. Wavelet approximation coefficients of the daily irradiance. Sample taken on 28.03.2021.

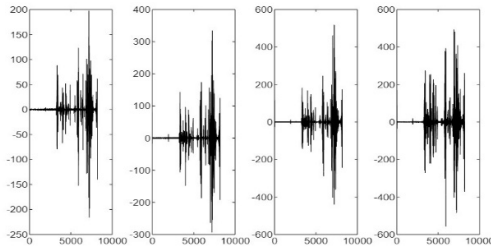


Fig. 8. Wavelet detail coefficients of the daily irradiance. Sample taken on 28.03.2021.

Analyzing Figure 5 - Figure 8, we notice that the wavelet coefficients in Figure 5 reconstruct the envelope of the signal. Approximation coefficients are the output of low-pass filters (h_i in Figure 4), and they should not affect the spectrum of the useful input signal. The wavelet coefficients noticed in Figure 5 and Figure 7 reconstruct the details of the signal and are the output of high-pass filters (g_i in Figure 4). Wavelets allow us to zoom at different frequency levels of the original signal, and we can, for example, suppress certain details for a better compression of the signal [19]. Data compression aids at the remote transmission

large quantities of data. Data can be thus further analyzed and processed.

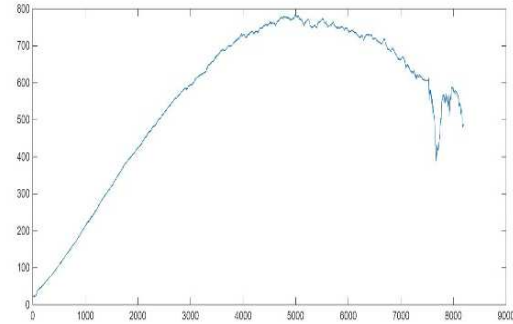


Fig. 9. SWT applied on the daily temperature. Sample taken on 27.03.2021.

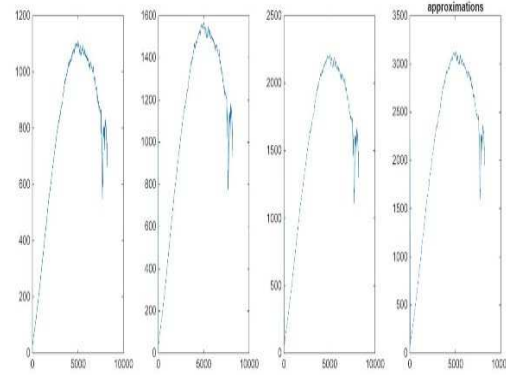


Fig. 10. Wavelet approximation coefficients of the daily temperature. Sample taken on 27.03.2021.

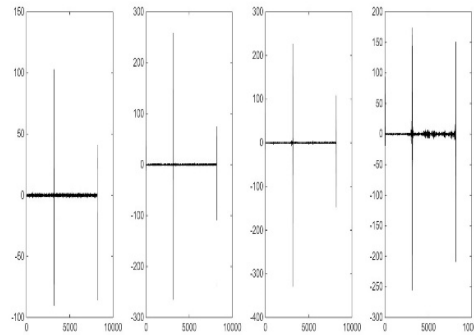


Fig. 11. Wavelet detail coefficients of the daily temperature. Sample taken on 27.03.2021.

Figure 9 represents the daily variation of the input temperature upon the solar cells. We notice a close similarity of the signal's tendency, with a more and more synthetized approximation at each decomposition level (Figure 10), while the details at each iterations are given in Figure 11, reflecting each different frequency level studied.

Based on the analysis of the data, the manufacture process of solar modules can be improved, searching which type of solar wafer reflects the highest irradiance values and the lowest temperature values, or the tilt angle for the solar module to achieve the best performances.

6. CONCLUSIONS AND FURTHER RESEARCH

The variability of weather has never been easy to predict, depending on too many variables. Forecasting is critical for an efficient operation and optimizing of solar grid-connected PV systems. In this paper, we attempt a short-range forecast, based on a few days.

We focus on interpreting some solar parameters with the aid of a powerful mathematical operator, the wavelet transform. The proposed wavelet based analysis software is a prototype, developed to see what information can be retrieved from the input values of the solar modules. The algorithm might be used to find the optimal position of the panels or the type of solar cells more suited for a given situation.

The data can also help researchers to develop a weather forecast algorithm, based on the evolution of the solar irradiance (a system useful for an optimal manufacture process of PV system).

Wavelets are a mathematical operator that allows the analysis of a signal at different depth/frequency levels. We begin with the highest resolution and zoom (using the wavelet coefficients) on the desired resolution levels to find the desired details.

We developed a prototype for a software system based on the SWT, applying the Daubechies mother wavelet on 4 levels of decomposition.

This software can be used to improve the manufacturing process of solar modules. Analyzing the registered data (the daily irradiance, or wafer's temperature), we can draw some conclusions upon the materials better suited for the construction or the tilt angle for the installation of these panels. Further research directions aim to extend the study upon different types of solar wafers (polycrystalline and

monocrystalline wafers), tilting the modules on several angles, to check the performances.

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Program bazat pe analiza Wavelet pentru sisteme de măsurare inteligentă, destinat îmbunătățirii procesului de producție a unui panou fotovoltaic. Rezultate preliminare

Sistemele de măsurare inteligentă și automata a condițiilor meteorologice sau a iradianței solare sunt create pentru a ajuta producătorul să optimizeze producția celulelor fotovoltaice. Tehnologia ar trebui să minimizeze impactul activității omului asupra mediului, propunând soluții mai ecologice pentru a suplini consumul de energie. In acest articol, propunem prototipul unui system bazat pe analiza Wavelet, destinat analizei mai multor parametri ai sistemului fotovoltaic. Vom folosi Transformata Wavelet Staționară. Scopul nostru este de a identifica un model general, care să ajute la îmbunătățirea procesului de producție a panourilor fotovoltaice. Transformata Wavelet Staționară și mai multe tipuri de undișoare mame au fost testate. Cele mai bune rezultate au fost obținute cu familia de undișoare mame Daubechies.

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