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Power spectral density and scaling exponent of high frequency global solar radiation sequences

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The part of the solar power production from photovlotaïcs systems is constantly increasing in the electric grids. Solar energy converter devices such as photovoltaic cells are very sensitive to instantaneous solar radiation fluctuations. Thus rapid variation of solar radiation due to changes in the local meteorological condition can induce large amplitude fluctuations of the produced electrical power and reduce the overall efficiency of the system. When large amount of photovoltaic electricity is send into a weak or small electricity network such as island network, the electric grid security can be in jeopardy due to these power fluctuations. The integration of this energy in the electrical network remains a major challenge, due to the high variability of solar radiation in time and space. To palliate these difficulties, it is essential to identify the characteristic of these fluctuations in order to anticipate the eventuality of power shortage or power surge.

The objective of this study is to present an approach based on Empirical Mode Decomposition (EMD) and Hilbert-Huang Transform (HHT) to highlight the scaling properties of global solar irradiance data $G(t)$.

The scale of invariance is detected on this dataset using the Empirical Mode Decomposition in association with arbitrary-order Hilbert spectral analysis, a generalization of (HHT) or Hilbert Spectral Analysis (HSA). The first step is the EMD, consists in decomposing the normalized global solar radiation data $G'(t)$ into several Intrinsic Mode Functions (IMF) $C_i(t)$ without giving an a priori basis. Consequently, the normalized original solar radiation sequence $G'(t)$ can be written as a sum of $C_i(t)$ with a residual r_n. From all IMF modes, a joint PDF $P(f,A)$ of locally and instantaneous frequency f and amplitude A, is estimated. To characterize the scaling behavior in amplitude-frequency space, an arbitrary-order Hilbert marginal spectrum is defined to:

$$I_q(f) = \int_0^{\infty} P(f,A)A^q dA \qquad (1)$$

with $q \geqslant 0$ In case of scale invariance: $I_q(f) \sim f^{-\Psi(q)}$, $\Psi(q)$ is the scaling exponent. This allows to characterize the scaling behavior of a process: fractal or multifractal with intermittent properties. For $q = 2$, the Hilbert spectrum is defined. In this work, The data are collected at the University site of Guadeloupe, an island in the West Indies, located at $16°15$ N latitude $60°30$ W longitude. Our measurements sampled at 1 Hz were performed during one year period. The analyzed data present a power spectral density $E(f)$ displaying a power law of the form $E(f) \sim f^{-\beta}$ with $1.6 \leqslant \beta \leqslant 2.2$ for frequencies $f \leqslant 0.1$ Hz, corresponding to time scales $T \geqslant 10$ s. Furthermore, global solar radiation data possesses multifractal properties. For comparison, other multifractal analysis techniques such as structure functions, MDFA, wavelet leaders are also used. This preliminary work set the basis for further investigation dedicated to simulate and forecast a sequence of solar energy fluctuation under different meteorological conditions, in the multifractal framework.