Power Quality in distribution power networks with photovoltaic energy sources

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***Abstract*- Solar radiation is characterized by short fluctuations introduced by passing clouds. These solar fluctuations will produce Voltage and power fluctuations at the PCC (Point of common coupling). Flicker level should be evaluated by using a flickermeter according to the standard IEC 61000-4-15. Models of the solar fluctuation, photovoltaic modules and power converter are shown in this paper and the flickermeter model is tested according to the IEC requirements and the CIGRE/CIRED/UIE test protocol.**

***Index Terms* – Power quality, Flicker, PV.**

I. INTRODUCTION

Due to the increasing penetration of distributed generation in electric power systems, power quality is becoming of crucial importance for the further deployment of renewable generation.

The irregular solar radiation is considered to be one of the main drawbacks of the large-scale application of photovoltaic (PV) in distribution networks. Moving clouds can produce fast and short irradiance fluctuations, which can produce voltage fluctuations in power networks. This effect is more important in weak residential and rural grids with high series resistance.

Flicker is defined as the impression of fluctuating brightness or color, occurring when the frequency of observed variation lies between a few hertz and the fusion frequency of images according to the IEEE standard dictionary of electrical and electronic terms (IEEE standard 100-1977). The flicker level is dependent on the amplitude of the voltage fluctuation, their frequency, and the shape of the waveform. All types of voltage fluctuations may be assessed by direct measurement using a Flickermeter, which complies with the specification given in IEC-61000-4-15 [1].

A test protocol is proposed by the CIGRE/CIRED/UIE voltage quality working group [2] to characterize the performance of existing flicker meters in the field.

In this paper, voltage fluctuation in power networks with photovoltaic energy sources will be analyzed and a flickermeter model will be used for the evaluation of the flicker assessment under sunny and cloudy situations.

II. DESCRIPTION OF THE MODEL

The scheme used for the implementation of the model is shown in Fig. 1.

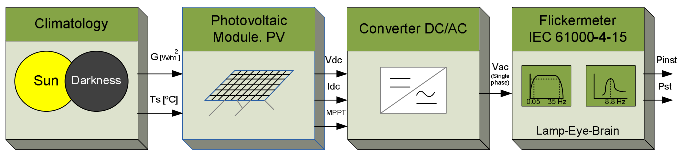

Figure. 1. Block diagram of the whole system.

A. Climatology

This block represents the effect that weather has on the PV generation. The outputs of this block are solar radiation G (W/m^2) and temperature T (ºC). Previous studies modeled this effect on photovoltaic panels [3], [4]. The effect of sunlight on a PV and its connection to the network through a converter is simulated in [5]. The purpose of all these studies is to calculate the Maximum Power Point Tracking (MPPT) to get the most use of the solar resource for getting maximum power production.

In this study, different weather scenarios will be taken into account. Such as the presence of solar radiation to a greater or lesser intensity depending on time, day and season or the presence of darkness caused by obstacles, clouds or other elements.

B. Photovoltaic module. PV

This block defines the characteristics of solar cells and their interconnection to the power network.

Some authors have used a model of solar cell consisting of five parameters [3], [5] that allow obtaining the inherent non-linear current voltage (I-V) relationship of a typical PV cell. To obtain the curves we use the features provided by the modules manufacturers. In this study the model of the solar cell shown in Fig.2 will be used.

In the presence of solar radiation, the diode (D) produces a current called Isc (Short-circuit current). This current is directly proportional to the solar radiation on the cell. Cell works as a diode. During darkness the solar cell is not an active device.

A control method for calculating the MPPT point will be applied. This model will allow obtaining the current Idc and the voltage Vdc, of the PV in these conditions.

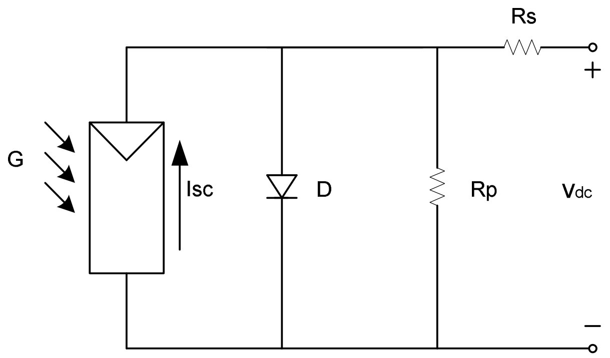

Figure. 2. Equivalent circuit model of a solar cell.

C. Converter DC/AC

This block contains a voltage converter from the PV voltage Vdc to the Vac that is injected to the power network. For the connection to the network it is necessary to use a power transformer at the PCC (Point of Common Coupling). Both are included in this block.

D. Flickermeter model

The flickermeter model [1] is composed by the following 5 blocks:

- Block 1: Input voltage adaptor
  This block includes a voltage adapting circuit that scales the RMS value of the input voltage down to an internal reference level.

- Block 2: Squaring
  This block simulates the squaring part of the lamp model. The lamp model consists of a squaring function and a low pass filter function.

- Block 3: Filtering
  a) Demodulator filter
  The demodulator filter consist of a first order high pass filter for suppressing the direct current component and a low pass filter for suppressing all components equal to or greater than the fundamental frequency of the carrier voltage.
  b) Weighting filter
  The weighting filter simulates the frequency response of a coiled coil filament gas filled lamp and the human visual system. The transfer function is of the following type:

$$\underline{F}_W(s) = \frac{k\omega_1 s}{s^2 + 2\lambda s + \omega_1^2} \frac{(1+s/\omega_2)}{(1+s/\omega_3)(1+s/\omega_4)}$$

  Where s is the Laplace complex variable and the constant values are given in [1].

- Block 4: Variance estimator
  This block, called non-linear variance estimator, is composed by a squaring multiplier and a first order low pass filter with a time constant of τ = 300ms. The purpose of this block is to simulate the storage effect of the human brain. The time signal at the output of block 4 represents the instantaneous flicker sensation, $P_{inst,max}$.

- Block 5: Statistical analysis
  Block 5 basically represents a statistical method that classifies and computes the short term Flicker level P_{st}.

In this study, the flickermeter model will be used to obtain flicker level (P_{st}) at the PCC where both the photovoltaic plant and the residential area are connected.

III. Experimental Results

The current version of IEC61000-4-15 [1] specifies a performance test limited to a set of rectangular voltage fluctuations. The CIGRE/CIRED/UIE Joint Working Group on Voltage Quality has defined several different test voltage patterns [2], (seeTable I).

The additional tests with specific voltage fluctuation patterns are introduced with the goal to standardize the technical implementation of Flickermeters. In comparison tests it was shown that commercial Flickermeters connected in parallel to the same voltage source with arbitrarily selected voltage fluctuation patterns, yielded substantially different P_{st} values, even though all Flickermeter manufacturers claimed that their products meet the voltage fluctuation tests specified in IEC 61000-4-15 [1].

A. Test #1: Rectangular Voltage Modulation Performance.

For all voltage fluctuations tabulated in Table II the flicker severity indicator P_{st} must be within the range of P_{st} = 1.000·(1.00 ±5%). Test that did not pass the Test Protocol are green marked.

TABLE I

Summary of Test Protocol

Category	Test	Excitation Signal	Output
IEC 61000-4-15	1	Rectangular fluctuation	Pst
	2	Rectangular fluctuation	$P_{inst,max}$
	3	Sinusoidal fluctuation	$P_{inst,max}$
No Influence test	4	Frequency variation	Pst
	5	High Frequency	$P_{inst,max}$
	6	Linearity	Pst
Influence test	7	Single Interharmonic	$P_{inst,max}$
	8	Harmonic-Interharmonic Pairs	$P_{inst,max}$
	9	Phase Jump	Pst
	10	Interruptions	Pst t
Complex Systematic	11	Wood Chipper pattern Rolling Mill pattern Arc Furnace pattern	Pst

TABLE II

Results for Test #1

Rectangular changes per minute	Pst results		Pst results	
	120-V lamp 60 Hz system	230-V lamp 50 Hz system	120-V lamp 50 Hz system	230-V lamp 60 Hz system
1	0.9999	0.9830	1.0015	0.9827
2	1.0135	1.0170	1.0137	1.0155
7	0.9758	0.9804	0.9864	0.9795
39	0.9911	0.9933	0.9917	0.9947
110	0.9952	0.9923	1.0010	0.9927
1620	0.9957	0.9972	0.9964	0.9968
4000	Test not required	1.2385	1.2383	Test not required
4800	1.0573	Test not required	Test not required	1.0575
Note: 1620 rectangular changes per minute corresponds to a rectangular square wave modulation frequency of 13.5 Hz.				

TABLE III

Results for Test #2

Hz	Pst results		Pst results	
	120-V lamp 60 Hz system	230-V lamp 50 Hz system	120-V lamp 50 Hz system	230-V lamp 60 Hz system
0.5	0.9960	0.9902	0.9958	0.9905
3.5	0.9985	0.9919	0.9962	0.9902
8.8	1.0031	0.9933	1.0006	0.9948
18	0.9993	0.9872	0.9894	0.9937
21.5		0.9876		
22	0.9950			0.9874
25		0.9993	1.005	
25.5	0.9939			0.9877
28		1.0325	1.0391	
30.5		1.0548	1.0530	
33+1/3	1.0440	0.7194	1.5428	1.0246
37	0.9956			0.9990
40	1.1231			1.1186

TABLE IV

Results for Test #3

Hz	Pst results		Pst results	
	120-V lamp 60 Hz system	230-V lamp 50 Hz system	120-V lamp 50 Hz system	230-V lamp 60 Hz system
0.5	0.9996	0.9939	0.9996	0.5304
1.5	0.9999	0.9934	0.9999	0.9934
8.8	0.9999	0.9937	1.0000	0.9937
20			1.0012	0.9920
25	0.9926	1.0040		
33+1/3	1.0518	1.5310	1.5427	1.0450
40	1.1311			1.1244

TABLE V

Results for Test #4

Power frequency (Hz)	Pst
49	0.9925
49.5	0.9926
50.5	0.9956
51	0.9948

TABLE VI

Results for Test #6

Pst results		
120-V lamp 60 Hz system	230-V lamp 50 Hz system	Pst = (1.00 ± 0.05)*(ɤ) ± 0.1
0.1917	0.1905	0.2 ± 0.1
1.9912	1.9852	2 ± 0.1
4.9547	4.9587	5 ± 0.1
9.9363	9.9324	10 ± 0.1
19.773	19.74	20 ± 0.1

B. *Test #2: Normalized Response for Rectangular Voltage Fluctuations.*

This test is to verify that the voltage modulation levels, for a maximum instantaneous value Pinst,max of 1.00 are within a tolerance of ± 0.05 of the voltage modulation percentages given in IEC 61000-4-15. Table III shows the results for Test #2.

C. *Test #3:Normalized Response for Sinusoidal Voltage Fluctuations.*

To perform a further evaluation of flickermeter implementations, sinusoidal modulation tests points have been defined in IEC 61000-4-15, Amendment 1 Table 1. Test #3 is to verify that the voltage modulation levels for a maximum instantaneous value Pinst max of 1.00 are within a tolerance of +/- 5% of the voltage modulation percentages given in IEC 61000-4-15,Amendment 1 Table 1. Table IV shows the results for Test #3.

D. *Test #4: Power Frequency Variation.*

The purpose of this test is to verify that a steady state frequency, within a specified tolerance of the nominal frequency, does not result in light flicker. A test point passes if the result is Pst of 1.00 ± 0.05. Table V shows the results for Test #4.

E. *Test #6: Linearity.*

This test will show whether the measured Pst has a linear relationship to the amplitude of the voltage fluctuations in the range 0.2 to 20.Table VI shows the results for Test #6.

IV. Conclusions.

In this paper, a detailed model of the flickermeter according to the IEC 61000-4-15 has been shown. The flickermeter model fulfils the requirements defined in the IEC 61000-4-15 standard. Additionally, it has been tested under additional tests defined in the CIGRE/CIRED/UIE test protocol.

Once the flickermeter model has been validated, it will be used for evaluating the flicker severity and the voltage fluctuations produced by photovoltaic energy sources.

Research studies have proved that irregular solar irradiation caused by cloud movement can produce voltage and power fluctuation from PV sources. For voltage fluctuation and flicker assessment is necessary to use a flickermeter such as the one shown in this paper.

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