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POWER QUALITY IN DISTRIBUTION POWER NETWORKS WITH PHOTOVOLTAIC ENERGY SOURCES

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Index

- Introduction
- Description of the model
- Experimental results
- Conclusions
- References

INTRODUCTION

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.

Introduction

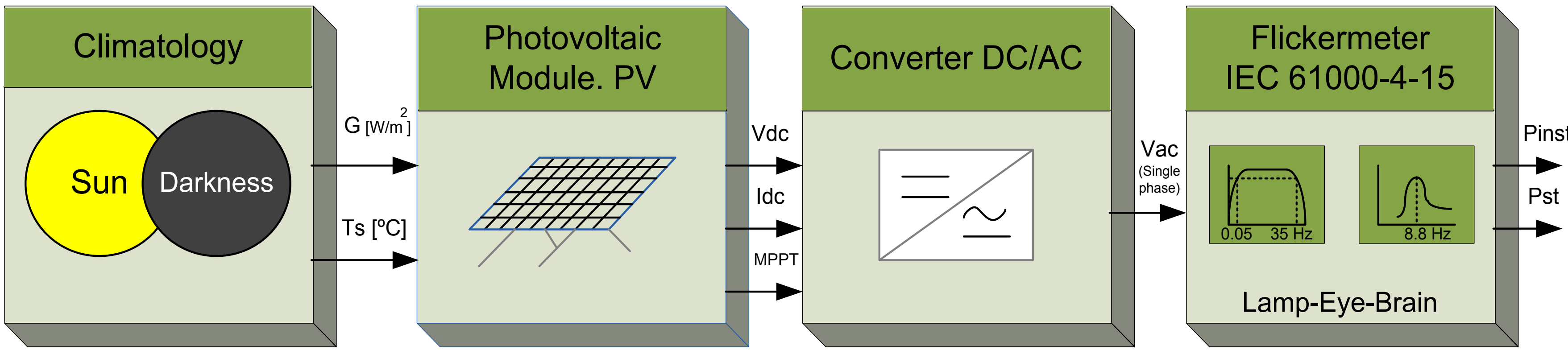
- Flicker is defined as the impression of fluctuating brightness or color, occurring when the frequency of observed variation lies between a few hertz and the fusion frequency of images.
- The flicker level is dependent on the amplitude of the voltage fluctuation, their frequency, and the shape of the 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.

Introduction

- A test protocol is proposed by the CIGRE/CIRED/UIE voltage quality working group 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.

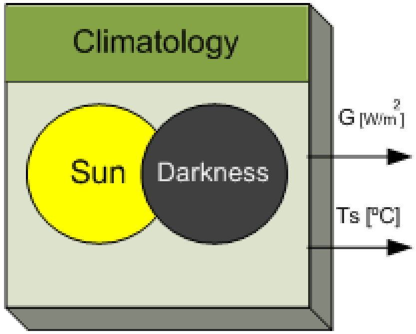
DESCRIPTION OF THE MODEL

Description of the Model



Block diagram of the whole system.

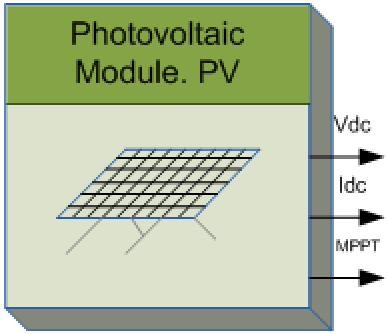
Description of the Model



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

- 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.

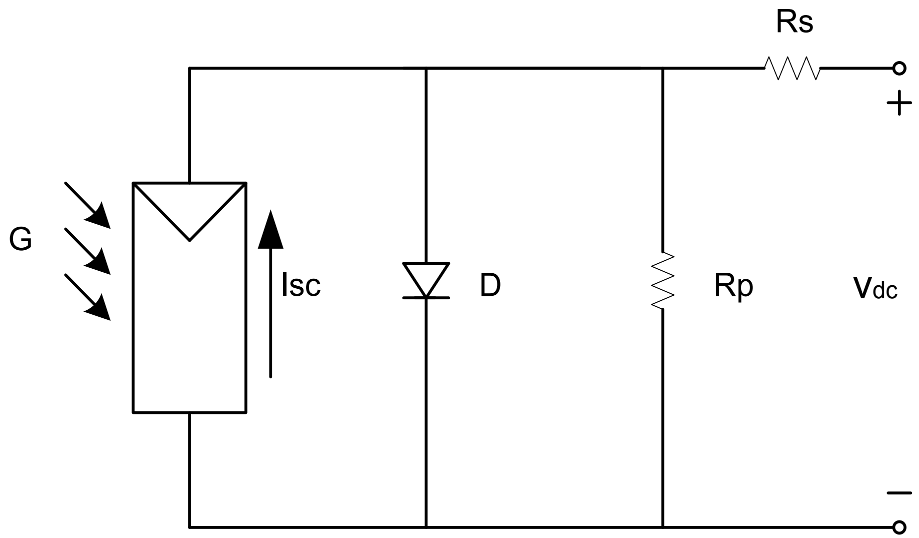
Description of the Model



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).

- To obtain the inherent non-linear current voltage (I-V) relationship of a typical PV cell we use the features provided by the modules manufacturers.
- A control method for calculating the MPPT point will be applied. This model will allow obtaining the current I_{dc} and the voltage V_{dc}, of the PV in these conditions.

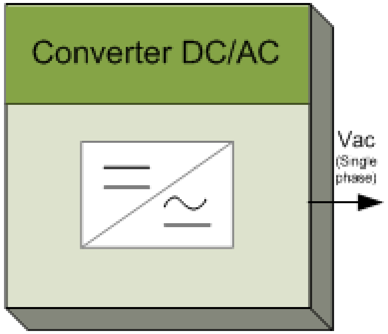
Description of the Model



Equivalent circuit model of a solar cell.

- In the presence of solar radiation, the diode (D) produces a current called I_{sc} (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.

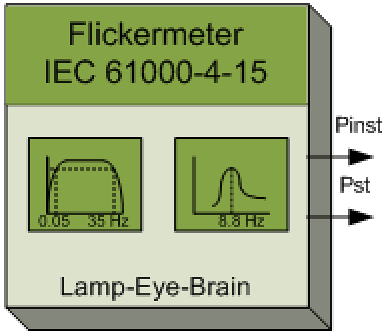
Description of the Model



This block contains a voltage converter from the PV voltage V_{dc} to the V_{ac} 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.

Description of the Model



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.

The flickermeter model 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.

Description of the Model

- 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:

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

Description of the Model

- 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}.

EXPERIMENTAL RESULTS

Experimental Results

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

Experimental Results

Test. Rectangular Voltage Modulation Performance.

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.				

Experimental Results

Test. Normalized Response for Rectangular Voltage Fluctuations.

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

Experimental Results

Test. Normalized Response for Sinusoidal Voltage Fluctuations.

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

Experimental Results

Test. Power Frequency Variation.

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

Experimental Results

Test. Linearity.

Pst results		
120-V lamp 60 Hz system	230-V lamp 50 Hz system	Pst = (1.00 ± 0.05)*(γ) ± 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

CONCLUSIONS

Conclusions

- In this study, 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.
- 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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