VOLTAGE FLICKER ASSESSMENT OF A WEAK SYSTEM INTEGRATED WIND FARM

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ABSTRACT

The subject of this paper is voltage flicker prediction and mitigation in the wind farm. Wind energy conversion systems produce fluctuating output power, which may cause voltage fluctuations and flicker. Accurate models for voltage flicker prediction are required so that large wind turbines may be connected to weak utility networks, in the confidence that excessive flicker levels will not occur. The problem is that flicker prediction in networks may be difficult since its evaluation requires long field testing time.This paper presents an analysis and the modeling of the flicker emission of wind turbines. Measurements compared with international standards(IEC 61000-4-15 and 61400-21) are discussed. It gives error analysis and correction method of the model. In addition, the error analysis of the demo model in MATLAB/SIMULINK is also discussed.

1. INTRODUCTION

The wind farm grid wind power, wind conditions, the wind turbine characteristics and grid position will cause the voltage fluctuation and flicker influential. This article discusses the problem of voltage fluctuation and flicker caused Romania distributed wind field grid. Through the main transformer which changes the voltage from 690V to 20kV, the wind farm connected to the station which changes the voltage from 20kV to 110kV by the overhead lines. The PCC (point of the common connection) of the short circuit capacity is 27MVA. The impedance angle is 70 °. As the short-circuit capacity of the system is only about three times of the installed capacity of the wind farm which is about 9MVA, it produces voltage fluctuations and flicker seriously. In order to ensure that it meets the network requirements, the need to calculate the actual flicker severity is the basis of the engineering of the design capacity of reactive power compensation.

According to the IEC61400-21 and IEC61000-4-15 standards, as well as GB/T 20320-2006 for wind farm voltage fluctuations, the simulation system consists of two parts: modelling of flickermeter based on IEC and modelling of the virtual grid system. Based on the country's wind turbine test data, the simulation system calculates the flicker value at the PCC of.

2. IEC FLICKER TEST SYSTEM MODELING

2.1 The principle of the IEC Flicker

The IEC61000-4-15 gives the flicker test simulation system complete block diagram and simulates the chain of "lamp-eye-brain". According to the block diagram (shown as Fig.1.1), we can design the flickermeter based on IEC standard which tests frequency range of 0.05~35Hz and has the most effective test at the nearby of 8.8Hz.

The flicker meter consists of three parts:

The frist part of the module 1 is composed of voltage input adapted to be suitable for the voltage value of the instrument, and the standard modulation wave voltage for the instrument self-test;

The second part of Module 2, Module 3 and Module 4 consists of the chain of "lamp-eye-brain". Among them, the role of the module 2 simulates lamp with square detection method; the module 3 simulates the human eye characteristics; the module 4 of the simulates the human brain for visual reflecting the memory effect;

The third part of module 5 statistical analysis the instantaneous flicker sensation level.

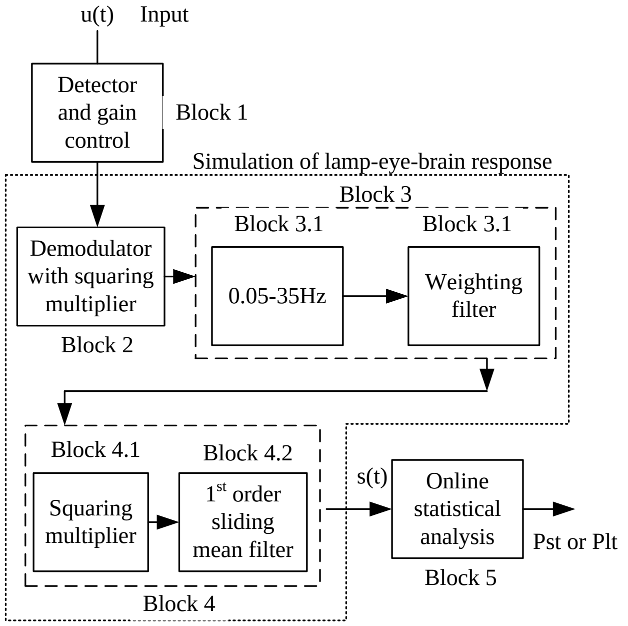

Fig. 1.1 Functional diagram of IEC flickermeter

2.2 Analysis the feature of the blocks

Voltage fluctuations can be regarded as the carrier voltage wave modulate by a voltage fluctuation component. For any waveform amplitude modulated wave can be seen as the synthesis of the various frequency components. The following analysis of the wave contains only a single frequency carrier. The wave analytic formula is shown as formula(2.1):

$$v(t) = V_m(1 + m\cos\omega_F t)\cos\omega_0 t \tag{2.1}$$

The result of squaring the voltage wave is shown as formula (2.2):

$$\begin{aligned} v^2(t) &= \\ & V_m^2(1 + 2m\cos\omega_F t + m^2\cos^2\omega_F t)\cos^2\omega_0 t \\ &= \frac{V_m^2}{2}(1 + \frac{m^2}{2}) + V_m^2 m\cos\omega_F t \\ &+ \frac{V_m^2 m^2}{4}\cos 2\omega_F t + \frac{V_m^2}{2}(1 + \frac{m^2}{2})\cos 2\omega_0 t + \cdots\cdots \end{aligned} \tag{2.2}$$

As m << 1, amplitude wave voltage multiplier component is smaller than the amplitude of the voltage of the modulated wave, so it can be negligible and when it is passed through a band pass filter which the dc component and the high-frequency component was filtered out. It will be described by the S-function and its frequency-domain characteristics.

0.05~35Hz band pass filter consists by a high-pass filter whose cut-off frequency is 0.05Hz and a low-pass filter whose cut-off frequency is 35Hz.

The 1st order high-pass filter transfer function whose cut-off frequency is 0.05 Hz is shown as formula (2.3) :

$$HP(s) = \frac{s/\omega_c}{1 + s/\omega_c} \tag{2.3}$$

Where:

$$\omega_c = 2\times\pi\times 0.05$$

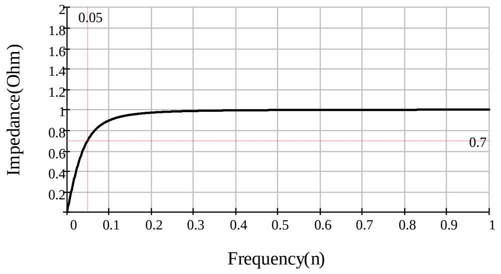

Fig. 2.1 The 1st order high-pass filter

The 6th order Butterworth low-pass filter whose the cut-off frequency is 35Hz is shown as formula (2.4) :

$$HL(s) = \frac{a}{s^6 + b\cdot s^5 + c\cdot s^4 + d\cdot s^3 + e\cdot s^2 + f\cdot s + a} \tag{2.4}$$

Where:

$$\omega_b = 2\times\pi\times 35,\ a = 1\times\omega_b^6,\ b = 3.86\times\omega_b,$$
$$c = 7.46\times\omega_b^2,\ d = 9.14\times\omega_b^3,$$
$$e = 7.46\times\omega_b^4,\ f = 3.86\times\omega_b^5$$

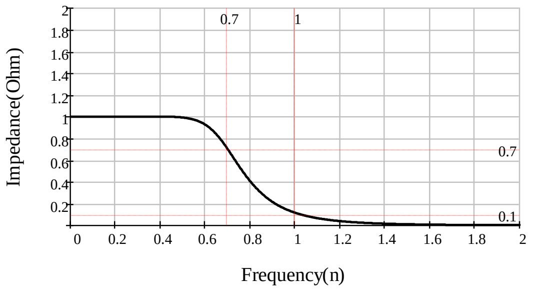

Fig. 2.2 The 6th Butterworth low-pass filter

Visual sensitivity weighting filter transfer function, is shown as formula (2.5), it can be further divided into two parts: a second order low-pass filter and the compensation part.

$$K(s) = \frac{k\omega_1 s}{s^2 + 2\lambda s + \omega_1^2}\times\frac{1 + s/\omega_2}{(1 + s/\omega_3)(1 + s/\omega_4)} \tag{2.5}$$

Where:

$$k = 1.74802,\ \lambda = 2\times\pi\times 4.05981,$$
$$\omega_1 = 2\times\pi\times 9.15494,\ \omega_2 = 2\times\pi\times 2.27979,$$
$$\omega_3 = 2\times\pi\times 1.22535,\ \omega_4 = 2\times\pi\times 21.9$$

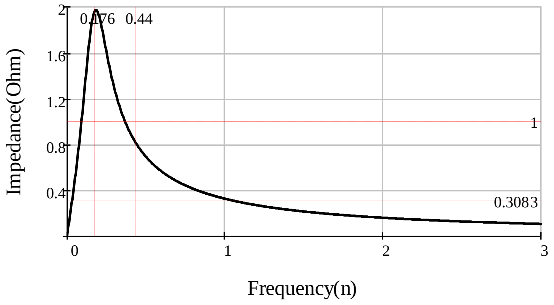

Fig. 2.3 the sensitivity weighting filter transfer function

Block 4 having a 1st order low-pass filter plays a smoothed effect. It can be used to simulate the human brain 's memory effect. The 1st order low pass filter transfer function is shown as formula (2.6):

$$HL(s) = \frac{1}{1 + s\cdot\tau} \tag{2.6}$$

Where:

$$\tau = 0.3$$

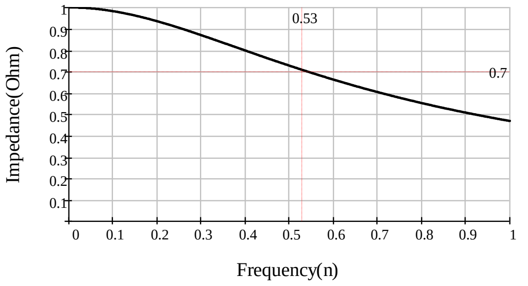

Fig. 2.4 A first-order low-pass filter

The instantaneous flicker sensitivity of the output time interval sampling is divided into L-level, then based on the probability of the data distribution histogram, we can make the histogram of which calls CPF. The worth the histogram of CPF is that it reflects the percentage of the instantaneous flicker value exceeds a certain limit of time. The short-term flicker severity values can be calculated by the formula (2.7):

$$p_{st}=\sqrt{K_{0.1}P_{0.1}+K_1P_1+K_3P_3+K_{10}P_{10}+K_{50}P_{50}} \qquad (2.7)$$

Where:

$$K_{0.1}=0.0314, K_1=0.0525,$$

$$K_3=0.0657, K_{10}=0.28,$$

$$K_{50}=0.08,$$

2.3 The error analysis of the model

Standard test data (instantaneous visual sensitivity S(t)=1) is the basis for testing. The curve of the data is shown as Fig. 2.5:

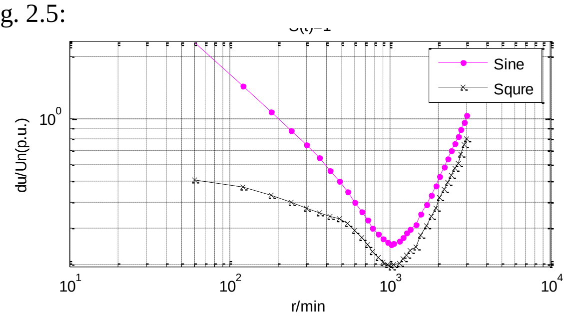

Fig. 2.5 The curve of the standard test data

According to the formula (2.7), the error is smaller as the Pst closer to the value of 0.714 , otherwise the error is larger.

Matlab comes with two examples of Flickermeter model, which divided into S-domain simulation analyzer method and the Z-domain Z-domain simulation analyzer method. They are both in accordance with IEC standard, this paper compares the error of the two flickermeters also. the test results are shown as Fig.2.6 and Fig.2.7:

1) self-built simulation model in this paper compared to the model that comes with Matlab, the calculated value is slightly higher , closer to the theoretical calculation value of 0.714;

2) these three models can be fitted well within a range of 3-25Hz by IEC test data , but at the low frequency band there is a certain error , this can be compensated by adding low frequency correction function.

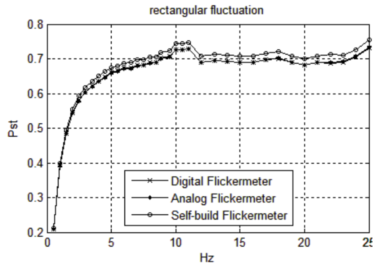

Fig. 2.6 The rectangular voltage fluctuations

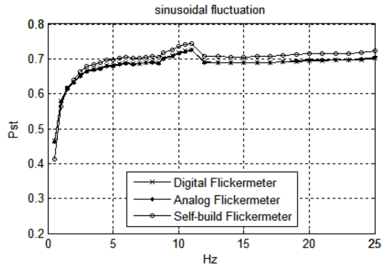

Fig. 2.7 The sinusoidal voltage fluctuations

3. CHANGES BASED ON VIRTUAL GRID WIND POWER GRID FLASH TEST

As the acquired test data is based on domestic test field, when the wind turbine connects to the actual power system, the flicker value related to the capacity of the system and the line impedance angle. This paper assesses the grid voltage flicker pre by the program of virtual grid method recommended by IEC61400-21.

Virtual grid consists of an ideal voltage source , a resistor and an inductor in series constituted and an analogue output characteristics of the current source, as shown in (3.1).

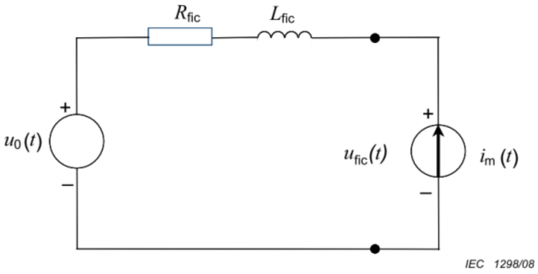

Fig. 3.1 Virtual grid

The instantaneous value of the line current of the wind turbine output is measured in 10 minutes. The waveform of the line current is shown as Figure (3.2) shows.

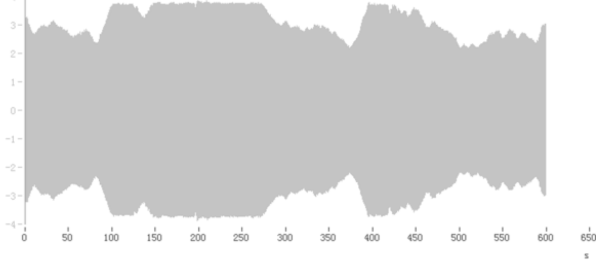

Fig. 3.2 The current waveform of out-side (10mins)

1) The ideal voltage source ia defined as equation (3.1)

$$u_0(t)=\sqrt{\frac{2}{3}}U_n\sin(\alpha_m(t)) \qquad (3.1)$$

The measuring the electrical angle of the fundamental voltage is as defined as formula (3.2):

$$a_m(t)=2\pi\int_0^t f(t)dt+\alpha_0 \qquad (3.2)$$

The ideal voltage source should have the following two characteristics:

a. Ideal voltage source should not be any fluctuations;

b.The ideal voltage source must have the same electrical angle of the fundamental with the measured voltage , thus ensuring correct the phase angle by PLL.

2) When the short circuit capacity of the systems and the impedance angle known, we can use Equation (3.3) to calculated the $S_{k,fic}$ and $\tan(\psi_k)$:

$$\begin{cases} S_{k,fic} = \dfrac{U_n}{\sqrt{R_{fic}^2 + X_{fic}^2}} \\ \tan(\psi_k) = \dfrac{2\pi \cdot f_g \cdot L_{fic}}{R_{fic}} = \dfrac{X_{fic}}{R_{fic}} \end{cases} \tag{3.3}$$

3) Finally, according to this model, the instantaneous value of the voltage wave can be obtained by using Equation (3.4) :

$$u_{fic}(t) = u_0(t) + R_{fic} \cdot i_m(t) + L_{fic} \cdot \frac{di_m(t)}{dt} \tag{3.4}$$

The paper models the fluctuation of the voltage in Matlab/Simulink environment, it is shown as Figure (3.3) . In this module , the PLL is used to correct the phase angle. The the line current source of the wind turbine voltage fluctuations can be obtained by analog fluctuations .

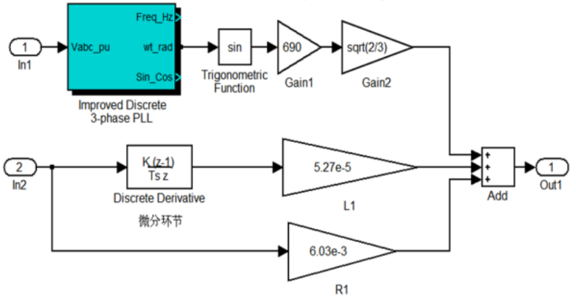

Fig. 3.3 The module of analog fluctuations in voltage

5) The voltage fluctuation instantaneous value of the PCC is obtained through a virtual grid method. The We can get the instantaneous visual sensitivity S(t) curve shown as Fig. 3.4. Then the Pst value can be obtained by the CPF curve of the probability and statistics.

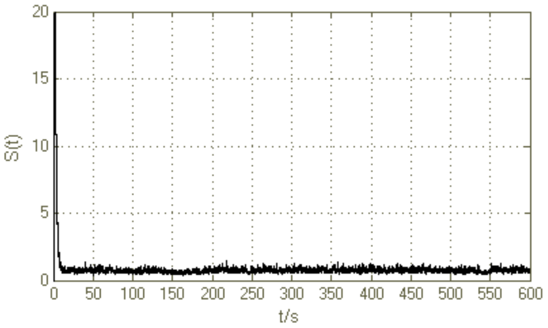

Fig. 3.4 A phase instantaneous visual sensitivity s(t)

4. CONCLUSION

The installed capacity of the wind power of Grid has an increasing trend, so the voltage fluctuations and flicker issues will become increasingly prominent, it should be considered seriously. This paper discusses how to simulate the flicker value of the wind farm based on virtual grid simulation. It estimates a much complete simulation reference flicker for wind farms, and the gives the following conclusions:

1) Based on the IEC 61000-4-15 standard, the simulation model can be used for off-line voltage fluctuations flicker analysis, but the low frequency band should be corrected. In addition, there are some low-band errors in the models of Matlab.

2) The use of virtual grid approach can effectively solve the problem that assess the reactive power compensation of wind farm capacity.

REFERENCES

[1] IEC Standard 61000–4–15 Ed. 1.1 (2003) Electromagnetic compatibility(EMC)—Part4 Testing and measurement techniques—Section15 Flickermeter:Functional and design specifications

[2] IEC Standard 61400–21 Ed. 2.0 (2008) Wind turbines – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines

[3] Wei Chun, Han Minxiao, Yan Wenli, “Voltage fluctuation and flicker assessment of a weak system integrated wind farm”, Power and Energy Society General Meeting, 2011 IEEE

[4] Sun T, Chen Z, Blaabjerg F. “Flicker study on variable speed wind turbines with doubly fed induction generators”. Energy Conversion, IEEE Transactions on. 2005, 20(4): 896-905.

[5] Hu W, Chen Z, Wang Y, et al. “Flicker study on variable speed wind turbines with permanent magnet synchronous generator” Power Electronics and Motion Control Conference 2008.

[6] Fadaeinedjad R, Moallem M, Moschopoulos G, et al. “Flicker Contribution of a Wind Power Plant with Single and Multiple Turbine Representations” Electrical Power Conference, 2007. EPC 2007. IEEE Canada.

[7] Dan A M, Dan G M, Rios S M. “Improved method for flicker evaluation”,Electric Power Engineering, 1999.

[8] Gutierrez J J, Ruiz J, de Gauna S R. “Linearity of the IEC Flickermeter Regarding Amplitude Variations of Rectangular Fluctuations”Power Delivery, IEEE Transactions on. 2007, 22(1): 729-731.