Flicker emission of wind farms during continuous operation

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Flicker emission of a wind farm during continuous operation has three main sources: wind turbulence, tower shadow and generator or power converter oscillations at frequencies. Flicker emission of a wind farm during continuous operation can be derived from the output of a single wind turbine since fast fluctuations are low correlated among turbines.

A stochastic model of the power spectral density (PSD) of power output is parameterized (Fig. 2 and Fig. 3).

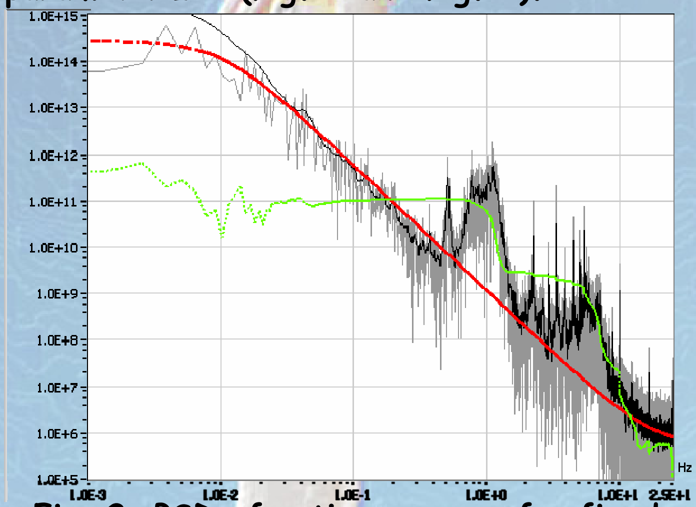

Fig. 2: PSD of active power of a fixed speed, stall regulated turbine at low winds (parameterization in red, accumulated error of the parameterization in green).

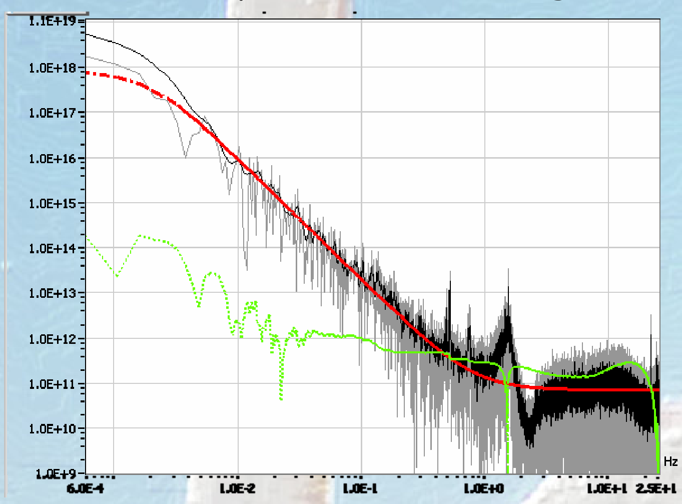

Fig. 3: PSD of a doubly fed, induction generator wind farm at low winds.

A statistical model of the flickermeter in the frequency domain has been derived (Fig. 1), based on the small signal model of the wind farm network (Fig. 4).

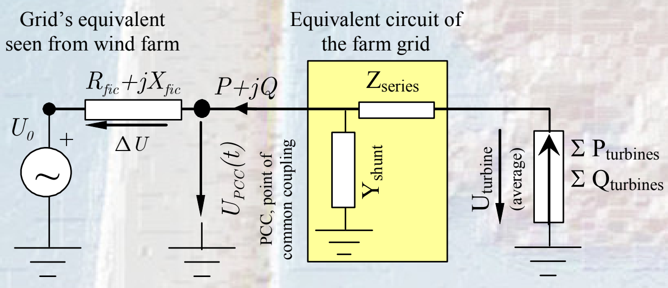

Fig. 4: Small signal model of the farm.

A simple formula to estimate flicker level from PSD and network parameters with 8 % uncertainty.

$$PSD(f)\approx N\,S_1\left(S_0\,\delta_0(f-f_0)+f^{-2r}+S_2\right)$$

The flicker level can be estimated as:

$$P_{st}=\frac{\cos(\psi_k)+\sin(\psi_k)\tan(\varphi)}{S_{k\ fict}}\sqrt{S_1 N Coef(S_0,f_0,S_2,r)}$$

where the parametric coefficient is:

$$Coef(S_0,f_0,S_2,r)\approx\frac{1}{36}S_0\,f_0^{1{,}55}+10{,}14\,S_2+0.1332\,Cosh\left[0{,}04462(r-5{,}383)(r+12{,}548)\right]$$

	Significance	Range
r	System order of the turbine active power output excited by the wind turbulence (i.e., half the slope trend of PSD in a double logarithmic plot)	1 ~ 1.7
$\frac{S_1}{S_n^2}$	Overall fluctuation level of the turbine (i.e., the PSD trend line at 1 Hz) in p.u. units	10^{-4} ~ 10^{-2}
S_0	Squared average of tower shadow power oscillation relative to S_1	5~100
f_0	Mean tower shadow frequency	0.5~ 2 Hz
S_2	Squared noise level on power output relative to S_1	0~0.01
S_n	Nominal power of the turbine	0,3~ 5 MW
N	Number of equivalent turbines in the farm	1~50

The model has been tested with data from several wind farms. In wind farms with squirrel cage induction generators, 80% of the flicker was due to spatial variations in the wind field that produces a torque modulation depending on rotor angle at blade crossing frequency (around 1 Hz). The remaining 20% flicker contribution was due to mechanical oscillatins in the 5,5 - 7 Hz range (see Fig. 5).

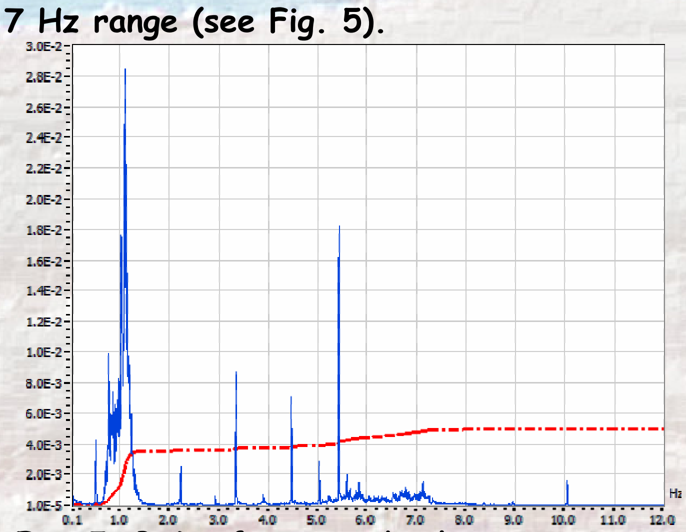

Fig. 5: PSD of squared voltage variations $b(t)$ and $\sigma_b^2|_{f_{max}}$ in a fixed speed, stall regulated wind turbine (contribution of each frequency in blue, accumulated flicker contribution in red).

In wind farms with variable resistance rotor, the opti-slip control dampers effectively fluctuations due to rotor angle (its flicker contribution is negligible) and the main source of flicker are the turbulence in the 4-14 Hz frequency range, which can be seen in Fig. 6 as a smooth tendency (the graph scales are not normalized).

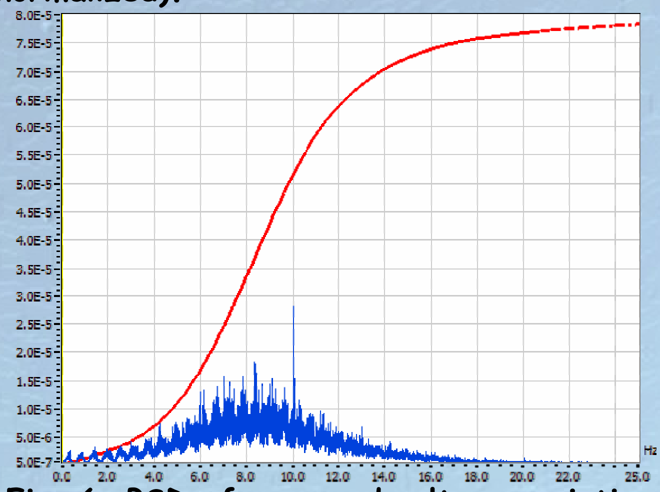

Fig. 6: PSD of squared voltage variations $b(t)$ and $\sigma_b^2|_{f_{max}}$ in a variable resistance induction generator (opti-slip) wind turbine.

In wind farms with doubly fed induction generators, the fluctuations due to rotor angle are muffled, accounting for only 5% of total flicker. The rest of the flicker is due to turbulence, as in the variable resistance induction generator case.

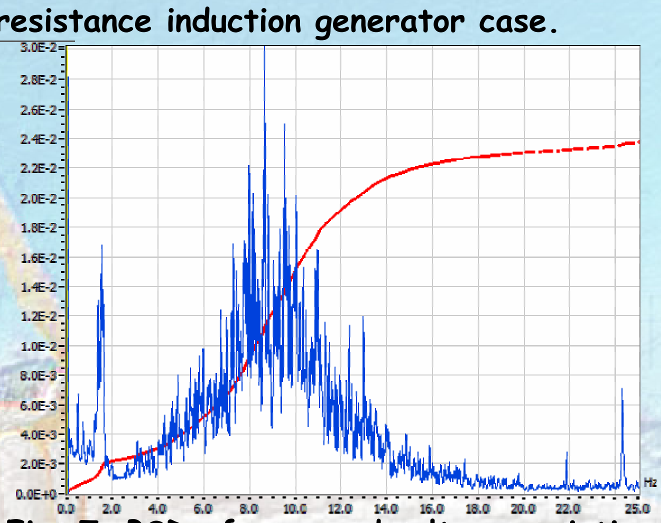

Fig. 7: PSD of squared voltage variations $b(t)$ and $\sigma_b^2|_{f_{max}}$ in a doubly fed induction generator.

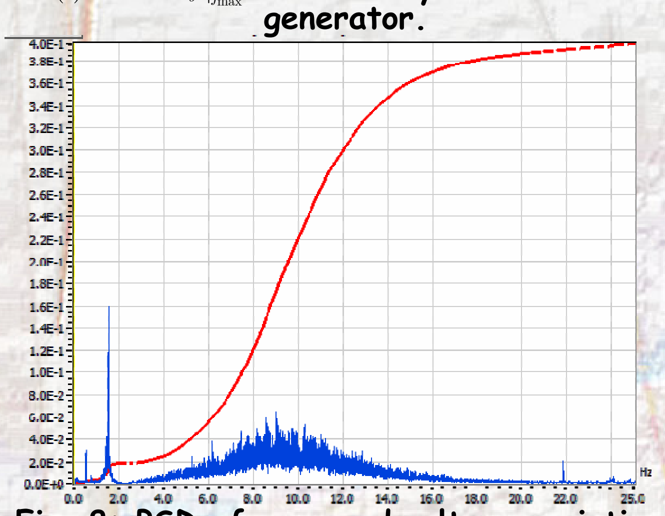

Fig. 8: PSD of squared voltage variations $b(t)$ and $\sigma_b^2|_{f_{max}}$ at a wind farm with 17 doubly fed induction generators.

In the cases analyzed, the flicker level was very low due to the strength of the network at the point of common coupling.

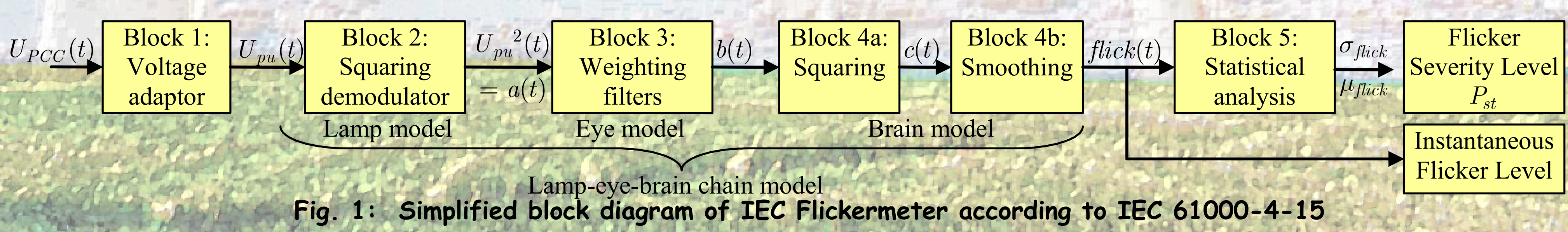

Fig. 1: Simplified block diagram of IEC Flickermeter according to IEC 61000-4-15

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