Flicker Measurement based on SVR for Fixed-Speed Wind Generator Systems

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Abstract

This paper presents a simulation model based on support vector regression (SVR) for flicker emission estimation from wind turbines. Training patterns are developed by varying the wind speed and network parameters that might affect the expected flicker levels. A comparison is done to the fixed speed wind turbine (WT), which leads to a conclusion that the factors mentioned above have different influences on flicker emission. The simulation results have shown that the flicker estimation is performed accurately.

1. Introduction

Recently, wind power generation has developed quickly throughout the world. As the wind power penetration into the grid increases very fast, the influence of wind turbines leading to flicker emission becomes an extremely important issue. Flicker emission can be a limiting factor for integrating wind turbines into weak grids as well as into strong grids where the penetration levels of wind power are high.

Load flow variations in the grid cause voltage fluctuations which are called a flicker. Grid-connected wind turbines often produce considerable fluctuations in output power due to wind speed variations, the wind gradient, tower shadow and wind shear effects [1]. As a result, an output power drop will occur three-times per revolution for a three-bladed wind turbine. This frequency is called the 3*p* frequency. The power pulsations of fixed-speed wind power generators up to one-fourth of the average power at the frequency of 3*p* will be generated [1].

During continuous operation, many factors affect flicker emission of grid-connected wind turbines, such as wind characteristics (e.g., wind speed mean value and turbulence intensity) and grid conditions (e.g., short-circuit capacity and angle of grid impedance) [1], [2].

Different methods may be assessed by the direct measurement using a flicker meter which complies with various specification standards [3]. However, at the design stage or before the installation of a WT or wind farm or an expansion of wind farm system, predicting the expected flicker is really necessary to minimize the flicker emission level during the system operation. For this purpose, suitable simulation models of WT and grid have been developed and applied, both in the time and frequency domains [4], [5].

In recent years, an intelligent estimation theory as SVR has been applied to various areas such as wind speed estimation, current estimation to predict the system output to the input values with a high accuracy [6], [7]. This paper presents the estimation of the flicker induced by the operation of grid-connected wind turbines by using SVR. The factors that affect flicker emission of wind turbines, such as wind characteristics (mean speed and turbulence intensity) and grid conditions (short-circuit capacity and grid impedance angle) are analyzed. Simulation studies are carried out using both the PSCAD/EMTDC software and Matlab program to obtain the short term flicker severity.

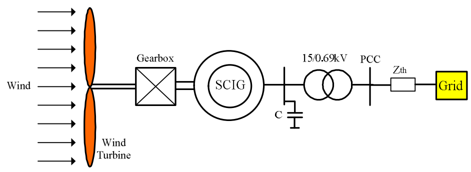

Fig. 1. Block diagram of grid-connected fixed-speed wind turbines.

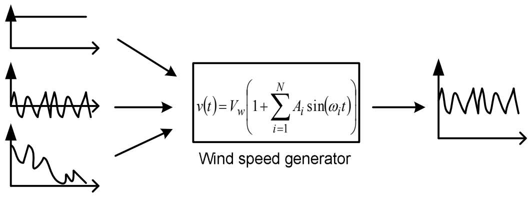

Fig. 2. Wind speed simulator.

2. Wind Turbine Modeling

The configuration diagram of wind turbine connected to the grid is shown in Fig. 1. The aerodynamic model of wind turbine can be characterized by well-known $C_p(\lambda,\beta)$ curves [8]. C_p is a power coefficient, which is a function of both the tip-speed-ratio λ and the blade pitch angle β. The tip-speed-ratio λ is defined as

$$\lambda = \frac{\omega \cdot R}{V_w} \tag{1}$$

where R is the radius of the blade [m], ω is the wind turbine rotor speed [rad/s], and V_w is the wind velocity [m/s].

The mechanical power that the wind turbine extracts from the wind is expressed as [8]

$$P_m = \frac{1}{2}\rho \cdot A.V_w^3 \cdot C_p(\lambda,\beta) \tag{2}$$

where ρ is the air density [kg/m^3] and $A_r = \pi R^2$ is the area swept by the rotor blades [m^2].

The wind speed variation can be modeled as a sum of harmonics for analysis as shown in Fig. 2. The wind speed is modeled as [8].

$$\upsilon(t) = V_w\left(1+\sum_{i=1}^{N} A_i \sin(\omega_i t)\right) \tag{3}$$

where $\upsilon(t)$ is the instantaneous wind speed at time t, V_w is the mean value of the wind speed, N is the number of harmonic samples, ω_i is the harmonic frequency, and A_i is the harmonic amplitude.

Torque produced by a mean wind speed, T_t, may be expressed as

$$T_t = 0.5\rho R^3 C_p(\lambda,\beta)\cdot V_w^2 \tag{4}$$

The fluctuating components due to tower shadow and wind shear effects must be superposed. The torque produced by each blade, T_i, can be expressed as

$$T_i = T_t + T_{shear} + T_{shadow} \qquad (5)$$

where T_{shear}, T_{shadow} are the torque fluctuation produced by wind shear and tower shadow, respectively [2].

3. Flicker Measurement

According to standard IEC 61000-4-15 [3], a flicker meter model has been built to calculate the short-term flicker severity P_{st}. The flicker meter architecture is described by the block diagram shown in Fig. 3 and can be divided into two parts, each performing one of the following tasks:

– Scaling the input voltage and simulation of the response of the lamp-eye-brain chain;

– Online statistical analysis of the flicker signal and presentation of the results.

The first task is performed by blocks 2, 3, and 4 in Fig. 3 while the second task is accomplished by block 5.

Applying the SVR to estimate the flicker, the identification of physical parameters is extremely important because it might affect the flicker emission of a given wind turbine. These physical parameters are the training inputs to SVR. To estimate the flicker, the training samples for input and output, the radial basis function(RBF) as a kernel function with parameters ε, σ, and C are usually selected based on a priori knowledge or expertise. Thereafter, Lagrange multipliers $(\alpha_i - \alpha_i^*)$ are decided by using Matlab.

To ensure the ability of estimating the flicker severity correctly, each parameter of the training set comprises the range of variations of the input parameters for the specific operating conditions and the flicker severity index P_{st} is calculated, as depicted in Fig. 4. Fig. 5 shows the wind speed for WT with the mean value at 11m/s.The range of parameter variations for each of four input parameters and base cases considered is shown in Table I and II.

The varying wind speeds result in the variations of the reactive power at the point of common connection (PCC), and therefore the fluctuations of the voltage at point PCC shown in Fig. 6 and Fig. 7.

4. Study Results

4.1 Mean Wind Speed

In Fig. 8, when wind speeds are increasing, the flicker emission also goes up. The flicker level begins to increase quickly at wind speeds from 8 m/s to 12 m/s. The instantaneous power will fluctuate around the rated value of the power at high wind speeds due to gusts and the speed of the pitch mechanism. Changes at wind speed of 1 m/s may give power fluctuations with a magnitude of 20%, which induces high flicker levels. As a result, as can be seen in Fig.6, RMS voltages at PCC also fluctuate.

In the case of high wind speed, variations in the wind speed will also cause power fluctuations but with a smaller magnitude in comparison with a pitch-controlled turbine [1].

As shown in Fig. 7, in the case of low wind speeds (less than 8 m/s), the flicker index is very low due to a small output power. Then this index increases with an approximately linear relation to the mean wind speed due to an increase of the turbulence in the wind, until it reaches a peak value of 12 m/s. For higher wind speeds, where the wind turbine reaches rated power, the flicker level decreases.

4.2 Turbulence Intensity

The flicker level goes up linearly with the increase of the turbulence intensity. The P_{st} has almost linear relation with the turbulence intensity in low wind speeds (e.g., 8 m/s) as shown in Fig. 8.

The more turbulence in the wind is, the larger flicker emission is. When the turbulence intensity increases, the wind speed changes considerably which results in a large variation of output power. As a consequence, the flicker emission becomes serious.

Table I Wind speed

Input parameters	Base case	Range of variation
Mean wind speed (V_w)	11m/s	(4 – 18) m/s
Turbulence intensity (I_n)	0.1	0.02 – 0.3

Table II Network parameters

Input parameters	Base case	Range of variation
Grid short circuit capacity (S_{sc})	10MVA	(4 – 20) MVA
Grid impedance angle (φ_{th})	60 degree	(10 – 90) deg

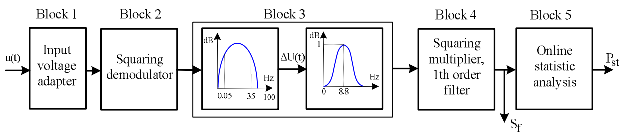

Fig. 3. Block diagram of the flicker meter model

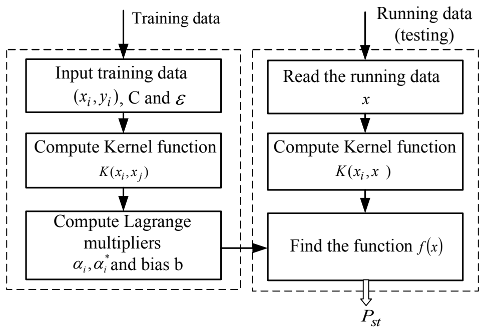

Fig. 4. Flowchart of flicker estimation

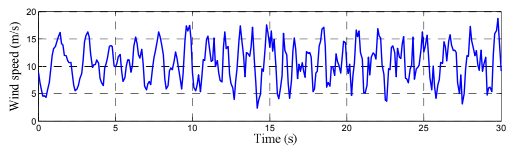

Fig. 5. Wind speed.

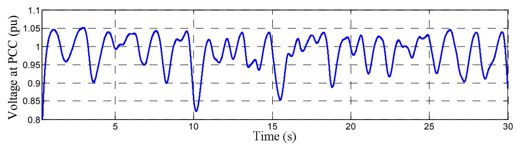

Fig. 6. Voltage at PCC.

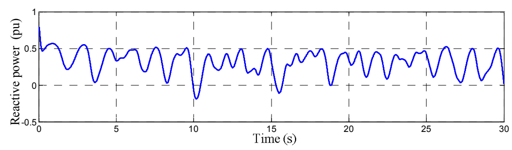

Fig. 7. Reactive power at PCC.

4.3 Short Circuit Capacity

Fig. 9 demonstrates the relationship between the short-term flicker severity P_{st} and the short circuit capacity S_{sc}. As the short circuit capacity ratio becomes bigger, the grid-connected wind turbines will be stronger. As expected, the wind turbine would produce larger flicker in weak grids than in stronger grids.

4.4 Grid Impedance Angle

The voltage change in a power line may be approximately calculated based on the following formula [9]:

$$\Delta V = \frac{P \cdot (r_0 l) + Q \cdot (x_0 l)}{V} \tag{6}$$

where P and Q are the active and reactive powers flow on the line respectively, r_0, x_0 are the resistance and reactance per unit length, respectively, V is the voltage at the line terminal, l is the length of the transmission line.

The determining factor for flicker is the difference between the grid impedance angle φ_{th} and the power factor angle φ that are defined as

$$\tan \varphi_{th} = \frac{X}{R} \tag{7}$$

$$\tan \varphi = \frac{Q}{P} \tag{8}$$

Equation (6) can be written as

$$\Delta V \approx \frac{2P \cdot (r_0 l) \cdot \cos(\varphi - \varphi_{th})}{V[\cos(\varphi - \varphi_{th}) + \cos(\varphi + \varphi_{th})]} \tag{9}$$

When the phase ange difference $(\varphi - \varphi_{th})$ reaches 90 degrees, the voltage change becomes zero. Hence, the flicker emission is minimized. Normally the fixed speed wind turbine absorbs reactive power from the grid while it is generating active power.

For the operating condition considered here to fixed-speed wind turbines, the minimum flicker emission occurs at a grid impedance angle between 75 to 85 degrees as shown in Fig. 11.

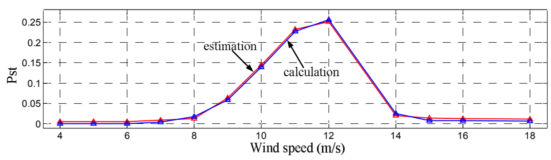

Fig. 8. Estimating P_{st} with the variation of mean wind speed.

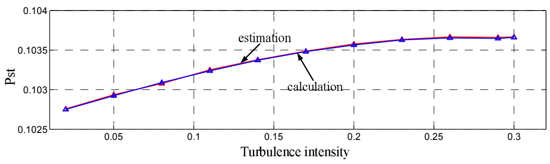

Fig. 9. Estimating P_{st} with the variation of wind turbulence intensity.

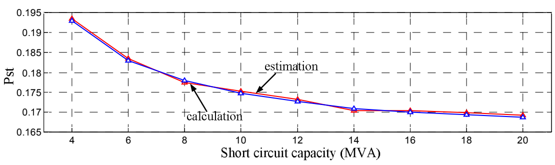

Fig. 10. Estimating P_{st} with the variation of network short circuit capacity.

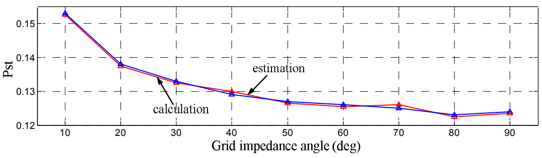

Fig. 11. Estimating P_{st} with the variation of phase angle.

Based on simulation results, the capability of estimating flicker using SVR is reliable. The maximum error values for both flicker estimation based on SVR and flicker calculation applying standard IEC are very small and these errors are less than 0.501%.

5. Conclusions

An application of support vector machine to the assessment of the flicker emitted by grid-connected wind turbines during the operation has been studied. Using this model, a set of training patterns was developed by varying the wind speed, the turbulence intensity, the short-circuit capacity and impedance angle of the network which might affect the flicker induced by the operation of the wind turbine. For these training data, a SVR-based model was developed being capable of predicting flicker emissions with the high accuracy and fast performance under any normal operating conditions and network characteristics. Applying SVR to estimate the flicker produced from a wind turbine is very suitable for design process of wind power system.

Acknowledgment

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