Computation of Flicker Due to Vertical Wind Shear in a Wind Turbine Mounted on a Hill with Cosine Approach

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Abstract –Wind energy produces no direct pollution under running condition. So use of wind energy is increased in a large extent. Power quality is key issue of current days apart from scarcity of energy. Energy with good power quality is demand of current days. Vertical wind shear hampers the power quality of wind energy. Vertical wind shear induces flicker in wind energy output. Assessment of flicker is very essential. In this paper a mathematical model is proposed to compute the flicker induced due to vertical wind shear with cosine approach. Turbine blade length and tower height are also considered in developing the model.

Key words — Flicker, shear, turbine, wind.

I. Summary of previous work

Random or repetitive variations in the RMS voltage between 90 and 110% of nominal can produce a phenomenon known as "flicker" in lighting equipment. Flicker is rapid visible changes of light level.[8] Definition of the characteristics of voltage fluctuations that produce Objectionable light flicker has been the subject of ongoing research. Vertical wind shear has considerable impact which is observed while conducting trials on the wind turbine. Tau Sun et. al [4] studied Doubly fed induction generator for computation of flicker. PSCAD is used by them for development of the model of flicker. They developed a wind turbine model with double fed induction generator. They considered a vector control scheme for the doubly fed induction generator. Short circuit capacity ratio and grid impedance angle is considered by them for development of the model. Graph of short term flicker emission severity verses average wind speed is provided by them. Braulio Barahona [5] studied the validity of standard method for computation of flicker. He considered fixed speed as well as variable speed wind turbine. He has dealt with standard method of computation of flicker and flicker type test. He computed site specific flicker. He also considered offshore wind farm for computation of flicker. Roger C. Dugan [8] has given various power quality parameters. He has given various methods to measure flicker emission severity. He has discussed short term flicker emission severity and long term flicker emission severity. Richard L. Hills [9] demonstrated the genration of wind energy.

2. Flicker Emmission Severity

Various authors defined flicker in sundry ways. The term flicker is sometimes considered synonymous with voltage fluctuations, voltage flicker, light flicker, or lamp flicker. The phenomenon is defined as a fluctuation in system voltage can result in observable changes in light output. Tao sun et al. [4] defined flicker as an imprint of unsteadiness of visual sensation, induced by a light stimulus, whose luminance or spectral distribution fluctuates with time, which can cause clientele's exasperation. Flicker is also defined as the measure of voltage deviation, which may cause brouhaha to consumer. Voltage flicker can be separated into two types. First is cyclic or repetitive and second type is non-cyclic or non-repetitive. Cyclic flicker is a result of periodic voltage fluctuations in the system voltage. Non cyclic refer to occasional voltage fluctuations. Flicker produced by wind shear is non-cyclic flicker with random variation in the amplitude of the voltage. Flicker occur in wind turbine due to continuous operation. During continuous operation of wind turbine flicker can occure due to vertical wind shear, horizontal wind shear, turbulence intensity, tower shadow effect, wake effect and wind gust. Flicker also occur in wind turbine due to switching operation. It can occur during start up of generators of wind turbines. Switching in and out of generators also cause flicker. Transition of winding in case of two speed, duel winding generators, also cause flicker . Switching of capacitor banks cause flicker as well.

3. Cosine Model of Flicker

Flicker can be computed as the ratio of the change in voltyage to the average voltage. It is expressed as the percenrage of the voltage. [8]

$$\mathbf{P_{st}} = \frac{\textbf{Change in the output voltage of the wind generator}}{\textbf{Average output voltage of the wind generator}} \mathbf{X\ 100} \qquad (1)$$

Flicker emission severity (P_{st}) can be written in the abbreviation form as follows.[8].

$$\mathbf{P_{st}} = \frac{\mathbf{V_{max}} - \mathbf{V_{min}}}{\left(\frac{\mathbf{V_{max}} + \mathbf{V_{min}}}{2}\right)} \mathbf{X\ 100} \qquad (2)$$

Further simplifying the equation

$$\mathbf{P_{st}} = \frac{2(\mathbf{V_{max}} - \mathbf{V_{min}})}{\mathbf{V_{max}} + \mathbf{V_{min}}} \mathbf{X\ 100} \qquad (3)$$

In equation (2) Vmax and Vmin is the maximum and minimum voltage recorded in ten minutes at the output of the turbine.

Now consider impact of area of the side of the building $\mathbf{A_b}$ on which turbine is sited. Short term Flicker emission severity increases with area of side of the building facing wind on which the turbine is mounted.

$$\mathbf{P_{st}} \propto \mathbf{A_b} \qquad (4)$$

Here impact of blade length is discussed. Now a days in order to capture more energy from wind the turbine blade length is increased. Range of blade length is 10 m to 80 m. Short term Flicker emission severity increases with wind turbine blade length.

$$\mathbf{P_{st}} \propto \mathbf{B_L} \qquad (5)$$

If we consider one blade length $\mathbf{B_L}$, then the impact of other blade is not considered. So twice the blade length is considered. It is approximated to the hub diameter.

$$\mathbf{P_{st}} \propto \mathbf{2B_L} \qquad (6)$$

Here impact of tower height $\mathbf{T_h}$ is depicted. In order to capture more energy from wind, the tower height is increased. Range of tower height is 50 m to 100 m. Short term Flicker emission severity decreases with height of the tower on which the turbine is mounted.

$$\mathbf{P_{st}} \propto \frac{\mathbf{1}}{\mathbf{T_h}} \qquad (7)$$

Here impact of hill height is echoed. Some turbines are erected on a building. Short term Flicker emission severity decreases with height of the hill $\mathbf{H_h}$ on which the turbine is sited. Vertical wind shear decreases with building height on which turbine is sited and consequently, the short term flicker emission severity is decreased.

$$\mathbf{P_{st}} \ \alpha \ \frac{\mathbf{1}}{\mathbf{H_h}} \qquad (8)$$

From equation 8 and 9 hill height and tower height is added.

$$\mathbf{P_{st}} \ \alpha \ \frac{\mathbf{1}}{\mathbf{T_h + H_h}} \qquad (9)$$

Further impact of vertical wind shear $\boldsymbol{V_{shr}}$is reverberated. Vertical wind shear is a change in the wind speed over a short distance with height in the atmosphere over a short span of time. It's unit is per second. Short term Flicker emission severity increases with vertical wind shear. Wind shear can be computed as the ratio of the change in wind speed between the two points to the change in the distance. [32]

$$\mathbf{V_{shr}} = \frac{\begin{matrix}\textbf{wind speed at the tip of top sided blade } - \\ \textbf{wind speed at the tip of bottom sided blade}\end{matrix}}{\textbf{Diameter of the rotor of the wind turbine}} \qquad (10)$$

Wind shear can be written in the abbreviation form as follows. Unit of wind shear is per second.

$$\mathbf{V_{shr}} = \frac{\mathbf{V_{Top}} - \mathbf{V_{Bottom}}}{\mathbf{d_{bt}}} \qquad (11)$$

$$\mathbf{P_{st}} \ \alpha \ \mathbf{V_{shr}} \qquad (12)$$

Here impact of vertical wind shear is reverberated. Vertical wind shear is a change in the wind speed over a short distance with height in the atmosphere over a squat span of time. It's unit is per second. Short term Flicker emission severity increases with vertical wind shear.

Short term flicker emission severity increases with vertical wind shear. Short term flicker emission severity decreases with average wind speed.

$$\mathbf{P_{st}} \ \alpha \ \frac{\mathbf{1}}{\mathbf{V_a}} \qquad (13)$$

So ratio of vertical wind shear to average wind speed is considered.

$$\mathbf{P_{st}} \ \alpha \ \frac{\mathbf{V_{shr}}}{\mathbf{V_a}} \qquad (14)$$

Here impact of blade length is discussed. Now a days in order to capture more energy from wind the turbine blade length is increased. Range of blade length is 10 m to 80 m. Short term Flicker emission severity increases with wind turbine blade length. Using equation 6, 12 and 13 equation is modified as

$$\mathbf{P_{st}} \ \alpha \ \mathbf{2\ B_L} \ \frac{\mathbf{V_{shr}}}{\mathbf{V_a}} \qquad (15)$$

Short term Flicker emission severity increases with surface roughness [31] of the terrain where the turbine is sited.

$$\mathbf{P_{st}} \ \alpha \ \mathbf{Z_0} \qquad (16)$$

Now consider impact of swept area of the turbine. Short term Flicker emission severity increases with the swept area of turbine. Swept area S_A is the area swept by the turbine blades when the blades rotate. It is found by the area the circle $S_A = \pi r^2$

$$P_{st} \propto S_A \tag{17}$$

Further Cosine model of flicker is developed using above equations.

$$P_{st} = \frac{S_A}{T_h + H_h}\left(\frac{V_{shr}}{V_a}\right)\cos\left(N\frac{V_{shr}}{V_a} + 1\right) + C \tag{18}$$

The values of constant C can be found by the table below. The value of C is found is found by vigorous experimentation on the wind turbine. P_{st} is the short term flicker emission severity which is a dimensionless quantity. T_h is tower height, Sa is swept area of the turbine, V_{shr} is vertical wind shear, V_a is average wind speed. N is the number of wind turbine blades. Here a three bladed wind turbine is used.

Table 1 value of c for different values of vertical wind shear

vertical wind shear	Value of c
2 to 3.5	10
3.5 to 4.5	11
4.5 to 5.5	12
5.5 to 6.5	13
6.5 to 7.5	14
7.5 to 8.5	15

For recording the wind speed anemometers are used. The location of the left and right hand sided anemometer in the horizontal line passing through the center of the hub and at 0.2 meters away from the tip of the blade. The location of the top and bottom anemometer in the vertical line passing through the center of the hub and at 0.2 meters away from the tip of the blade. With the help of left side and right hand sided anemometer it is ensured that the wind speed near the tip of the blade is same on right hand side and left hand side of the blade so, there is no impact of horizontal wind shear on voltage flicker. With help of top and bottom sided anemometer the wind speed at the top and bottom side of the wind turbine is measured near the tip of the blade.

The maximum wind speed at the top sided blade of the turbine and minimum wind speed at bottom side of the turbine in the time span of 10 minutes is recorded with upper anemometer and lower anemometer respectively. At the same time the maximum and minimum RMS values of voltages are recorded using analog voltmeter for same duration i.e. in time span of ten minutes. Vertical wind shear is computed as the ratio of change or difference in the wind speed at top and bottom sided blade of the turbine to the distance between the two points of measurement. The unit of vertical wind shear is per second.

IV. Validation

In the last section mathematical model of the flicker is given in this section validation of the model I s given. Flicker is measured with change in vertical wind shear. Readings are noted in a wind turbine test set up and graph is plotted. Laboratory wind turbine test set up is developed by welding mild steel angular cross section bars. In mild steel structure, five fans are fitted at one end. In the test set up there is a provision to insert anemometers to record wind speed at particular point. Wheels are fitted to the tunnel to facilitate its movement from the walls for conducting trials. The test set is kept away from the walls so as to reduce the effect of walls on the wind speed. Front side wheel can be swiveled so that movement of test set up is easy. Wind tower models can be kept in the test set up. Various wind turbine towers are developed. Tubular, lattice and guy wire type towers are developed which can be kept in the tunnel for conducting tests on the wind turbine. Wind turbine blades can be changed. Wind turbine generator can be changed as well. Wind turbine test set up is covered by mild steel wire mesh for safety purpose. With mild steel wire mesh, wind turbine is visible from outside. Two safety doors are fitted to the test set up which can be closed when the turbine blades rotate. The test set up is surrounded by a protective wire mesh so that under high speed it is safer for the person working on the wind turbine test set up. The cosine model is much closer model to the actual flicker.

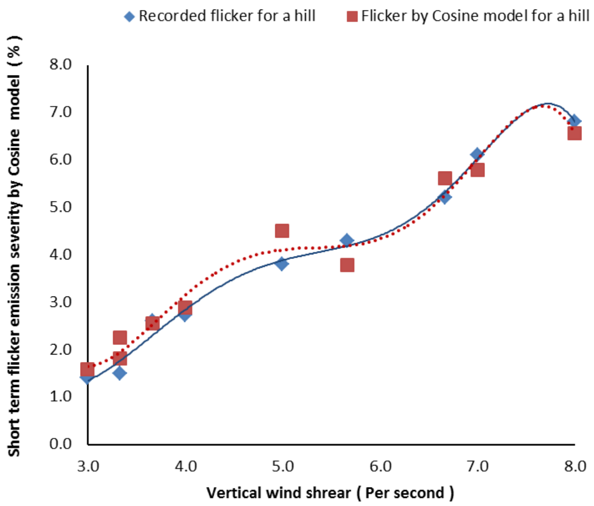

Fig 2 Impact of vertical wind shear on short term flicker emission severity with cosine model **for a hill**

V. Conclusion

Flicker emission severity increases with increase in vertical wind shear. Cosine model is closure to actual flicker. The model utilizes wind tower height, hill height, average wind speed and vertical wind shear to compute flicker.

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