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Evaluation of Flicker Measurement in Grid-connected Wind Turbine

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***Abstract*—Wind energy is becoming the mainstream source of power generation worldwide. However, as the wind speed variate, it results in power fluctuations, and power converters adversely affect the power quality of grid-connected wind turbines (WT). The power quality measurement procedure is defined in the standard IEC-61400-21. The updated standard IEC-61400-21-1 provides a uniform methodology, which will ensure the accuracy of the testing and assessment, i.e., voltage quality (emissions of flicker and harmonics). The flicker emission produced by the turbine due to rapid changes in wind speed results in fluctuating power, which can lead to voltage fluctuations at the point-of-common-coupling (PCC). The IEC-61000-4-15 standard describes the measurement specification of the flicker meter. The accuracy of the measuring methods is an essential part of the assessment of power quality in the grid-connected WT. This paper introduces the innovative procedure of flicker measurement model of grid-connected WT. Therefore, the paper deals with the verification test of the measurement procedure for the flicker, and the results demonstrated through the simulation according to the measurement and assessment standard IEC-61400-21-1.**

***Index Terms*—Power quality, voltage fluctuation, flicker and harmonics measurements.**

I. Introduction

As a matter of fact, the development of renewable energy sources has a positive impact on the environment [3]. However, the power quality issues affect distributed generation due to the infrequent nature of renewable energy resources like the speed of wind in the wind energy sector [4]. Wind energy can achieve top rank in electricity production if the industry can conquer the rising challenges of power quality [1], see in Fig.1. The power fluctuation of the wind turbine produces variations in the illumination intensity of the light source. Such a variation produced by voltage fluctuation is known as a flicker. The International Electro-technical Commission (IEC) standard specifies the procedures for the measurement and assessment of power quality disturbances such as flicker and harmonics emission by grid-connected wind turbine (WT) [13]. Thus, power-quality does not depend only on the ratio of voltage fluctuation in the power production as other factors also contribute to it, i.e., distortion in voltage and current, transient, harmonics and flicker [16]. In wind power systems,

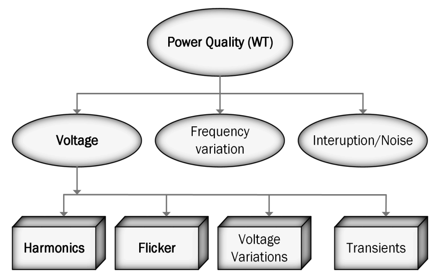

Fig. 1: Power quality challenges in wind turbine

the voltage fluctuations are measured by flicker meter to estimate the flicker severity [10]. Flicker produced during the start-up, at cut-in wind speed, switching between generators and during running operation. It is known as continuous and switching operations of the grid-connected wind turbine (WT) [13]. Moreover, the grid resistance-reactance (X/R)-ratio is an essential factor of flicker and harmonics emission [18]. The flicker emission can be limited by controlling the short-circuit-ratio (SCR) and rating of the wind turbine. There is a trade-off between flicker and operational parameters of WT. Therefore, flicker measurement is a critical challenge and requires special procedure for analysis and assessment [7]. An accurate flicker measurement allows to achieve the maximum optimized level of the power production in WT [12].

The manufacturers of WT and the IEC maintenance team have been taking actions for the standardization of power quality challenges [5] and are currently working on the validation of measurement procedure. The prime objectives are to align the dynamic simulation model with the upcoming standards of wind energy generation [2], design the robust measurement procedure [8], and specify the consistency in the results and enhancing the accuracy in the results. The IEC 61400-21 standard specifies the flicker measurement and assessment procedure and defines the simulation design of a fictitious grid during continuous and switching operations. The standard of IEC-61000-4-15 [8] specifies a measuring method by simulating the process of physiological visual (lampeyebrain chain) perception [10] [15]. The flicker meter measures the short and long flicker severity independently or while integrated with a fictitious grid. The measurement accuracy declines in the digital implementation procedure of the fictitious grid due

to various factors, e.g., phase lock loop (PLL) that are not precisely encircled in the IEC 61400-21 standard [16].
Considering all the factors and information stated before, this paper focuses on the flicker measurement and assessment procedure and demonstrates the measurement results according to the recently updated standard IEC 61400-21-1 [7]. The flicker assessment and measurement model is designed in Matlab (Simulink). The overall results validation is being performed by two simulation tests which include: 1) the validation of flicker measurement as per the requirement of the IEC 61400-21-1 standard, and 2) performance validation of the fictitious grid. The present study and analysis specially provide the benefits of the industry of WT manufacturers concerned with power quality and power production. The arrangement of the paper is as follows:
Section II summarizes the model architecture of flicker measurement, assessment model, and determines the main functional parameters of measurement procedure according to the IEC 61400-21-1 standard. Section III presents the comprehensively validated measurement procedure during switching and continuous operations. This section describes a correlative analysis of the flicker emission, assessment, and simulation results including flicker coefficient c_{ψ_k}, voltage changes factors Ku_{ψ_k}, and short flicker P_{st}. Finally, conclusion is presented in Section IV.

II. Flicker Measurement Model in Grid-Connected WT

The architecture model of measurement and assessment procedure for flicker uses a model designed by standard IEC-61400-21-1 [16]. The flicker emission specifies that flicker is caused by grid-connected WT [17]. Therefore, the IEC-61400-21-1 standard focused on two sections, i.e., measurement procedure and further characterizing by two situations: continuous operation and switching operations [12]. The normal operation of the turbine excluding start-up and shutdown time of the transaction is known as the continuous operation of the WT, and the continuous operation measurement model is shown in Fig.2. Flicker produced during continuous operation causes power fluctuation due to variation in wind speed in the WT.
There are various types of switching operational characteristics, such as a) WT start-up at cut-in wind speed, b) WT start-up at rated wind speed or higher wind speed, and c) The switching between generators or a generator with multiple winding. The switching operations determine the support of flicker step factor and voltage change factor. Further, the parameters are described by numbers of switching (N_{10m} and N_{120m}) based on manufacturers' information. The step factor $Kf_{\psi k}$ and voltage change factor $Ku_{\psi k}$ can be regulated by the control system of the WT. The diagram of flicker measurement procedure during switching operation is shown in Fig.3.

A. Framework of Measurement and Assessment

As per the standard of IEC-61400-21-1, the flicker measurement procedure consists of first four blocks, and assessment is executed by the last two blocks. The assessment blocks recall

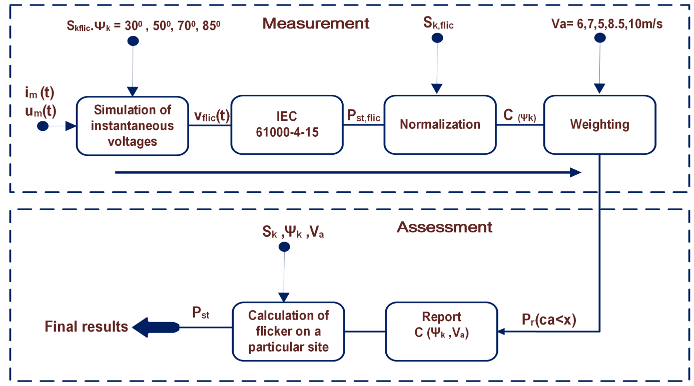

Fig. 2: Measurement and assessment procedures for flicker during continuous operation of the WT according to the IEC 61400-21-1

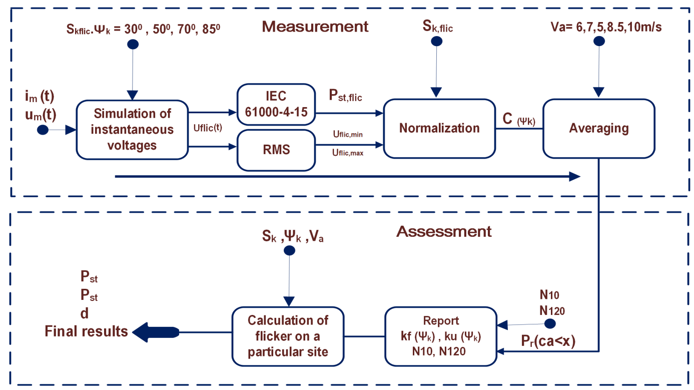

Fig. 3: Measurement and assessment procedures for flicker during switching operations of the WT in accordance with IEC 61400-21-1

the overall estimation of the blocks including the parameters of continuous and switching operations. The estimation of the preliminary stage concerns the power quality for standardization of WT. This estimation is based on power signal and flicker evaluation, which is demonstrated in the previous IEC standards. In this context, the IEC working group of the technical committee has examined the results and compared the method based on current i_s and voltage signals u_s. Finally, IEC 61400-21-1 introduced that flicker evaluation depends on the current i_{mt} and voltage u_{mt} time-series measured at the PCC terminals nearby WT. However, the literature survey addressed that the flicker is not caused only by the WT itself [17]. In short, the voltage fluctuations also ingress from the grid side at the PCC terminal where flicker is measured [18]. Thus, the voltage fluctuations imposed on the WT depend on the grid conditions [19]. Therefore, the measurement model developed in the upgraded standard IEC 61400-21-1 allows the independent measurement of the voltage fluctuations. The model is known as a fictitious grid that enables the analysis of voltage fluctuations caused exclusively by the WT. The fictitious grid estimates the voltage fluctuation from the input side, and precise estimated values of voltage fluctuations are delivered to the flicker meter. The flicker severity is measured by flicker Meter (FM) and the measuring procedure is determined in the IEC-61000-4-15 standard [2]. The flicker measurement procedure as per standard IEC 61400-21-1 provides the estimation to obtain various parameters namely: voltage changes, flicker step factor, flicker coefficient, and voltage change factors during continuous and switching operations.

1) Implementation of Fictitious Grid: The initial stage of the voltage and current processing procedure determines the fictitious voltage $u_{fic}(t)$ and characterizes the causes of the voltage fluctuations [14]. The standardized fictitious grid is shown in Fig.4.

The fictitious grid performed by an ideal voltage source (phase-to-neutral) integrated with instantaneous value $u_o(t)$ and impedance of the grid is represented by two electrical components such as R_{fic} in series with an inductor L_{fic}. Moreover, the WT, which described the instantaneous values of the line current source, $i_m(t)$ is also represented by the current generator of the WT. The fictitious grid's output is fluctuated voltage integrated with the instantaneous values $u_{fic}(t)$, as follows [10].

$$u_{fic}(t) = u_o(t) + R_{fic} \times i_m(t) + L_{fic} \times \frac{di_{m(t)}}{dt} \tag{1}$$

In equation number: 1, the critical signal is ideal voltage source $u_o(t)$ and it requires assurance for the sufficient performance of the signal $u_o(t)$. Therefore, the voltage source $u_{o(t)}$ must fulfill two conditions. First, flicker should be zero in the ideal voltage source $u_o(t)$. Second, the electrical angle of the $u_o(t)$ should be the same as the fundamental component of the input voltage, which means that the phase angle must be correct and in between $u_{fic}(t)$ and current source $i_m(t)$, these parameters provide $\mid u_{fic}(t) - u_o(t) \mid << \mid u_o(t) \mid$. Thus, $u_o(t)$ is the same as the fundamental voltage u_fic. Therefore, the execution properties of the $u_o(t)$ is represented by [16] as follows:

$$u_o(t) = \sqrt{\frac{2}{3}} \times U_n \times \sin(\alpha(t)) \tag{2}$$

Where U_n is the r.m.s values of the nominal voltage in the grid-connected WT, and the electrical angle $(\alpha(t))$ of the pure fundamental component, the $(\alpha(t))$ can be define as follows:

$$\alpha(t) = 2\pi \times \int_t^0 f_{dt} + \alpha(o) \tag{3}$$

where the $f(t)$ is varying frequency over the time; t is the starting time-series, and $\alpha(o)$ is the angle at time $t = 0$. Furthermore, R_{fic} and L_{fic} should be selected to drive the appropriate network impedance phase angle ψk to be determined in the equation below:

$$tan(\psi k) = \frac{2\pi \times f_g \times L_{flic}}{R_{flic}} = \frac{X_{flic}}{R_{flic}} \tag{4}$$

where f_g is the nominal grid frequency (50 or 60 Hz), and the three-phase short-circuit apparent power of the fictitious grid is defined by the equation as follows:

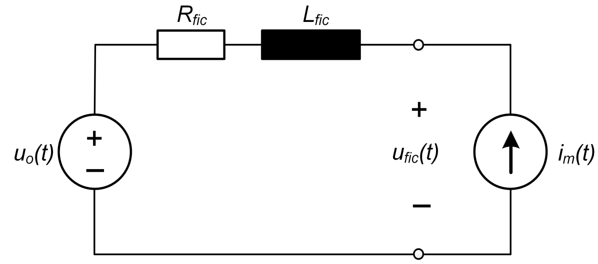

Fig. 4: Fictitious grid used for flicker assessment in Grid-connected WT.

$$S_{k,fic} = \frac{U_n^2}{\sqrt{R_{fic}^2 + X_{fic}^2}} \tag{5}$$

The flicker meter IEC 61000-4-15 evaluates the flicker severity P_{st} and instantaneous flicker P_{inst}. For the measurement of P_{st} and P_{inst}, the flicker meter used the short-circuit ratio $\frac{S_{k,fic}}{S_n}$ (SCR) between the range of 20 and 50. The accuracy of the flicker meter depends on the P_{st}, which should be better than 5%, this ratio is recommended by IEC 61400-21-1.

The flicker meter standard IEC-61000-4-15 defines voltage fluctuation processing procedure with the four quantifying steps: 1) the voltage change factors in percent, 2) the modulated frequency of the voltage change, 3) characteristics of the physical light-source, and 4) the procedure of the human brain recognition of the voltage fluctuation [16]. Thus, the flicker measurement procedure through the flicker meter is an efficient way of observing the voltage fluctuation [10]. The measurement procedure of the flicker meter is verified by an incandescent lamp with voltage fluctuation [8]. The fundamental phenomenon of flicker measurement is designed based on the physiological and psychological involved in the measurement of perception [6]. The literature survey analysis indicated that the procedure in IEC 61000-4-15 does not efficiently estimate the minimum voltage fluctuations, which means very low accuracy [11]. This paper does not precisely focus on the dynamics of the flicker meter. However, the flicker meter plays an important role in the verification tests of the flicker measurement.

B. Continuous Operations

The detail about the procedure of the flicker measurement and assessment during continuous operation is shown in Fig.2. The continuous operation of WT produces the flicker emission (99_{th} or 95_{th} percentile) coefficient ψ_k. The C_{ψ_k,V_a} is provided (95_{th} percentile) for the grid-connected network impedance phase angles ($\psi_k = 30, 50, 70$ and 85) at different wind speed distribution ranges $V_a = 6, 7, 5, 8.5, 10m/s$. The range of wind speed is set according to the Rayleigh distribution [9], the probability distribution fits the annual wind speed distribution as $F_v = 1 - exp(-\frac{\pi}{4}(\frac{v}{v_a})^2)$.

The WT flicker coefficient is measured during continued operation as follows:

$$C_{\psi_k,V_a} = P_{lt} \times \frac{S_k}{S_n} \tag{6}$$

The flicker coefficient is C_{ψ_k,V_a}, where the flicker coefficient depends on the grid impedance angle ψ_k and wind speed V_a and S_k is the short circuit apparent power of the grid. The rated apparent power of the WT is S_n, and P_{lt} indicates a long flicker emission. Normally, the low wind speed produces low flicker coefficient [16] [17].

C. Switching Operations

The characteristic shall be stated for the switching operations where significant voltage variations are given in three points, i) start-up at cut-in wind speed in WT, ii) WT start-up reached at rated wind speed, iii) the unfavorable situation of switching between generator where WTs are connected with one or more generator (multiple winding). Normally, the measurement of switching operations is within a $10-minute$ period N_{10} for short-flicker measurement and 2-hours N_{120} for long-flicker measurement. The flicker step factor is a standardized measurement procedure of the flicker emission with respect to a single switching operation of a WT as follows:

$$K_f(\psi_k) = (1/30) \times \frac{S_k}{S_n} \times P_{st,flic} \times T_p^{0.31} \tag{7}$$

where $K_f(\psi_k)$ is the flicker step factor of the WT in terms of a single switching operation, and $T_p^{0.31}$ is the duration of the voltage variation, which is due to the switching operation, P_{st} is the flicker emission from the WT, S_n is the rated apparent power of the wind turbine and S_k is known as the short-circuit apparent power of the grid. The flicker step factor considered the network impedance phase angle $(30, 50, 70$ and $85)$. The variable-speed WTs produced low flicker step factors [12] as compared to the fixed-speed WT, which may generate the range from average (pitch controlled) to high (stall controlled). In the single switching operation of a WT, the voltage change factor $K_u(\psi_k)$ is measured by the following equation:

$$K_u(\psi_k) = \sqrt{3} \times \frac{U_{fic,max} - U_{fic,min}}{U_n} \times \frac{S_k}{S_n} \tag{8}$$

Where $K_u(\psi_k)$ is the voltage change factor of the WT according to the specified switching operation. The U_{min} and U_{max} are the minimum and maximum voltage (R.M.S phase-to-neutral). The U_n is the nominal phase-to-phase voltage, S_n is the rated apparent power of the WT, and the S_k is the short-circuit apparent power of the grid. The flicker step factor and voltage change factor should be evaluated as the average results of the around 15 values.

TABLE I: The verification test using values of WT

Nominal values of the WT		
Symbol	**Value**	**Units**
Sn	3	MVA
Un	12	KV
In	144	Am

D. Verification test and measurement results

This section describes a correlative analysis of the flicker emission measurement and assessment concerning continuous and switching operations measurement procedure according to the standard IEC 61400-21-1. The simulation framework model is designed for the flicker measurement and assessment during continuous and switching operations as depicted in Fig.2 and Fig.3. The outcomes of flicker measurement depend on the various dynamics particularly on the analysis of estimated results and adopted measurement procedure for flicker. Therefore, flicker measurement testing includes, 1) testing of the designed simulation model for flicker measurement, 2) assuring the implementation of flicker measurement model based on continuous and switching operations procedure, and 3) comparing the estimated results with the standard IEC 61400-21-1. The paper is focused on the measurement procedure results, which were validated under the light of standardization, specified in the standard IEC 61400-21-1. These are the two fundamental tests performed by manufacturers of the WT: namely 1) The validation test of the flicker measurement, 2) The accuracy performance test of the fictitious grid.

a) The validation test of the flicker measurement: The WT parameters used in the testing of verification are shown in Table.I. The voltage and current lead to time-series values $u_m(t)$ and $i_m(t)$, and the flicker coefficient is the output of the $'Normalization'$ block as see in Fig.2. The flicker coefficient can be verified using sinusoidal modulated signal based on the predetermined values of the flicker coefficient c_{ψ_k}.

The input current $i_m(t)$ is same in all these tests. However, a sinusoidal signal varies with the fluctuations, which are characterized by the current changes $\triangle I/I$, and the amplitude modulation frequency f_m. The three phase input current equations 9-11 are written as follows:

$$i_m(t) = \sqrt{2} \times I_n \times (1 + \triangle\frac{I}{I} \times \frac{1}{100} \times \sin(2\pi f_m t)) \times \sin(2\pi f_g t) \tag{9}$$

$$i_m(t) = \sqrt{2} \times I_n \times (1 + \triangle\frac{I}{I} \times \frac{1}{100} \times \sin(2\pi f_m t)) \times \sin(2\pi f_g t) - (120\pi/180) \tag{10}$$

$$i_m(t) = \sqrt{2} \times I_n \times (1 + \triangle\frac{I}{I} \times \frac{1}{100} \times \sin(2\pi f_m t)) \times \sin(2\pi f_g t) + (120\pi/180) \tag{11}$$

Where f_g is the nominal grid frequency around 50Hz. The input voltage signal $u_m(t)$ with the same frequency and

TABLE II: Desired values of c_{ψ_k} = 2,00+/-5 when Sk,fic=20Sn

fm(Hz)	**Current fluctuation $\triangle I/I$ for 50 Hz**			
	ψ_k **30°**	ψ_k**50°**	ψ_k**70°**	ψ_k**85°**
0.5	8.031	10.401	17.860	49.537
1.5	3.618	4.684	8.029	21.924
8.8	0.833	1.064	1.712	3.192
20	2.294	2.773	3.748	4.763
25	3.335	3.901	4.892	5.686
33.3	6.648	7.330	8.289	8.881

phase angle described in the equations 12-14, the three phase modulated input voltage equations are as follows:

$$um_t = \sqrt{\frac{2}{3}} \times U_n \times (1 + 3 \times \frac{1}{100} \times \frac{1}{2} \times \sin(2\pi f_m t)) \times \sin(2\pi f_g t) \quad (12)$$

$$um_t = \sqrt{\frac{2}{3}} \times U_n \times (1 + 3 \times \frac{1}{100} \times \frac{1}{2} \times \sin(2\pi f_m t)) \times \sin(2\pi f_g t) - (120\pi/180) \quad (13)$$

$$um_t = \sqrt{\frac{2}{3}} \times U_n \times (1 + 3 \times \frac{1}{100} \times \frac{1}{2} \times \sin(2\pi f_m t)) \times \sin(2\pi f_g t) + (120\pi/180) \quad (14)$$

Where the network impedance angles ψ_k are described in the Table.II. In the fictitious grid simulation model, the parameters regulated by the current changes $\triangle I/I$ accordingly with the angle ψ_k and the amplitude modulation frequency f_m gradually increases. The SCR of the WT is also included in the estimation of the voltage change factor. The results showed that the voltage change factor continuously changes versus SCR emission. The short-circuit apparent power $S_{k,flic} = 20 \times S_n$ from the fictitious grid is fixed. The current changes $\triangle I/I$ as per the angle ψ_k, and the amplitude modulation frequency $f_m = 8.8Hz$ is also fixed. In the scenario of switching operation, the WT converters produce the emission of SCR. Therefore, SCR gradually increases and fixes the short-circuit apparent power at the fictitious grid $S_{k,flic} = 20 \times S_n$. According to the IEC standard [7], the fictitious grid short-circuit apparent power range is $S_{k,flic} = 20 - to - 50 \times S_n$.

The IEC-61400-21-1 standard is assured that the observed flicker coefficient c_{ψ_k} should be 2 within the tolerance of $\pm 5\%$. The simulation model produces approximate results with the applicable requirement specified in the standard IEC-61400-21-1 during switching and continuous operation. The obtained results of flicker coefficient c_{ψ_k} variation around $\pm 2\%$ with the tolerance of $\pm 5\%$ maximum range in between $1.96 - to - 2.2$ (see Fig.6), and the average range approximate $1.90 - to - 2.0$ is shown in Fig.5. The maximum flicker coefficient c_{ψ_k} is seen in Fig.6. Similarly, the three-phase average short flicker P_{st} around P_{st} is $7.8 - to - 8.8$, as shown in Fig.7.

b) The performance test of the fictitious grid: This section validates the simulation results of the fictitious grid. The input parameters for the simulation are current signal $i_m(t)$, grid frequency and SCR (switching) at WT. The IEC-61400-21-1 [7] specified that the test is performed to observed the flicker coefficient c_{ψ_k} and desired requirement around 2.0 within a tolerance of $\pm 5\%$.

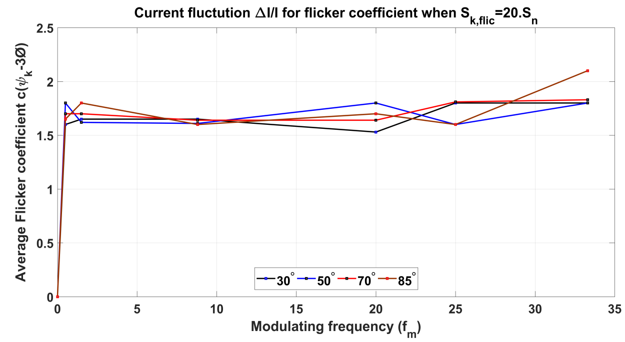

Fig. 5: Average flicker coefficient c_{ψ_k}

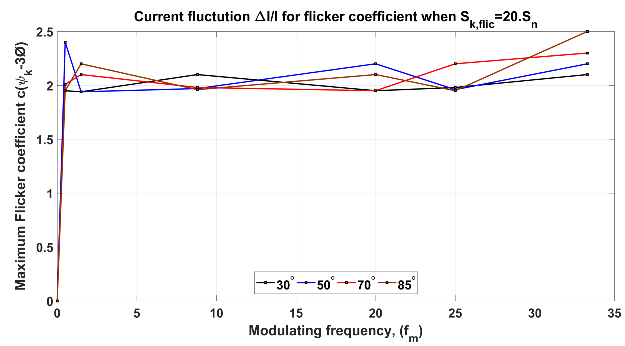

Fig. 6: Maximum flicker coefficient c_{ψ_k}

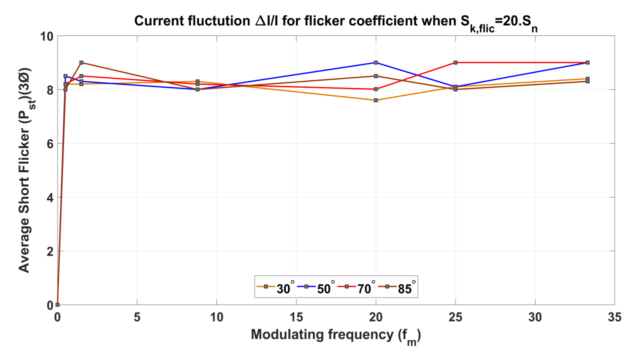

Fig. 7: Average short flicker P_{st}

No doubt the performance test of a fictitious grid cannot be completed without the distorted $u_m(t)$ voltage with multiple zero crossings [14]. The fluctuated voltage $u_m(t)$ integrated with fundamental voltage and levels of harmonics are as written in the Table.III. In addition, this voltage fluctuation $u_m(t)$ is measured by multiple zero crossings, and the short circuit apparent power $S_{k,flic}$ is fixed in the fictitious grid. In the simulation process, all the harmonics have a $180°$ phase shift within the $50Hz$ fundamental. In other words, all have a negative going zero crossing in the signal while the fundamental has a positive going zero crossing. As discussed

TABLE III: Specification of test for distorted voltage with multiple zero crossings

Harmonic order	3	5	7	9	11	13	17	19	23	25	29	31
U - % of Un	5	6	5	1.5	3.5	3.0	2.0	1.76	1.41	1.27	1.06	0.97

above the distorted voltage is sinusoidally modulated at $8.8Hz$ with a relative amplitude of 0.25%. The three phase voltage signal $u_m(t)$ are written as follows:

$$u_m(t) = \sqrt{\frac{2}{3}} \times U_n \times (1 + 0.25 \times \frac{1}{100} \times \frac{1}{2} \times \sin(2\pi 8.8t)) \times \sin(2\pi f_g t) + (U_v \times \frac{1}{100} \times \sqrt{\frac{2}{3}} \times U_n \times \sin(2\pi 8.8 f_n t + \pi)) \tag{15}$$

$$u_m(t) = \sqrt{\frac{2}{3}} \times U_n \times (1 + 0.25 \times \frac{1}{100} \times \frac{1}{2} \times \sin(2\pi 8.8t)) \times \sin(2\pi f_g t) - (\sin(2\pi/180) + (U_v \times \frac{1}{100} \times \sqrt{\frac{2}{3}} \times U_n \times \sin(2\pi 8.8 f_n t + \pi)) \tag{16}$$

$$u_m(t) = \sqrt{\frac{2}{3}} \times U_n \times (1 + 0.25 \times \frac{1}{100} \times \frac{1}{2} \times \sin(2\pi 8.8t)) \times \sin(2\pi f_g t) + (\sin(2\pi/180) + (U_v \times \frac{1}{100} \times \sqrt{\frac{2}{3}} \times U_n \times \sin(2\pi 8.8 f_n t + \pi)) \tag{17}$$

These three phase voltage equations 15-17 consists of voltage fluctuated $u_m(t)$ with the inter-harmonic frequencies. In this case, the modulating frequency f_v is increased with steps of $0.5Hz$ and has reached the maximum modulating frequency of up to $30Hz$. The simulation results of the average flicker coefficient c_{ψ_k} versus the harmonics order during switching and continuous operations are presented in Fig.8.

The flicker coefficient c_{ψ_k} achieves the approximate values described in the standard IEC-61400-21-1, the obtained results within the range $1.50 - 2.05$; however the deviation in the level of tolerance is around $\pm 3\%$ due to the inter-harmonics and SCR emission from the switching operation of a WT. Further, the flicker performance estimated by average short flicker P_{st} approximate $07 - 09$. All the results, study, and analysis ensures that the interoperability issues such as the signal detection through PLL are the critical challenges in the measurement and assessment process of the fictitious grid [17] [14]. The voltage change factors depend on the switching operation of the WT and impedance angle ψ_k also involved in the measurement procedure. In the fictitious grid during switching and continuous operation, the short circuit power $S_{k,flic}$ gradually increases with voltage change factors Ku_{ψ_k}. Therefore, it is necessary to identify that voltage change factor Ku_{ψ_k} and ψ_k strongly interlink with the flicker measurement in WT. Thus, the fictitious grid performance assesses the values of voltage change factors Ku_{ψ_k}. The values of voltage

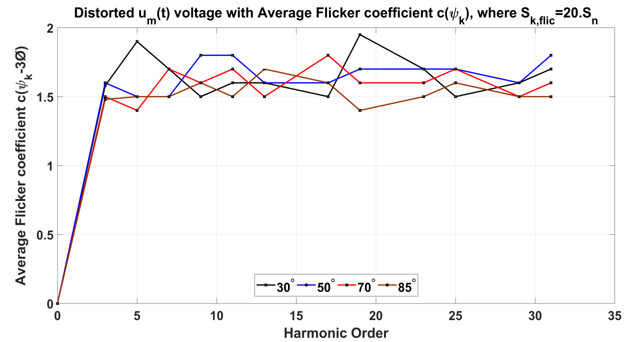

Fig. 8: Average flicker coefficient c_{ψ_k} versus harmonics order

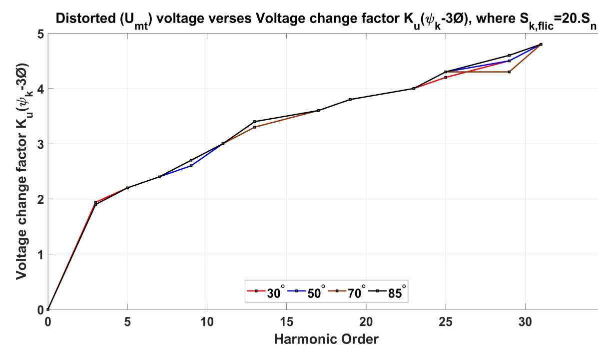

Fig. 9: Voltage changes factors Ku_{ψ_k} verses harmonics

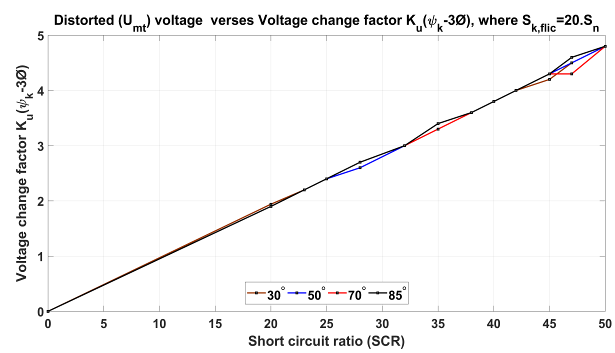

Fig. 10: Voltage changes factors Ku_{ψ_k} verses SCR

change factor is Ku_{ψ_k}, which is directly proportional to both parameters such as harmonics and switching operation (SCR) in WT as shown in Fig.9, and Fig.10. These results indicate that the three-phase voltage input $u_m(t)$ reduces the level of inter-harmonic frequencies by appropriate filtering techniques. The results would be obtained with minimum voltage fluctuation at the PCC. Moreover, the overall measurement procedure is effected by the performance of the fictitious grid. The measurement performance can be upgraded by implementing an efficient and robust PLL in the fictitious grid, and, on the other hand, the filtering part is also necessary to be upgraded in the flicker meter [17].

III. Conclusion

The study presents a procedure for determining the flicker measurement and assessment characteristics of WT. The study demonstrates the effectiveness of the digital flicker measurement during continuous and switching operations of grid-connected WTs as per recently updated standard IEC 61400-21-1.

This paper evaluates the two key verification of flicker measurement tests by employing simulation model. The first test is related to the correlation analysis of the flicker emission measurement. The flicker coefficient c_{ψ_k} should be 2 within the tolerance of $\pm 5\%$ as per IEC-61400-21-1 standard, and the obtained simulation results approximately validates the applicable requirement of the standard. However the deviation in the tolerance level of flicker coefficient c_{ψ_k} around $\pm 2\%$ is in line with the tolerance of $\pm 5\%$. This deviation in the measurement is caused by the presence of inter-harmonics in the flicker meter and fictitious grid decline its accuracy due to presence of harmonics. Thus, harmonics in the input signal cause of declining the performance of PLL results the desired requirement of accuracy can not achieve in the fictitious grid. Therefore, the results from the second test demonstrates the accuracy of the fictitious grid performance. The accuracy of fictitious grid is analyzed by the average flicker coefficient c_{ψ_k}, and the factors of voltage change Ku_{ψ_k} versus harmonics and SCR. The obtained simulation results are in line with the desired values described in the standard IEC-61400-21-1. While the deviation in the level of tolerance range is around $\pm 3\%$ due to the inter-harmonics and SCR emission produced by the switching operation in the WT. The performance of fictitious grid is also affected by differential issues in the PLL. Moreover, the voltage change factors Ku_{ψ_k} play an important role in the measurement procedure because of the two factors (1) switching operation directly links with impedance angle ψ_k and (2) the short circuit power $S_{k,flic}$. Thus, these two factors affect the measurement procedure, which are influenced by the voltage change factors Ku_{ψ_k} in the fictitious grid. To conclude, the appropriate accuracy measurement can be assured by increasing the strength of the filters operation in the flicker meter, and enhancing the performance capability of signal detection of PLL in the fictitious grid.

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