Impact of Connected Flicker Sources on DFIG Performance

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***Abstract*—Doubly Fed Induction Generator (DFIG) has become the most popular wind turbine generator that has been installed worldwide since a decade ago. It cannot be denied that the expansion of loads might be increased from time to time which might also influence the performance of DFIG. Moreover, at the same time, Fault Ride Through (FRT) must also be complied by the grid-connected DFIG. In this paper, an investigation of Flicker Disturbance on DFIG Performance is studied. The flicker disturbance could be sourced from pulsating loads such as arc furnace, compressor, and welding machine loads, it will affect the industrial production process and could cause fatigue due to loss of concentration as a contribution of eye epileptic when working under rapid blinking light. Additionally, when significant flicker sources connected to the system with DFIG, the FRT such as voltage profile at PCC and DC-Link might cause the protection system operates to disconnect the DFIGs from the grid.**

Keywords—DFIG, FRT, Flicker, PCC, DC-Link.

I. INTRODUCTION

The catastrophic impact of conventional based power plants such as diesel, steam, and gas to the environment has forced many countries all around the world to intensify the possibility to extract energy from the renewable energy sources that benign to the environment. However, many of the renewable energy sources are still in the progress of research in terms of technical and economic study.

Currently, wind turbine generator (WTG) become one of the most renewable based-power plants that are installed widely worldwide. It has reached about 597 GW installation until last semester in 2018 [1]. One of the WTG types that is widely installed worldwide is Doubly Fed Induction Generator (DFIG). Its popularity due to the capital cost is much cheaper than its closest rival, full converter type. The cost of a DFIG can be reduced significantly as it uses one-thrid converter size compared to the full converter type. The typical configuration of DFIG is shown in Fig. 1.

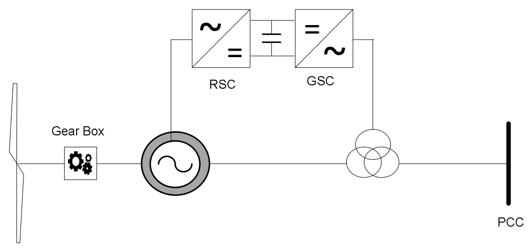

Fig. 1. Typical of DFIG

A DFIG consists of two converters that are fed from the grid side (GSC) and the other one is connected directly to the rotor side of the machine (RSC). To allow better energy transfer between the DFIG and the grid, with a proper controller, a capacitor is placed between GSC and RSC that well-known as DC-link. As aforementioned, the size of these two converters is about 30% which in turn could reduced the total cost of a DFIG manufacture.

Different from the first generation of modern wind turbines (fixed speed), a variable speed such as DFIG, is designed to optimally extracted wind energy through its pitch control and power electronics devices. However, as mentioned and discussed in many references [2-4], a DFIG is quite sensitive from grid faults.

One of the common power quality issues in a power system is flicker. Flicker is a voltage variation between 90-110% of the nominal voltage [5], [6] due to the continues load variation. According to Ref [7] and [8], flicker is a power quality issue problems that occurs about 60%. Arc furnace, compressor, and pulsating loads are the most loads type that is responsible to cause the flicker events [9]. Certain levels of flickers may correspond to a high loss of economic losses when it affects the production process. Moreover, when it reaches light facilities, it might cause the epileptic impact and reduce the operator's concentration and even might lead to an operator's fatigue [7], [10].

In this paper, a source of flicker is placed close to the DFIG to investigate its impacts on the DFIG performance as a flicker is a common power quality issue that usually occurs in the power system as aforementioned above. The fundamental performance indicators such as voltage profile at the point of common coupling (PCC), the voltage at DC link and dispatched power are studied and complied with grid code of voltage ride through.

II. SYSTEM UNDER STUDY

The system under study is depicted in Fig. 2. It consists of six identical 1.5 MW DFIG connected to the grid via a 30 km transmission line. The source of the flicker is represented by a variable load that is placed close to the WTG.

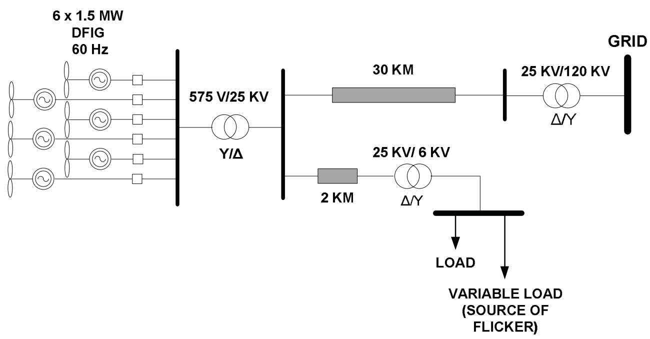

Fig. 2. System Under Study

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The parameters used in the system under study is provided in Table I.

TABLE I. PARAMETERS OF DFIG

Rated Power	9 MW (6 x @ 1.5 MW)
Stator Voltage	575 V
Frequency	60 Hz
R_S	0.023 pu
V_{DC}	1150 V

TABLE II. PARAMETERS OF TRANSMISSION LINE

R_1, R_0 (Ω/km)	0.1153, 0.413
L_1, L_0 (H/km)	1.05×10^{-3}, 3.32×10^{-3}
C_1, C_0 (F/km)	11.33×10^{-9}, 5.01×10^{-9}

TABLE III. PARAMETERS OF LOADS

Static Load	1.0 MW
Variable Load	Nominal Load = 7000 A, Pf = 0.9

III. GRID CODE OF VOLTAGE RIDE THROUGH

One of the important indicators to examine the capability to maintain the connection of DFIG with the grid is the voltage profile at PCC. This voltage profile is regulated in the grid code of Voltage Ride Through (VRT) which differs from one country to another. Two VRT of Spain and the USA [11] are used in this paper to examine the capability of DFIG during the flicker event.

A. Voltage Ride Through of Spain

One of the striches grid codes is Spain Fault Ride Through (FRT) or so-called Spain Voltage Ride Through (VRT).

The VRT of Spain grid code is shown in Fig. 3, where the maximum allowable voltage rise or so-called voltage swell is 130% that lasts for 0.5s. After that, voltage recovery after post-fault is 120% that lasts until 1.0s. The maximum voltage profile in the VRT usually indicates as a High Voltage Ride Through (HVRT).

In Fig. 3, the normal operating range of voltage profile at PCC is within 90-110%. The lowest voltage drop allowed is 50% during fault starting and last for 0.15s and increased to 60% after that up to 0.25s. During post-fault, the voltage recovery should be gradually above 60% (following the rise step shown in Fig.3) up to 80% at 1.0s and then gradually increase since then until reaching 90% at 15.0s. The shaded area above the normal condition area is normally classified as Low Voltage Ride Through (LVRT) of Spain. All voltage profiles at PCC during fault and post fault that violate the HVRT and the LVRT will consequently cause the WTG disconnected from the grid.

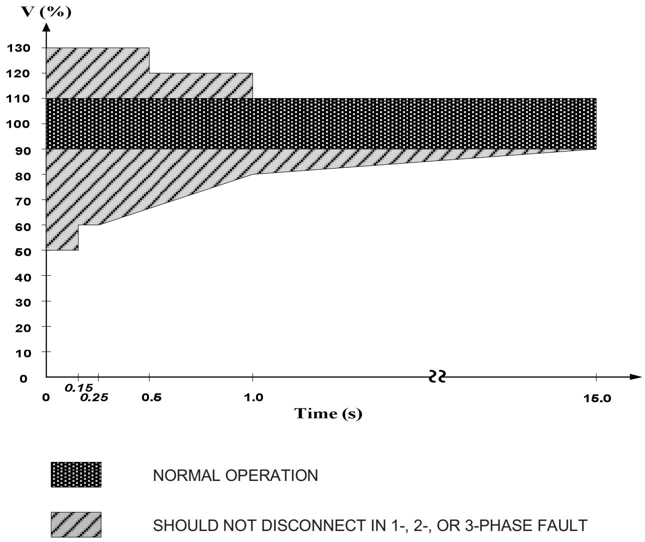


Fig. 3. VRT of Spain grid code

B. Voltage Ride Through of USA

Similar to VRT of Spain, VRT of USA has also both HVRT and LVRT. The maximum HVRT is allowed 120% for 1.0s and gradually drops up to 5% every second and ended at a maximum of 110% at 4.0s. All voltage rise beyond this line should disconnect the WTG from the grid. The normal voltage operation in this grid code is 95%-105%. When fault started and causing voltage drop up to the very minimum value that lasts only up to 0.15s. After that, the voltage must be within the shaded area that gradually increases sharply up to 90% at 2.0s. All voltage drops beyond the minimum line will cause the WTG should be disconnected from the grid.

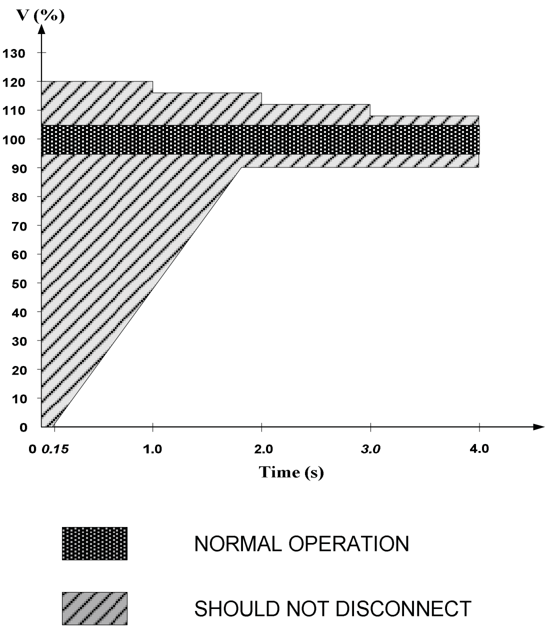


Fig. 4. VRT of US grid code

IV. SIMULATION RESULTS AND DISCUSSIONS

The simulation results of this study are shown in Fig 5 to 10. Fig. 5 shows the generated power of DFIGs that is rated at 9 MW. It can be seen that during the flicker event, the power experiencing rapid oscillation that might lead to short instability. Another part that is also taken into account for the DFIG performance is voltage profile at DC link. Although voltage DC as shown in Fig. 6 during flicker event is still under a safety margin of 1.2 pu [11], for a long duration of flicker might lead to the damage of the converters.

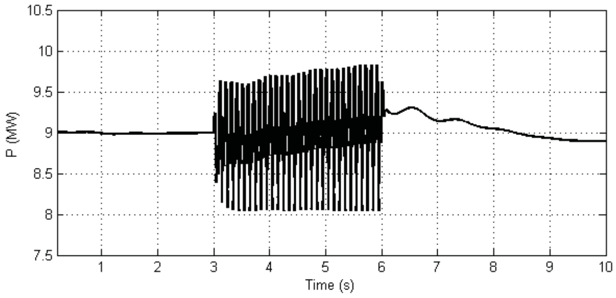


Fig. 5. Generated power response.

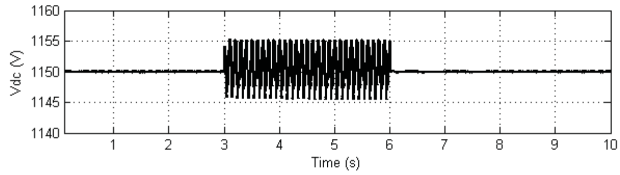


Fig. 6. Voltage profile at DC link

The most important parameter that usually refers to disconnect a WTG is voltage profile at PCC. As shown in Fig.7, voltage profile at PCC experiencing rapid oscillation as well where when it complies with HVRT of Spain its maximum voltage violates the HVRT of Spain and should be ended by the disconnection of the WTG. Similar to HVRT of Spain, HVRT of USA also slightly violated by the maximum overshoot of the oscillated voltage at PCC during the flicker event. If the protection system is sensitive enough, the small violation point may lead the WTG to be disconnected from the grid.

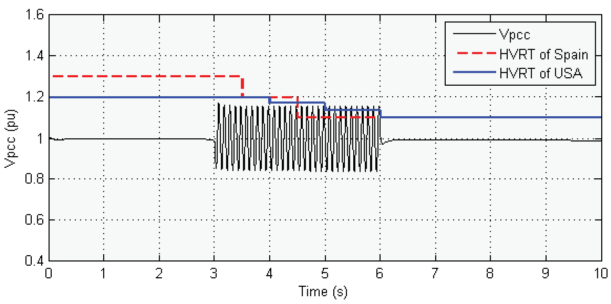


Fig. 7. Voltage profile at PCC in compiling with HVRT

Fig. 8 exhibits the complying voltage at PCC during the flicker event with LVRT of Spain and USA. When examines with the LVRT of Spain, the minimum oscillation voltage at PCC is within the safety margin of LVRT, meaning that does not require the WTG to be disconnected from the grid, however, when applied to LVRT of USA, the minimum allowable voltage drop is violated and if this LVRT of USA is adopted as consequent, the WTG should be disconnected from the grid.

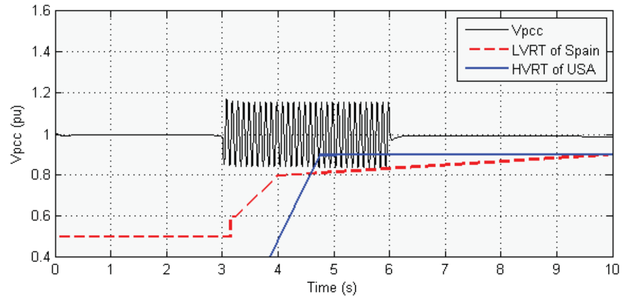
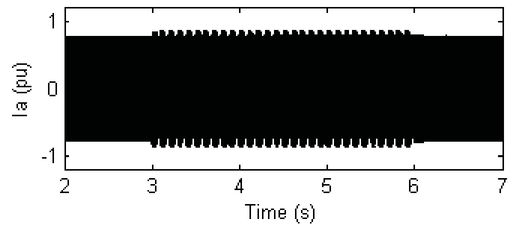
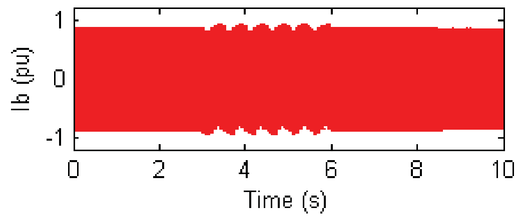


Fig. 8. Voltage profile at PCC in compiling with LVRT

The current flow for both stator and rotor of the induction generator of the DFIG is shown in Fig. 9 and 10 respectively. All phases for both currents are shown a similar trend where a slight increase in the magnitude for both current phases at stator and rotor. This indicates the flicker does not affect much in the stator and rotor currents.



(a)



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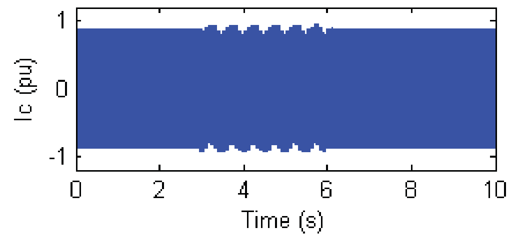
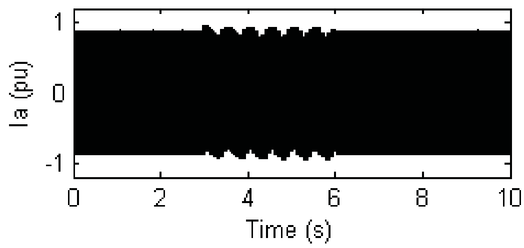
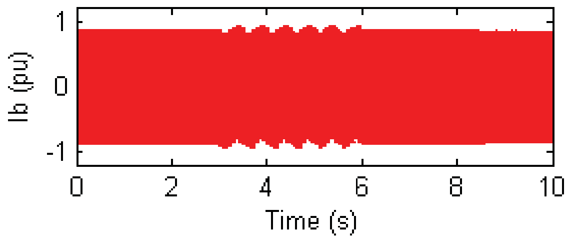


(c)

Fig. 9. Stator current of the DFIG (a) phase-a; (b) phase-b; and (c) phase-c



(a)



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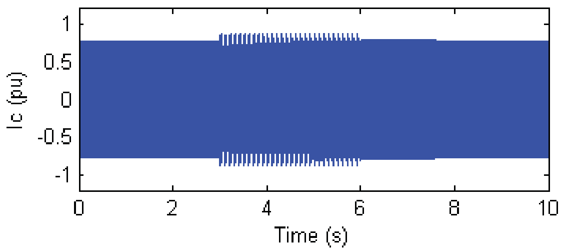

(c)

Fig. 9. Rotor current of the DFIG (a) phase-a; (b) phase-b; and (c) phase-c

CONCLUSION

This paper presents a study of flicker impact on the performance of DFIG. Some important parameters such as voltage profile at PCC, the voltage at DC link, transferred power and stator and rotor current of the generator are investigated. A Voltage Ride Through (VRT) for both Spain and USA Grid Codes that are used to examine the flicker impact on DFIG performace. It can be concluded that such a flicker source with its duration could be ended up by the disconnection of WTG from the grid due to some violation of the minimum or maximum allowable voltage at the point of common coupling (PCC). Therefore it is suggested to provide a FACTS device to compensate such this flicker problems that might disturb the continuity of power dispatch.

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