Impacts of Grid Frequency Variation on Dynamic Performance of DFIG Based Wind Turbine

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August 17, 2018

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Abstract. Wind energy is one of popular sources of renewable energy that massively used to generate electric power nowadays. Among wind generator technologies, Doubly Fed Induction Generator (DFIG) is placed as the first dominant wind generator type that is installed worldwide since 2004. Its popularity is due to the advantages of its capability to extract more energy compare to the fixed speed type. Moreover, it uses only one-third converter size which reduced the total construction cost compared to its closest rival, Full Converter Wind Turbine Generator Type. Although DFIG widely installed worldwide, it is in fact, very sensitive to the grid disturbances such as frequency variation. Based on IEEE standard for 60 Hz system, a power system should not be allowed to work in less than 59.3 Hz or more than 60.5 Hz. In this paper, DFIG-grid connected is extensively simulated in the condition of frequency variation that is carried out using Matlab/Simulink. The results show that some important parameters such as power output of the generator, voltage at point of common coupling, voltage at DC link and generator speed are experiencing significant rise/drop which in turn might damage the wind turbine generator.

1. Introduction

It is inevitable for every country all around the world to intensively explore their renewable energy sources to mitigate the detrimental impacts of conventional energy sources to environment. Moreover, the deposit sources of these conventional energy sources decreases from time to time which may lead to global economic instability. Therefore, many countries, particularly for some groups of developed countries have installed large number of renewable based power plants such as hydro, wind and solar [1, 2]. For the last decades, wind turbine generators have significantly increased in installation number all around the world by about 540 GW until February 2018 [3] as can be seen in Fig. 1.

Among other types of wind turbine generators (WTGs), Doubly Fed Induction Generator (DFIG) becomes the most popular since last decade [4]. Its popularity is due to several advantages including capability to extract more energy compare with the fixed speed type [5], and its benefit in reducing the construction total cost by having only one-third capacity of converters [6] compare with its closest rival, Full Converter Wind Turbine Generator. The general configuration of DFIG is shown in Fig. 2.

As can be seen in Fig. 2, a DFIG consists of two converters; Rotor Side Converter (RSC) a converter that connects to the rotor of the induction generator and Grid Side Converter (GSC), a converter that connects with the grid side. These two converters is linked by a capacitor or so-called DC link capacitor. These one-third sizes of converters play an important role to allow absorb and deliver some amount of reactive power from/to the grid. Its 30% converters size could reduce the construction cost significantly compared to its closer rival Full Converter Wind Turbine Generator [7]-[9].

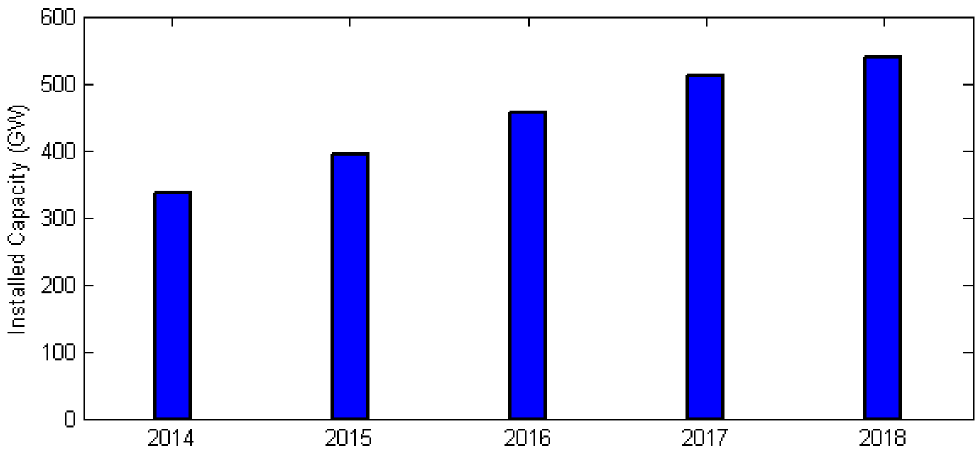


Figure 1. Number of wind turbine generator installation worldwide until February 2018 [3].

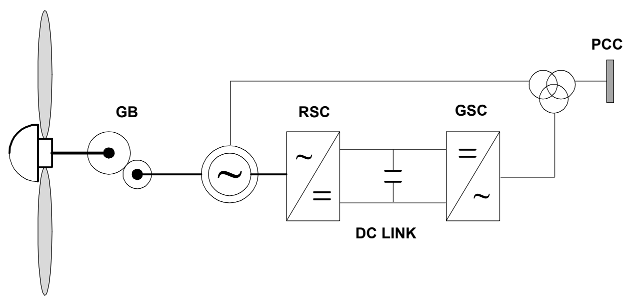


Figure 2. Typical configuration of a DFIG

As large scale type of WTG, DFIGs normally connected to the grid and capable to provide limited reactive power when required by the grid. However, DFIGs are sensitive to the grid faults that may lead to the disconnecting it from the grid. Disconnecting a large MWs DFIG from the grid means large economic loses to the WTGs' owner. Some papers discusses the impact of DFIGs' dynamic performance during grid faults such as voltage sags [10] and swell [11] as well as internal faults event that might occur at the converters of DFIG [12, 13]. However, not much attention is given to the case of grid frequency variation impacts on the dynamic performance of DFIG.

Based on IEEE standard [14] for 60 Hz system, a power system should not be allowed to work in less than 59.3 Hz or more than 60.5 Hz. However in the real cases, many frequency variations occur even more severe than the limit of IEEE Standard as can be seen in several places all around the world such as summarize in table 1.

In this paper, two cases of grid frequency variation are applied to investigate the dynamic responses of the DFIG. All system are carried out and extensively simulated in Matlab/Simulink environment.

Table 1. Major Frequency Deviation Cases from 1970s-2000s

Places	Frequency Deviation	Causes	Year	Ref.
East Ontario, Canada	58.7 Hz-62.6 Hz	Islanding Electrical Grid	1972	[15]
New York City, USA	< 47.5 Hz	Islanding Electrical Grid	1977	[16]
West and South Coast of England	47.3 Hz	Islanding Electrical Grid	1981	[17]
France	49.6 Hz	Cascading Fault	1985	[17]
Italy	NA	Cascading Transmission Line	1994	[15]
Perth, Australia	<3.5 Hz/s	Cascading Outage	1994	[17]
Brazil	55.25 Hz-58.0 Hz	Cascading Fault	1996	[15]
Malaysia	49.1 Hz	Cascading Fault	1996	[15]
Italy	47.0 Hz	Lack of Generation	2003	[18]
Europe	NA	Cascading Outage	2006	[19]

2. System under Study

The system under study consist of six 1.5 MW DFIG, 60 Hz that are connected to the grid via 30 km distribution line as depicted in Fig. 3. The system parameters are provided in Table 2-3.

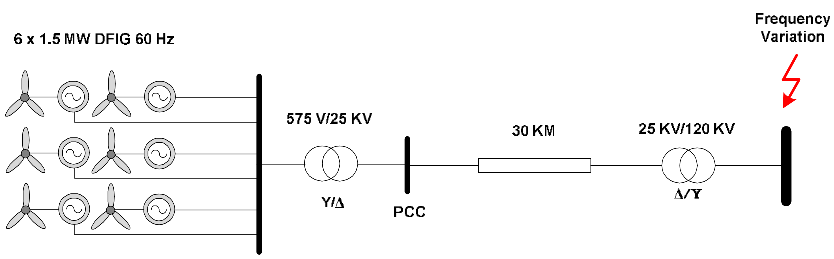


Figure 3. System under Study

Table 2. Parameters of DFIG

Parameters	DFIG
Rated Power (MW)	6 x 1.5 MW
R_s (p.u.)	0.023
H(s) (p.u.)	0.685
V_{dc} (V)	1150

Table 3. Parameters of Distribution Line and Grid

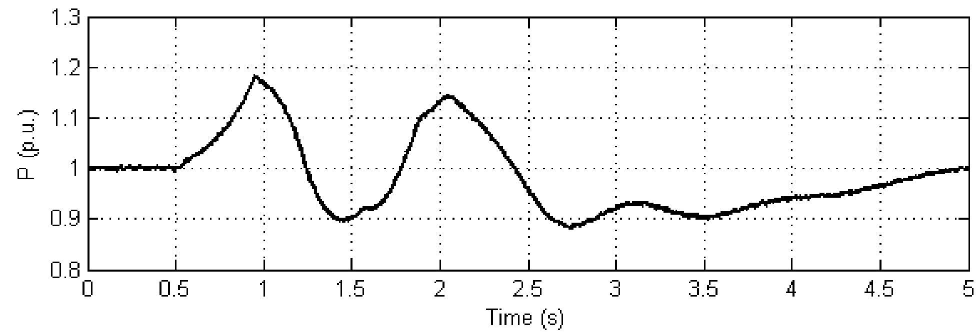
Parameters	Distribution line
R_1 (ohms/km)	0.1153
R_0 (ohms/km)	0.413
L_1 (H/km)	1.05e-3
L_0 (H/km)	3.32e-3
C_1 (F/km)	11.33e-9
C_0 (F/km)	5.01e-9

3. Simulation Results and Discussion

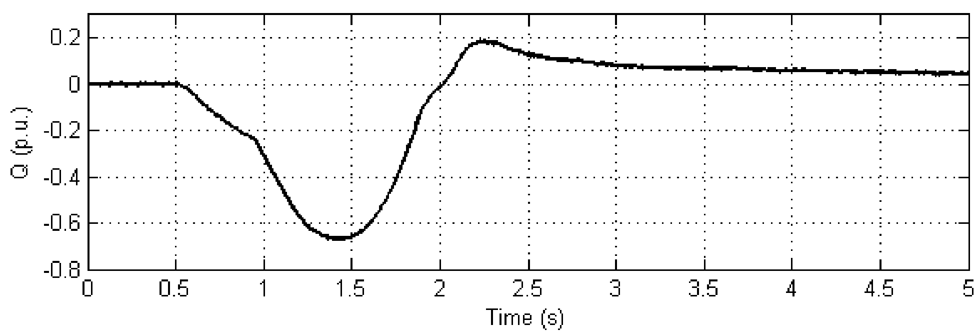
In this study, there are two cases are investigated. Where the two cases are applied to the system under study for about 8 cycles from 0.5s-2.0s for the case I and II.

3.1. Case I

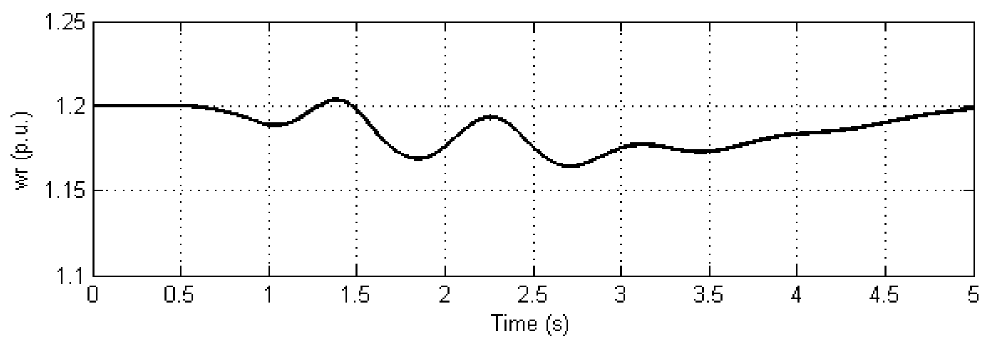
In this case, a frequency drop of -3.5Hz/s is applied and lasting for 1.5s. Some of the most important parameters of dynamic performance of DFIG during the fault are shown in Fig. 3(a)-3(d).



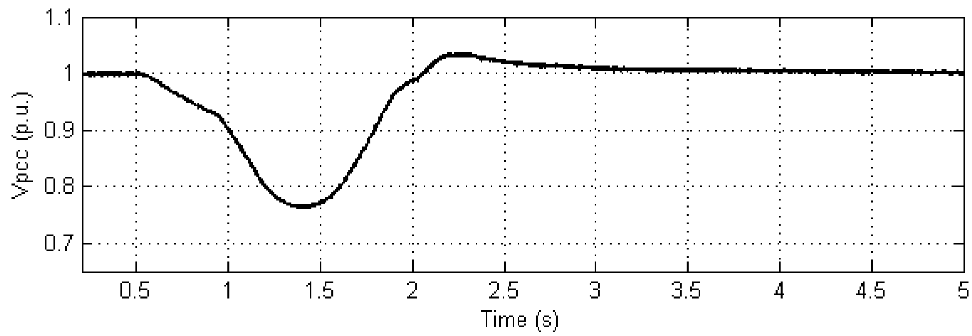
(a)



(b)



(c)



(d)

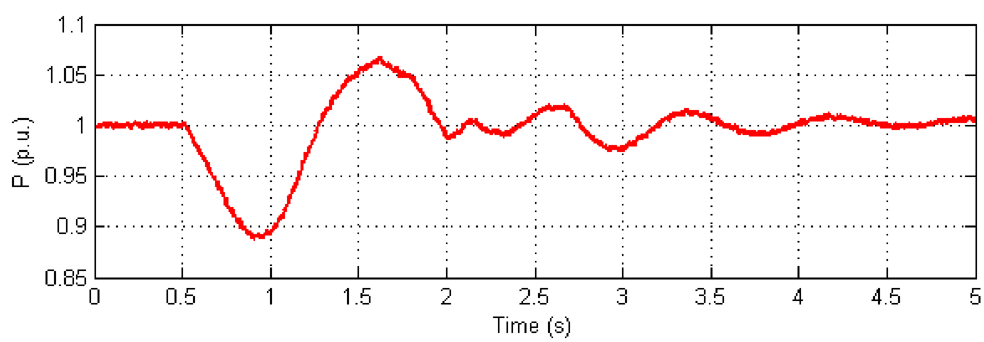
Figure 4. Dynamic responses of DFIG during frequency drop for -3.5 Hz/s; (a) P output response, (b) Reactive Power output response, (c) Generator Speed (ω_r) response, and (d) Voltage Output profile at PCC.

Fig. 3(a) shows that there is an oscillation on the generated power when grid frequency drop started at 0.5s. Moreover, although the drop of grid frequency is returned to normal in 2.0s, the trend of generated power to return to normal is achieved after 5.0s. This condition might influence the critical load that connected to the grid and rely on the power supply from the DFIGs.

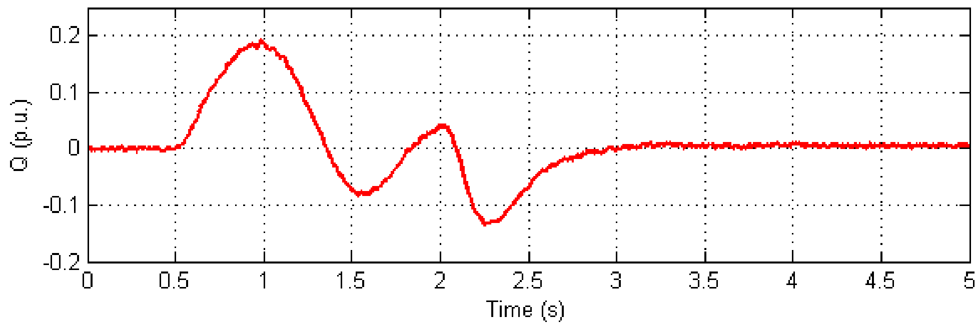
As can be seen in Fig. 3(b), the frequency drop of -3.5 Hz/s from 0.5s to 2.0s causes the drop of reactive power output of DFIG by about 0.7 p.u. meaning that there is a momentary reactive power supply of DFIGs to the grid. However, the control mechanism of the DFIG could return the generated reactive power to normal condition quickly after the frequency drop return to normal. Fig. 3(c) shows the similar trend with the Fig. 3(a) as the generated power is related to the rotor speed of the induction generator. Meanwhile, Fig. 3(d) tends to give the same response with the reactive power profile shown in Fig. 3(b) as they influence each other. The voltage drop at PCC (Fig. 3(d)), although dropped about 0.25 p.u., is still within the safety margin of almost international grid codes.

3.2. Case II

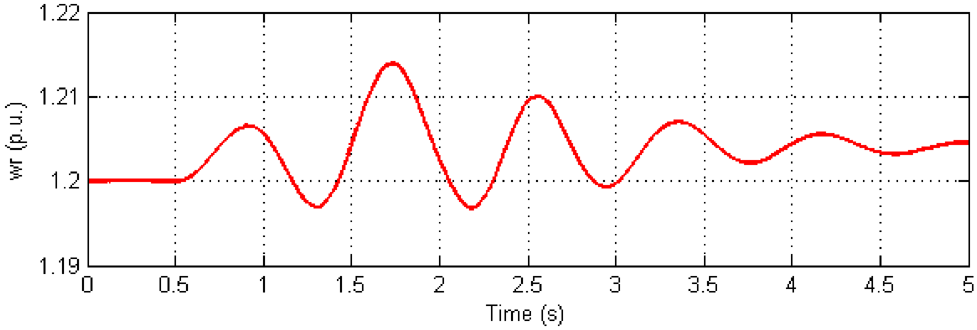
The extensive simulation for Case II, is aimed to investigate the impacts of increased frequency change about +3.5Hz/s. The simulation results are shown in Fig. 4(a)-4(b).



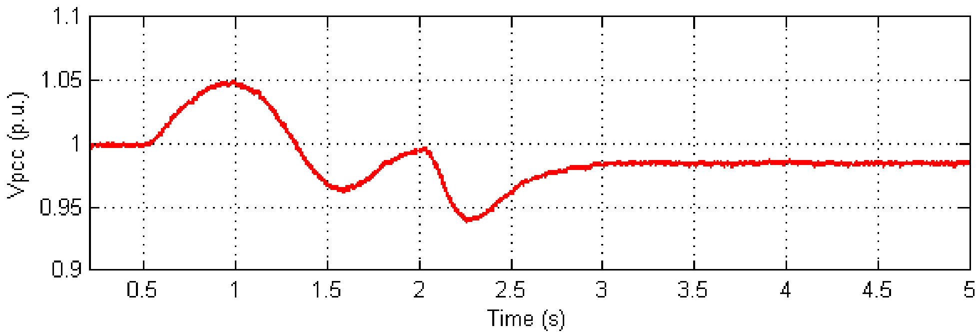
(a)



(b)



(c)



(d)

Figure 5. Dynamic responses of DFIG during frequency ramp for +3.5 Hz/s; (a) P output response, (b) Reactive Power output response, (c) Generator Speed (ω_r) response, and (d) Voltage Output profile at PCC.

Fig. 5(a)-(d) shows the dynamic response of DFIGs during frequency ramp of +3.5 Hz/s that is started from 0.5s to 2.0s. In this case, oscillation of generated power is lesser than the first case and reaches faster steady state as shown in Fig. 4(a). This condition might not risk the critical loads that are connected to the grid. Reactive power, Q, is oscillating right after frequency ramp is started at 0.5s but short after fault cleared out at 2.0s, generated Q returned to its defined state at 3.0s (Fig. 4(b)).

Generator speed (ω_r) is swing right after the frequency fault started and tends to reach stable condition after 5.0s as plotted at Fig. 4(c). Meanwhile, low amplitude oscillation of voltage profile at PCC (as shown in Fig. 4(d)) occurs due to the grid frequency fault and might reach its defined value longer than the first case. However, its level does not violate the most of common international grid codes as normal voltage level must not lower or higher than ± 5%.

4. Conclusion

In this paper, dynamic responses of DFIGs-Grid connected are investigated during grid frequency change. The dynamic responses of DFIG during grid frequency drop of -3.5 Hz/s (Case I) are worse than the grid frequency ramp of +3.5 Hz/s (Case II) for the studied systems. The oscillation reaches higher amplitude and longer steady state time for both P and Q in the first Case. Moreover, voltage profile at PCC experiencing larger drop in Case I than Case II. This study might be continued for the sustained frequency drop/ramp as future work and the results might be considered for the related authorities in designing and developing the WTGs grid connected.

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