

Dynamic performance comparison of DFIG and FCWECS during grid faults

A. M. Shiddiq Yunus^{*1}, Makmur Saini², Ahmed Abu-Siada³

^{1,2}Politeknik Negeri Ujung Pandang, Jalan PerintisKemerdekaan Km. 10 Makassar, Indonesia

³Curtin University, Kent Street, Bentley WA, Australia

*Corresponding author, e-mail: shiddiq@poliupg.ac.id¹, makmur.saini@poliupg.ac.id², a.abusiada@curtin.edu.au³

Abstract

Among several types, variable speed-based wind turbine generator (WTG) is the most popular type installed worldwide. This type of WTG is able to extract 5% more energy from wind speed compared to the fixed speed WTG. There are two kinds of variable speed based WTG; Doubly Fed Induction Generator (DFIG) and Full Converter Wind Energy Conversion System (FCWECS). DFIG and FCWECS are placed at the first and second topWTG installation worldwide since 2004. However, both of them are very sensitive to the grid dip fault and may violate the allowable margins identified by various international Fault Ride Through (FRT) codes. This paper aims to investigate the responses of DFIG and FCWECS during certain level of grid dips and compare their performance under such event. Results show some differences of the performance of DFIG and FCWECS during voltage sag event, however the voltage profile at the point of common coupling is much better in case of DFIG. Results also recommend that DFIG can be effective when connected to weak grids whilst FCWECS is preferably to be connected to strong grids.

Keywords: DFIG, FCWECS, FRT, voltage dip and wind

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1. Introduction

Due to the catastrophic impacts of conventional based power plants, many countries are now more concern on renewable based power plants. Among the renewable based power plants, wind turbine generator (WTG) is relatively popular due to the rapid increase of power electronics development that can be equipped to WTG. According to the report of JRC, the total number of WTG installed worldwide is about 430 GW in 2015 [1]. In this report, Doubly Fed Induction generator (DFIG) dominated about 54% installation, brings it into the top installed WTG worldwide and followed in the second position by Full Converter Wind Energy Conversion System (FCWECS) that installed about 17.5% for both onshore and offshore. Although both DFIG and FCWECS are capable in extracting more energy about 5% compare to the fixed speed [2-4], both of them are very sensitive with grid fault such as voltage dip [5, 6]. When severe fault occurs at the grid side, voltage profile at point of common coupling (PCC) may violate the international grid codes including fault ride through (FRT) such as FRT of Spain. Therefore it is necessarily important to investigate the system with DFIG and FCWECS whether they comply the fault ride through (FRT) or not. If voltage at PCC violates the FRT, the WTG should be disconnected from the grid to avoid any damages on the WTG. One of the International FRTs is FRT Spain as illustrated in Figure 1 [7].

Area "A" shows the maximum allowed voltage rise in FRT Spain with maximum 130% that allowed for 0.5s and furthermore it maximum margin drops to 120% and lasting for 1.0s. A normal margin is shown within area "B". Approximately 10% above or less than the normal rate (100%) is still classified as in normal condition. Area "C" indicates the lower voltage drop that allowed in FRT Spain. When voltage drop hit beyond the allowed margin as shown in area "C", the WTG must be disconnected soon from the grid. There are many papers discussed about DFIG and FCWECS as discussed in [8-18] however, no attention are given for head-to-head performances comparison between them when faults are applied in the same type and magnitude particularly when both of WTGs should comply the grid code.

This paper highlights the comparison of dynamics performances between two types of variable speed based WTG. These two types; DFIG and FCWECS placed in the top first and second position in their popularity in worldwide installation. The comparison can give the related authority to determine the most appropriate selection between the two for their needs according to these two types based on their capability in comply the grid codes during voltage dip events. To validate the results, two cases of different levels of sag were applied using extension simulation with Simulink/Matlab where the systems for both models are built.

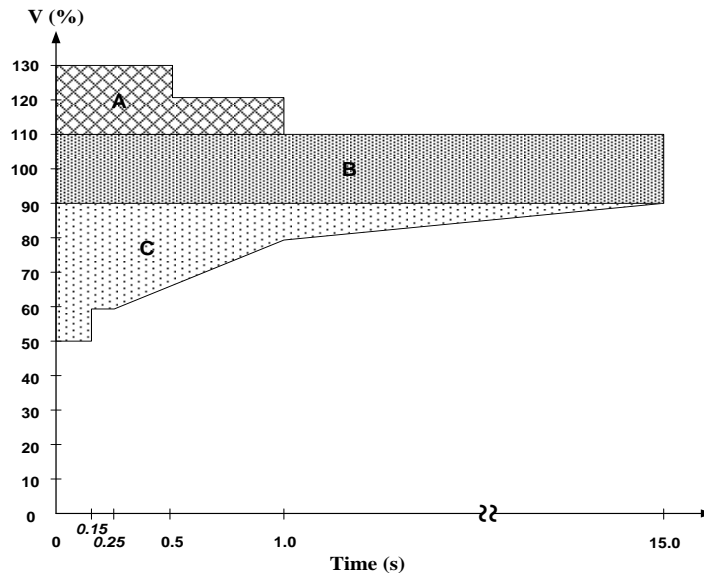


Figure 1. FRT of Spain grid code [7]

2. System Under Study

2.1. Doubly Fed Induction Generator (DFIG)

An DFIG system consists of two converters that are called Grid Side Converter (GSC) and Rotor Side Converter (RSC) which is linked with a capacitor to allow transfer of some amount of energy from/to the grid [19-23]. It is much popular compare to the FCWECS as an DFIG has about one third power electronics capacity which in turn reduced the total cost of an DFIG significantly compared to a FCWECS. The generic model of a DFIG can be seen in Figure 2. Slip rings make the electrical connection to the rotor. If the generator is running super-synchronously, the electrical power is transferred to the grid through both the rotor and the stator. Meanwhile, electrical power is delivered into the rotor from the grid, if the generator is running sub-synchronously. A speed variation of $\pm 30\%$ around synchronous speed can be obtained by the use of a power converter of 30% of nominal power. Furthermore, it is possible to control both active (P_{ref}) and reactive power (Q_{ref}), which gives a better grid performance and the power electronics enables the wind turbine to act as a more dynamic power source to the grid. Parameters of DFIG converters are provided in Table 1. Typical configuration of a DFIG and its Matlab/Simulink model can be seen in Figure 2(a) and (b) respectively.

2.2. Full Converter Wind Energy Conversion System (FCWECS)

The counterpart variable speed of DFIG is FCWECS. Using PMSG or WRSG, it allows reducing the cost by considering applying many poles generators for slow generator speed. Therefore, the generic typical model of a FCWECS as shown in Figure 3(a) giving an option to use or not a gearbox depends on the type of selected generator. A FCWECS using full converter that placed between generator and the grid side. A capacitor is used as DC link to adapt voltage fluctuate due the natural intermittent of wind speed [24, 25]. With 100% capacity of converters employed in FCWECS the cost should also be increased. The Matlab/Simulink model of the studied FCWECS is shown in Figure 3(b).

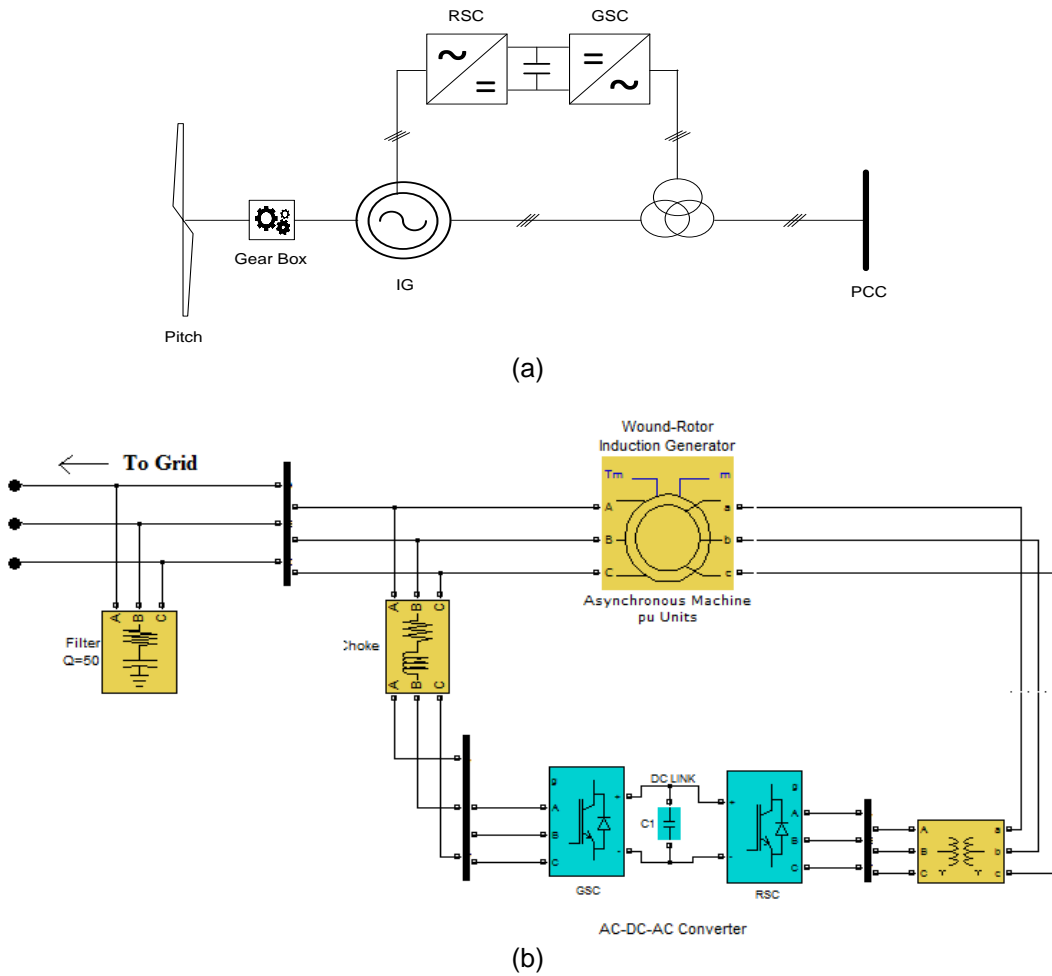


Figure 2. (a) Typical generic model of a DFIG with partial power converters and (b) Matlab/Simulink Model for DFIG

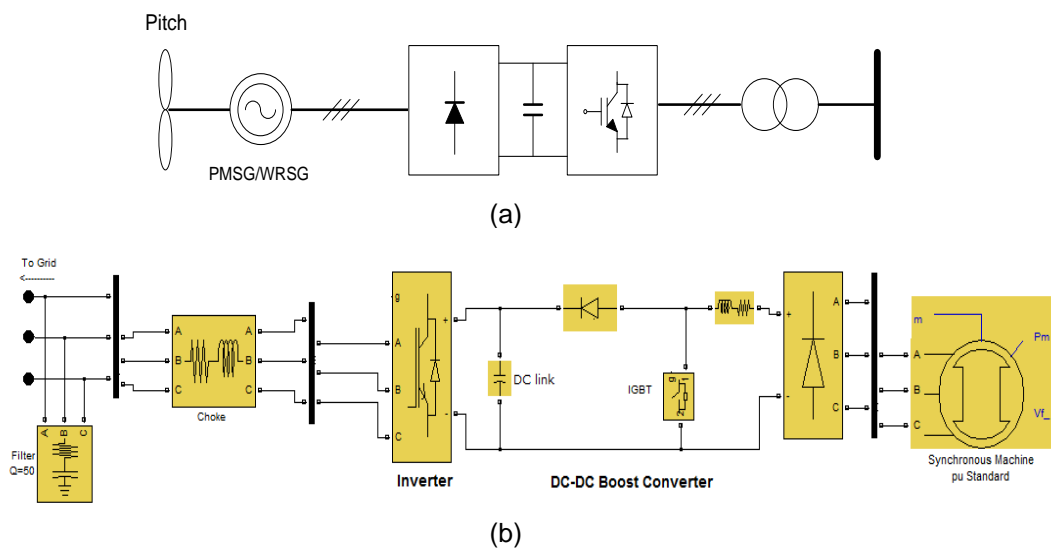


Figure 3. (a) Typical generic model of a FCWECS with full converter and (b) Matlab/Simulink Model for FCWECS

The FCWECS configuration that is shown in Figure 3 consists of two converters: machine side converter (MSC) and grid side converter (GSC). MSC operates as a driver that is controlling the generator torque, whilst GSC will control the amount of active and reactive power to be transferred to the grid. Capacitor is used as a storage device that will store the captured wind energy and might instantaneously be transferred to the grid. In this configuration, the voltage across the DC link capacitor will be maintained constant. Parameters of FCWECS converters are provided in Table 1.

Table 1 Parameters of Both WTG Converters

Parameters	DFIG	FCWECS
Grid side coupling inductor (L, R) (pu)	0.3, 0.003	0.15, 0.003
Nominal DC bus Voltage (V)	1150	1100
DC bus Capacitor (F)	0.01	0.09

2.3. System under Study

As can be seen in Figure 4, system under study consists of 5x1.5 MW DFIG/FCWECS. The WTGs is connected through a step-up transformer and a 30 Km distribution line. Before connected to the grid, a step-up transformer is used to match the grid voltage 120 kV. All models used in this study are developed and carried out using Matlab/SIMULINK. The main parameters used for the system under study including DFIG and FCWECS are provided in Tables 2 and 3 [3].

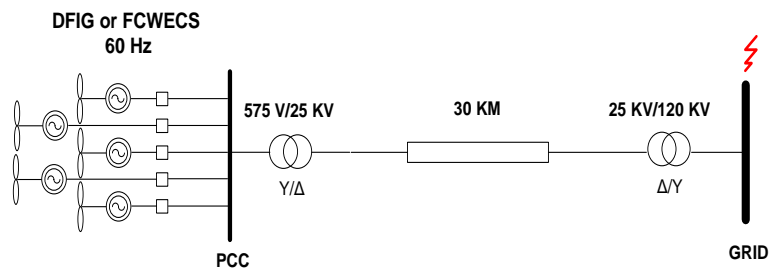


Figure 4. System under study

Table 2. Parameters of Distribution Line

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

Table 3. Parameters of DFIG and FCWECS Model

Parameters	DFIG	FCWECS
Rated Power	5 x 1.5 MW	5 x 1.5 MW
R_s (p.u.)	0.023	0.006
$H(s)$ (p.u.)*	0.685	0.62
V_{dc} (V)	1150	1100

3. Results and Discussion

There are two magnitude level of grid dip applied in this study; voltage dip of 0.5 p.u. (case I) and 0.3 p.u. (case II) Both cases are assumed to be last for 0.05s (around 3 cycles). The simulation results for case I and case II are plotted in Figure 5 and Figure 6 respectively.

3.1. Case I

As can be seen in Figure 5(a), during the grid dip, generated power of DFIG is drop significantly to 0.4 p.u. moreover, when fault is cleared out at 0.55s, generator tends to generate more power before quickly return to normal. Meanwhile, generated power of FCWECS is drop slightly below the DFIG's response. However, when fault is cleared out, FCWECS experiencing a better self-healing to return quickly to the steady state position.

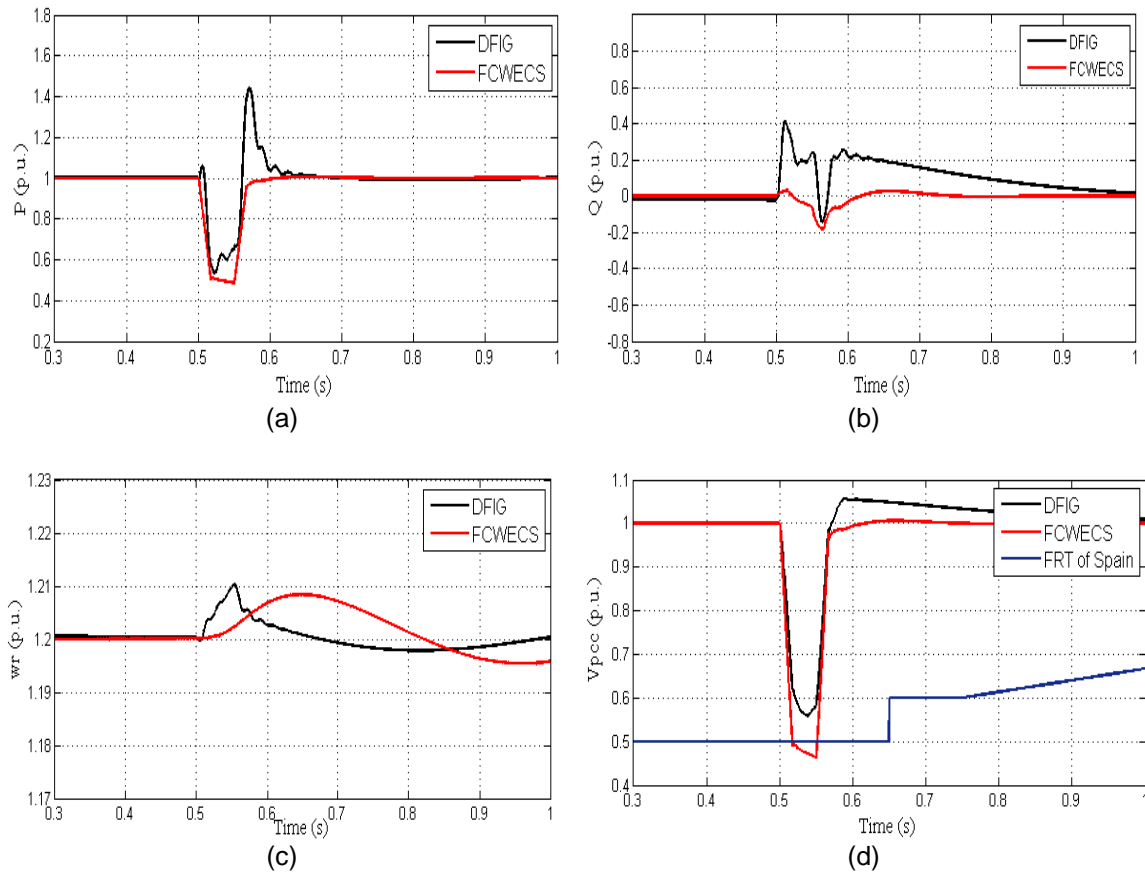


Figure 5. Responses of both DFIG and FCWECS during grid voltage dip of 0.5 p.u.
 (a) Generated Power; (b) Reactive Power; (c) Generator Speed (ω_r); and
 (d) Voltage Profile at PCC

Reactive power produced by DFIG is also larger than FCWECS as shown in Figure 5(b). Meanwhile both DFIG and FCWECS experiencing oscillate ω_r during grid dip of 0.5 p.u. (Figure 5(c)). The main indicator for FRT in grid codes is voltage profile at PCC as it is the one who determined whether the WTG can be remain connected to the grid or not. As plotted in Figure 5(d), voltage drop at PCC for FCWECS drops below the minimum voltage that allowed in FRT of Spain as described in Figure 1, meaning that the FCWECS type should be disconnected from the grid to avoid any damages on WTG. However, for DFIG, voltage drop at PCC is still within the safety margin of FRT Spain, therefore in this case, DFIG is remaining safe to be connected with the grid.

3.2. Case II

Severer case is applied in case II where the magnitude of voltage dip is set to 0.3 p.u. Similar trend to case I, generated active power is drop almost 75% for both DFIG and FCWECS, however, FCWECS experiencing better response when the grid dip is cleared out as can be seen in Figure 6(a). Figure 6(b) shows that reactive power is delivery more by DFIG compared to FCWECS with higher amount compare to case I. Similar to case I, FCWECS experiencing larger oscillation of ω_r and required more time to get into steady state compare to DFIG as depicted in Figure 6(c). As the magnitude of voltage dip is larger than in case I, the voltage drop for both DFIG and FCWECS hit and violate the minimum allowable voltage drop by FRT Spain, therefore in such case, both DFIG and FCWECS should be disconnected from the grid.

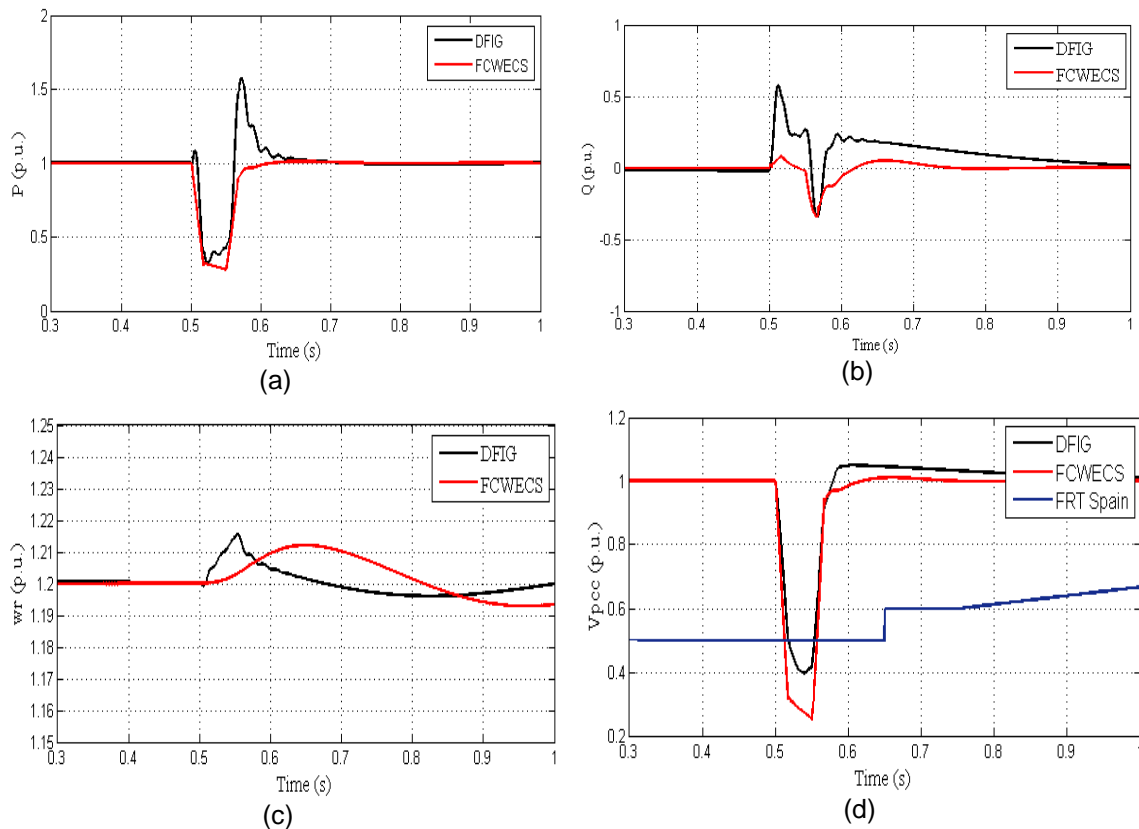


Figure 6. Responses of both DFIG and FCWECS during grid voltage dip of 0.3 p.u. (a) Generated Power; (b) Reactive Power; (c) Generator Speed (ω_r); and (d) Voltage Profile at PCC

4. Conclusion

In this paper, performance comparison of the DFIG and FCWECS under voltage sag events is presented. Results show that, performance of FCWECS is better in terms of the generated active and reactive power and also the generator shaft speed oscillation. However, DFIG shows a better performance in terms of the voltage profile at the point of common coupling particularly when complying with the low voltage FRT of Spain. In case of significant voltage dip event, both DFIG and FCWECS can not be remained connected to the grid in order to avoid any damages to the WTGs. These results can help in selecting the suitable WTG type based on the grid requirement and operating conditions. If the grid is stiffer, FCWECS could become an option. However, for weak grids, a DFIG might be a better option to connect with.

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