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Microgrid Control based on a DFIG Integrated with a BESS

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Abstract

This study presents an improved doubly fed induction generator (DFIG) that is integrated with a battery energy storage system (BESS) for microgrid control. The proposed DFIG can generate independently the power output of the rotor-side converter (RSC), grid-side converter (GSC), and battery-side converter. The maximum power point tracking (MPPT) is included in the RSC to maximize the generated power of DFIGURE. The power of the GSC is used to smooth total wind power of DFIG and to maintain stably AC voltage and frequency in the island mode. The battery-side converter is used to keep the dc link voltage of a back-to-back converter. The effective of the proposed DFIG is validated by simulations on Matlab / Simulink environment.

***Keywords**: Microgrid, Doubly fed induction generator (DFIG), Battery energy storage system (BESS), Maximum power point tracking (MPPT).*

Introduction

Variable-speed wind turbines are widely investigated among wind turbine technology because they can achieve high efficiency compared to the fixed wind speed wind turbines. The converters used in such wind turbines can enable changes in generator speed according to the wind speed, which leads to the achievement of maximum wind power. In variable-speed wind turbine technologies, doubly fed induction generator (DFIG) is widely used because it is more economical. The rating of the power converters of DFIG is around 30% of the generator rating which leads to lower converter cost compared to the other configurations [1-2]. With the deployment of wind generations in microgrids, the requirements of power quality can achieve by reducing the fluctuations in wind power [3-5].

Recently, several configurations of DFIG have been introduced to reduce their fluctuations in output power. Additional energy storage systems (ESSs) such as battery energy storage systems (BESSs), flywheel energy storage systems (FESSs), electrical double-layer capacitors (EDLCs), and superconducting magnetic energy storages (SMESs) are coupled to the DFIG [6-8]. BESSs have been implemented widely among these ESSs because of their high energy density, efficiency, and versatility. In addition, their performance and lifetime have increased whereas their cost has reduced [9]. An improved DFIG model with a BESS has been introduced for smoothing its wind power output [10-13]. However, no work has explored the use of the improved DFIG for microgrid control.

In this study, an improved DFIG with a BESS used for control a microgrid is presented. The proposed DFIG model is used to control the microgrid in the both operation modes: grid-connected and islanded modes. In the grid-connected mode, the proposed DFIG model can control smoothly its power output. In the islanded mode, the proposed DFIG can control the

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voltage and frequency of the microgrid. The effectiveness of the proposed DFIG is validated through simulations using Matlab / Simulink.

1. DFIG Control System

An improved DFIG model and its control system are shown in Figure 1. It consists of the rotor-side converter (RSC) control system, the grid-side converter (GSC) control system, and the battery-side control system. Both RSC and GSC use the two-level control scheme that includes an external controller and a current controller. By comparison, the conventional DFIG system has the GSC and RSC control systems. Both DFIGs have similar current controllers in the RSC and GSC. The different between to DFIGs is in the external control system because a BESS is integrated with the DFIG

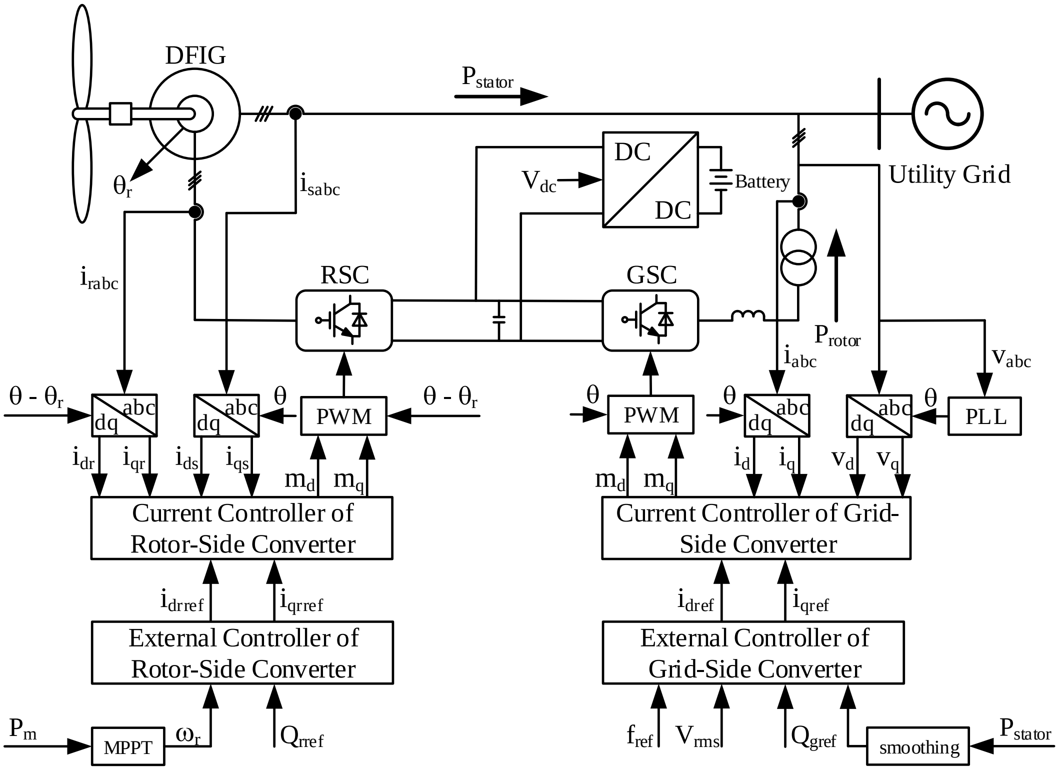

Figure 1. Overall Control of the Improved DFIG

A dc-dc converter in the battery-side converter is used to control the dc bus voltage of the BTB converter, which can enable the battery operating into charge and discharge modes. The converter is in the charge mode in case of an increasing in the dc bus voltage. Besides, the converter is in the discharge mode in case of the reduction of the dc-link voltage [14]. For simplification, an ideal battery is considered in this study, in which the state of charge of battery is neglected.

1.1. Rotor-Side Converter Control System

The function of maximum power point tracking (MPPT) is implemented in RSC. This approach was achieved by designed a speed controller [15]. The output power of the wind turbine depends on the speed of the DFIG as shown in Figure 2. By controlling the speed of the DFIG, the maximum power output of the wind generator is achieved. The speed reference ω_{ref} according to maximum power output is given by (1):

$$\omega_{ref} = A_0 + A_1 P_m + A_2 P_m^2 \tag{1}$$

where A_0, A_1, A_2 are the coefficients determining that the turbine will operate at $c_{p,out}$ and defined by (2) and (3), P_m is mechanical power of DFIGURE

$$K_1 \begin{bmatrix} v_{wind,1} \\ v_{wind,2} \\ v_{wind,3} \end{bmatrix} = \begin{bmatrix} 1 & K_2 \cdot v_{wind,1}^3 & K_2^2 \cdot v_{wind,1}^6 \\ 1 & K_2 \cdot v_{wind,2}^3 & K_2^2 \cdot v_{wind,1}^6 \\ 1 & K_2 \cdot v_{wind,3}^3 & K_2^2 \cdot v_{wind,1}^6 \end{bmatrix} \begin{bmatrix} A_0 \\ A_1 \\ A_2 \end{bmatrix} \tag{2}$$

$$\begin{cases} K_1 = \dfrac{1}{v_{wind,n}} \\ K_2 = \dfrac{1}{v_{wind,n}^3} \end{cases} \tag{3}$$

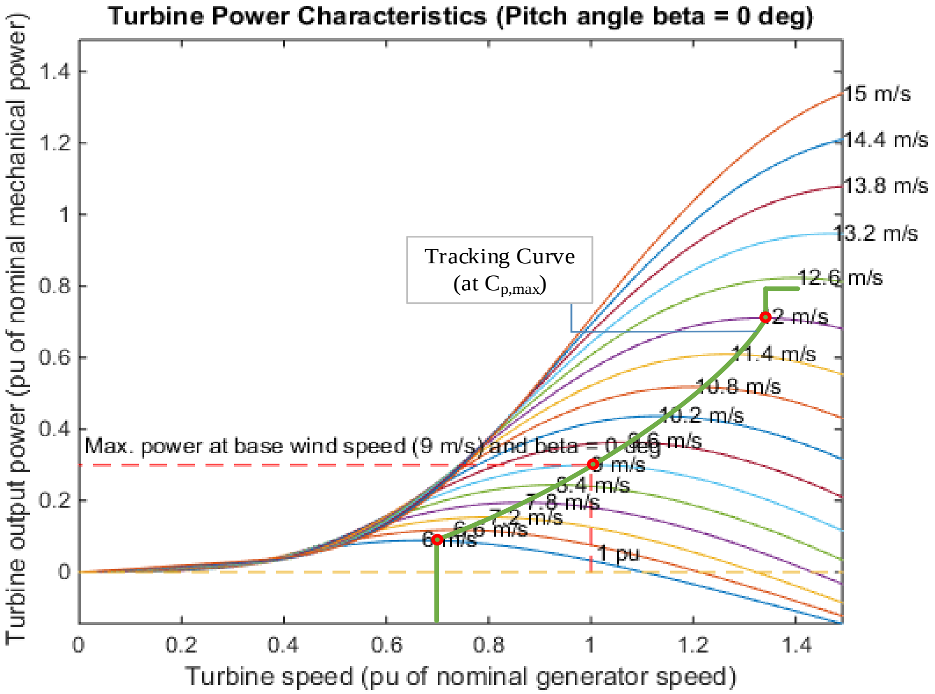

Figure 2. The Characteristic of Maximum Power Tracking Curve

The implementation of the wound type induction generator in d-q reference frame is used for designing the control system of the RSC. The mathematical representation of such generator is given by [16]:

$$v_{dr} = R_r i_{dr} + \frac{d\lambda_{dr}}{dx} - (\omega_s - \omega_r)\lambda_{dr} \tag{4}$$

$$v_{qr} = R_r i_{qr} + \frac{d\lambda_{qr}}{dx} + (\omega_s - \omega_r)\lambda_{qr} \quad (5)$$

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds} \quad (6)$$

$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs} \quad (7)$$

where λ_{dqr} is the dq-axis rotor flux linkage, v_{dqr} is the dq-axis rotor voltage, ω_s and ω_r is the synchronous angular frequency and the rotor respectively, R_r, L_r, L_m are the rotor resistances, inductances and mutual inductances respectively.

Substituting equations (6) and (7) into (4) and (5), we have:

$$v_{dr} = R_r i_{dr} + \frac{d\lambda_{dr}}{dx} - (\omega_s - \omega_r)(L_r i_{dr} + L_m i_{ds}) \quad (8)$$

$$v_{qr} = R_r i_{qr} + \frac{d\lambda_{qr}}{dx} + (\omega_s - \omega_r)\big(L_r i_{qr} + L_m i_{qs}\big) \quad (9)$$

The rotor currents i_{dr} and i_{qr} can be independently controlled as shown in equations (8) and (9). The proportional-integral (PI) controller is used to compensate the error signals. Figure 3 shows the control block diagram of RSC.

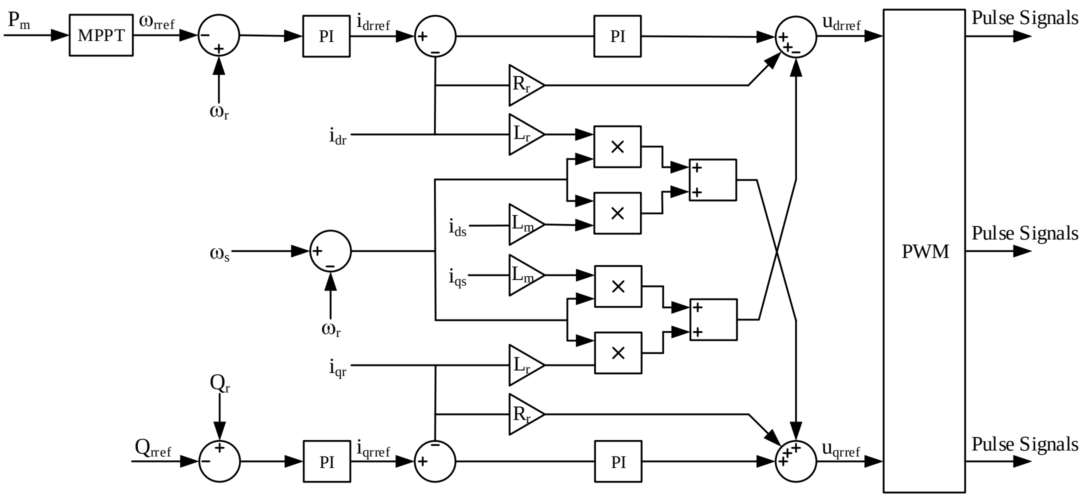

Figure 3. Rotor-Side Converter Control Scheme

1.2. Grid-Side Converter Control System

The GSC can control frequency, voltage and wind power as well. Two cascaded control loops is implemented in the GSC control scheme. The outer regulation loop is applied to control the total amount of DFIG power, in which a first-order low-pass filter is used for reduce the fluctuations in wind power in the grid-connected mode. In the islanded mode, the outer regulation loop regulates the AC voltage and frequency. The reference current i_{dg}^{ref} for use in the inner controller is obtained from the output of this outer loop. The output voltage of GSC is predicted by feed forward compensation that can assist the current controllers [17]. Figure 4 shows the control block diagram of GSC. The PWM signals are obtained from the outputs of the current controllers, v_{dg} and v_{qg} , which are used to drive the power switches.

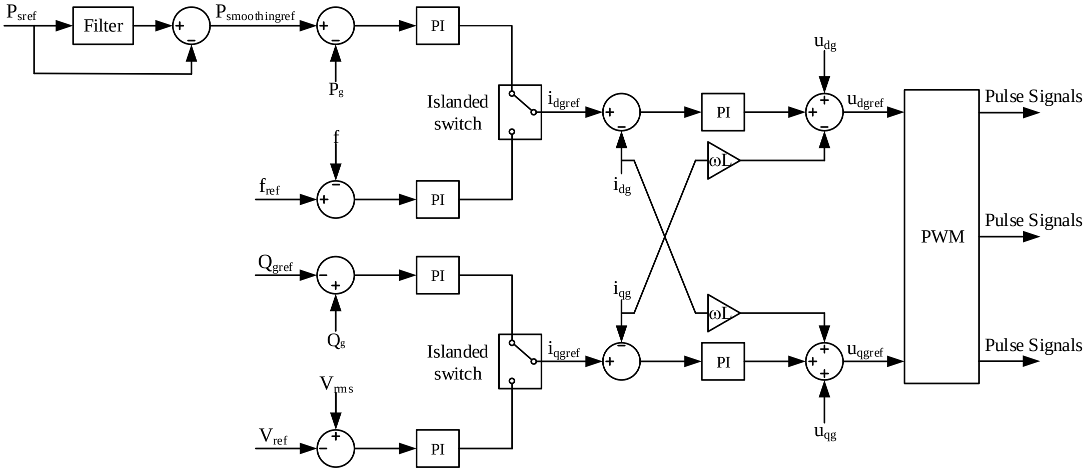

Figure 4. Grid-Side Converter Control Scheme

1.3. Control Scheme of Battery-Side Converter

The dc bus voltage is maintained stably by a BESS-side converter that uses a cascade control scheme [18]. The outer loop controls the dc link voltage whereas the inner current control loop is used to regulate the battery current. The output of the outer loop is current i_{bref} that is the current reference for the inner loop. Figure 5 shows the control scheme of the battery-side converter control.

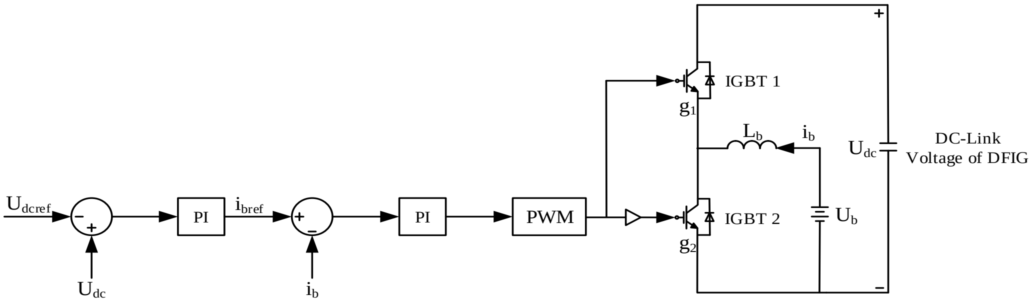

Figure 5. Control System of the BESS-Side Converter

2. Microgrid System

Figure 6 shows the microgrid with an improved DFIGURE The microgrid consists of a diesel generator, a load, and an improved DFIGURE In grid-connected mode, the frequency and voltage of microgrid is controlled by the utility grid. Thus, the improved DFIG controls its power generation for smoothing its output power. In island mode, the microgrid controls its frequency and voltage because it is disconnected from the main grid.

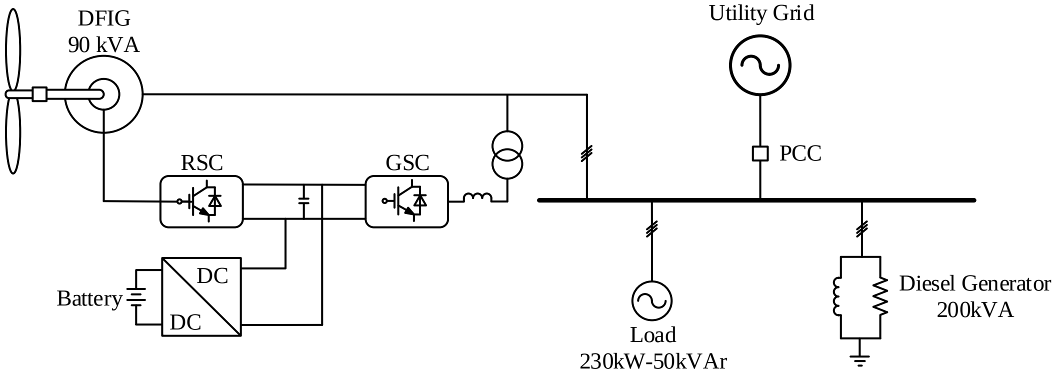

Figure 6. Configuration of the Test Microgrid

The wind power generation is affected by the wind speed. The data of wind speed is shown in Figure 7. The 9 m/s mean speed corresponds to 30 kW of wind power generation. A Δ/Y transformer and a filter installed on the GSC can reduce the harmonics caused by converters. A 500 V battery connected in parallel with the capacitor through the dc - dc converter. The dc bus voltage of BTB converter is controlled stably at 1200 VDC by battery. Such battery can charge or discharge its power for compensating the fluctuations in wind power. The diesel generator with 200 kVA supplies the main power to microgrid.

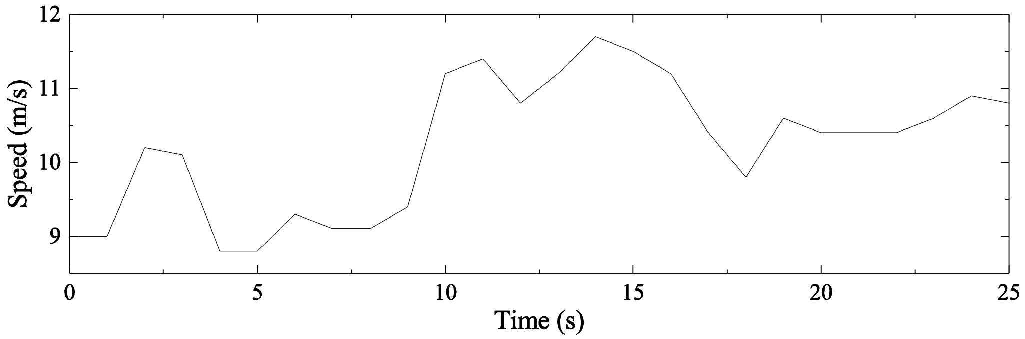

Figure 7. Actual Wind Speed Data

3. Simulation Results

Two scenarios of control microgrid using improved DFIG system are considered in this paper, which are control microgrid in the grid-connected and islanded modes. The performance of the improved DFIG is tested in the power control mode, frequency, and voltage control.

3.1. Microgrid Control in the Grid-Connected Mode

Under normal conditional, RSC controls the active power of the improved DFIG with MPPT function as shown in Figure 8. Therefore, the output of DFIG is maximizes according to the variable wind speed. In addition, the stator output power of DFIG is compensated by charging or discharging a BESS. Therefore, the fluctuations in wind power are reduced. For example, the wind speed rises at approximately 10s, which causes an increasing of the wind power output. At this time, the excess wind power is stored in the battery. At 16s, the wind power reduces because the wind speed is reduced. The BESS discharges its power for compensating the reduction of wind power (Figure 9).

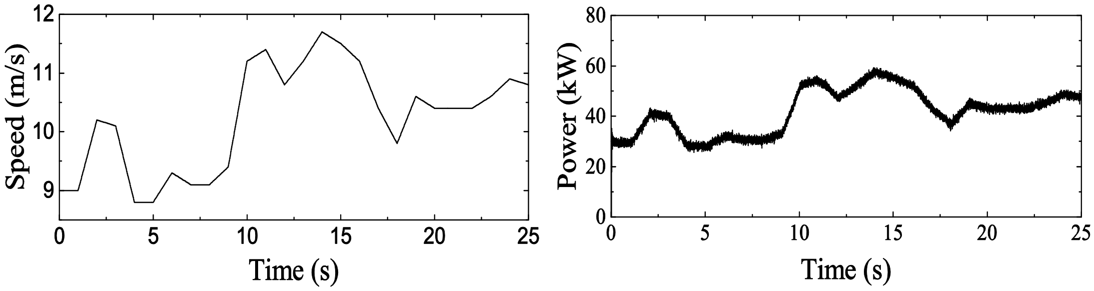

Figure 8. The Output Power of DFIG Using MPPT

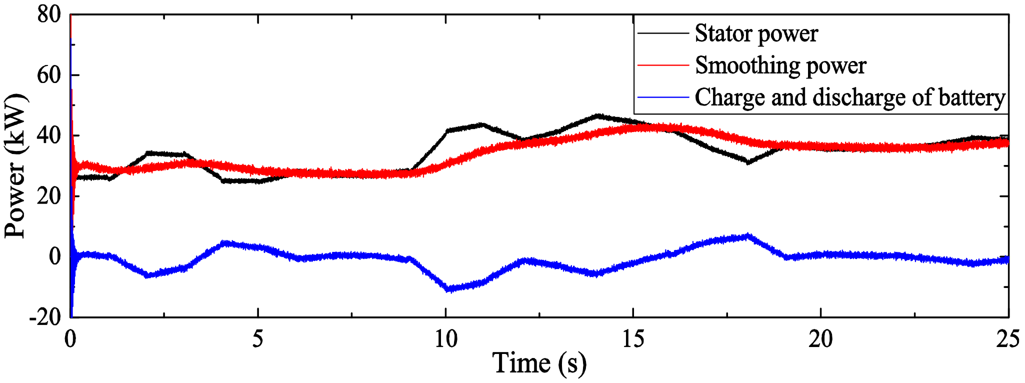

Figure 9. Smoothing Wind Power of DFIG

3.2. Microgrid Control in the Islanded Mode

Microgrid is in the islanded mode at 5s. The voltage and frequency of microgrid in the islanded mode are shown in Figs. 10 and 11, respectively. Simulation result shows that the frequency and AC voltage are maintained stably by the GSC. The power output of the proposed DFIG is shown in Figure 12, which are the total power of stator-side and rotor-side of DFIGURE The power output of rotor side is controlled by GSC by the role of the BESS. By charging and discharging the BESS, the total output of DFIG is maintained constantly. As a result, the voltage and frequency of the microgrid are controlled stably in the allowed ranges.

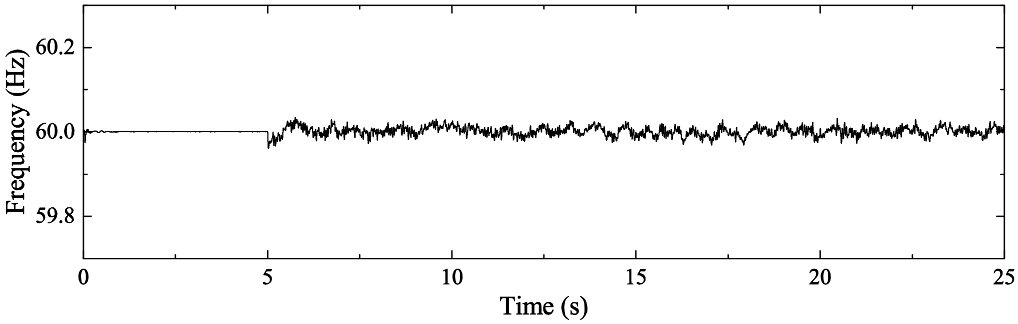

Figure 10. Microgrid Frequency

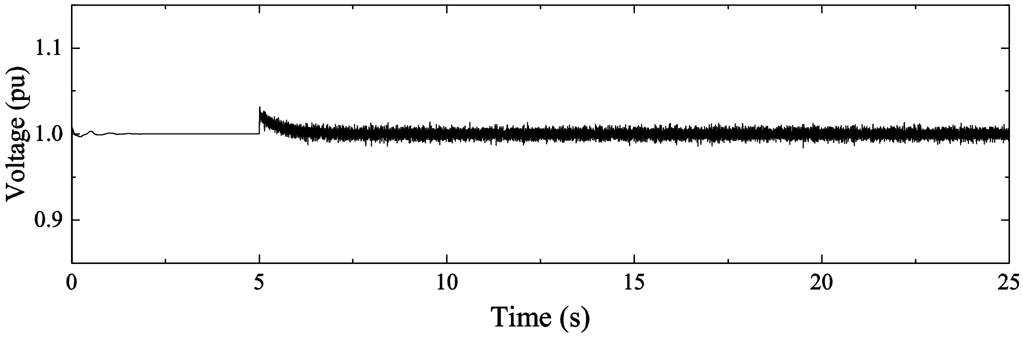

Figure 11. Microgrid Voltage

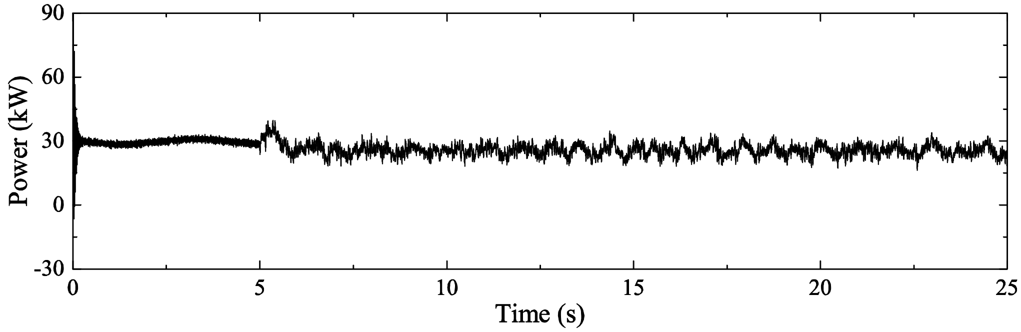

Figure 12. Power Output of DFIG

4. Conclusion

In this study, an improved DFIG model with a BESS was proposed to control microgrid in both operation modes. The control performance of microgrid was tested using Matlab / Simulink. It was found that the proposed DFIG can generate power with low fluctuations in the grid-connected mode. Additionally, it can also maintain stably frequency and voltage of the microgrid. Moreover, this proposed DFIG is also allowed the implementation of low voltage ride-through capability.

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