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Research Article

Power Control in the DFIG-based Wind Energy System Using OPAL-RT

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Abstract

The operation of wind power plants connected to the grid has been increasing rapidly in recent years. Wind power plants are attractive to use because they both relieve the network and are comparatively economical. However, wind farms are affected by the problems that may occur during their operation depending on the network. These problems are especially seen as voltage drop and increased oscillations. Dynamic modelling and control of the wind farm gains importance against these problems. Among the most important reasons for using DFIG in turbine systems are high energy yield, reduction of mechanical loads, applicability of easier angle control system, wide control of active and reactive power, and fluctuations in output power. In this study, power control results of DFIG based wind energy system by using OPAL-RT technology are given and real time control simulation is performed. Real time results have shown that when the Id current is changed in the system, active power decreases to balance the total while the reactive power increases.

Keywords: DFIG based wind system, OPAL-RT, Power control, Real time simulation

OPAL-RT Kullanarak DFIG Tabanlı Rüzgâr Enerji Sisteminde Güç Kontrolü

Öz

Şebekeye bağlı rüzgar santrallerinin işletmesi son yıllarda hızla artmaktadır. Rüzgar enerjisi santrallerinin kullanımı caziptir çünkü hem şebekeyi rahatlatırlar hem de nispeten ekonomiktirler. Ancak rüzgar santralleri şebekeye bağlı olarak çalışmaları sırasında oluşabilecek sorunlardan etkilenmektedir. Bu sorunlar özellikle voltaj düşüşü ve artan salınımlar olarak görülmektedir. Rüzgar santralinin dinamik modellenmesi ve kontrolü bu sorunlara karşı önem kazanmaktadır. DFIG'nin rüzgar enerji sistemlerinde kullanılmasının en önemli nedenleri arasında yüksek enerji verimi, mekanik yüklerin azaltılması, daha kolay açı kontrol sisteminin uygulanabilirliği, aktif ve reaktif gücün geniş kontrolü ve çıkış gücündeki dalgalanmalar bulunmaktadır. Bu çalışmada DFIG tabanlı rüzgar enerjisi sisteminin OPAL-RT teknolojisi kullanılarak güç kontrol sonuçları verilmiş ve gerçek zamanlı kontrol simülasyonu yapılmıştır. Gerçek zamanlı sonuçlar, sistemdeki Id akımı değiştiğinde, aktif gücün reaktif güç artarken toplamı dengelemek için azaldığını göstermiştir.

Anahtar Kelimeler: DFIG tabanlı rüzgar sistemi, OPAL-RT, Güç kontrolü, Gerçek zamanlı simülasyon

1. Introduction

With the increased consumption of petroleum sources and the rise in energy prices, renewable energy sources have recently become the focus of attention, given environmental issues. Regarding global energy use, especially in the coming years, renewable energy sources are expected to play a major role in energy economy (Alhajomar, 2019). It is reported by experts that global energy production will double in 2025 and triple in 2050.

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In energy production, it is estimated that the ratio of renewable energy sources to the total production will be 60% in 2025. Thus, it is expected that renewable energy sources, which are continuous and seen as never-ending resources, will meet the world's uncontrolled energy need in an economical way (Drennen, 1994). The growth of universal pollution and the exhaustion of oil resources promoted many countries starting to implement renewable energy plans such as wind turbines, solar energy, and the installation of small hydro-electric power plants. Compared to other energy sources, it is observed that the presence of wind energy in energy production systems is increasing worldwide. Unlike other energy generation systems, wind turbines are not frequently maintained, they do not work continuously, they can operate independently from the network, their installation does not endanger homes, businesses or commercial structures, does not cause environmental pollution, provides low cost energy production.

The share of wind turbine systems that have popularity among their sources in electricity generation is increasing day by day. Wind turbines have two types of working conditions as constant speed (1% wind speed change) and variable speed. The asynchronous generator used in fixed speed wind turbines is directly connected to the network. Since the mains frequency is equal to this uncontrollable speed, changes in wind speed cannot be stored as energy. So these turbulences in the wind can cause power surges causes, thus affects the power quality of the network. In variable speed wind turbines, where the generator is controlled by the power electronic unit, power fluctuations due to wind changes can be eliminated by changing the rotor speed, since rotor speed control is possible.

Thus, power fluctuations from wind transformation and powertrain can be reduced. As a result, the effect of variable speed wind turbines on power quality can be improved compared to fixed speed wind turbines (Larsson, 2000). Double Feed Asynchronous Generator (DFIG) can work at different speeds. Due to its advantages such as four-zone active-reactive power capability and low converter costs, it has recently been preferred in modern wind turbine systems (Mirzakhani, 2018). In DFIG, lower power losses are observed compared to fixed speed asynchronous generators and synchronous generators. The stator of DFIG is directly connected to the mains, and the rotor windings are fed back by means of controlled voltage transducers from the stator terminals. These transducers supply excitation current to DFIG, so their capacity corresponds to 20% -25% of the total capacity of DFIG.

Among the most important reasons for using DFIG in turbine systems are high energy yield, reduction of mechanical loads, applicability of easier angle control system, wide control of active and reactive power, and fluctuations in output power. However, the performance of DFIG is not only dependent on the asynchronous machine, but also on the d-q vector control method applied to the generator (Bakir & Kulaksiz, 2020).

In this study, it provides power control of DFIG based wind energy system using OPAL-RT technology. Real time results have shown that when the I_d current is changed in the system, active power decreases to balance the total while the reactive power increases.

2. Material and Method

2.1. Wind power system modeling

The DFIG wind energy system consists of a wind turbine, back-to-back converters, a resistive-inductive (*RL*) filter and grid. The back-to-back converter configuration includes a rotor side converter and a grid side converter. The system is depicted in Fig. 1.

At the DFIG rotor side, the rotor current dynamics is developed, in the synchronously rotating *d-q* reference frame, using the stator flux orientation, where the *q*-component of the stator voltage is aligned with the reference frame such as $v_{sd} = 0$ and $v_{sq} = V_s$. This dynamics is provided by the following expressions (Tanvir, 2015).

$$\begin{cases} \frac{di_{rd}}{dt} = -ai_{rd} + s\omega_s i_{rq} + \frac{R_s b}{\omega_s} V_s + \frac{1}{\sigma L_r} v_{rd} \\ \frac{di_{rq}}{dt} = -ai_{rq} - s\omega_s i_{rd} - bsV_s + \frac{1}{\sigma L_r} v_{rq} \end{cases} \quad (1)$$

where, $\sigma = 1 - \frac{L_m^2}{L_s L_r}$ is the leakage factor, $s = \frac{\omega_s - \omega_r}{\omega_s}$ is the slip, $a = \frac{R_r L_s^2 + R_s L_m^2}{\sigma L_s^2 L_r}$, $b = \frac{L_m}{\sigma L_s L_r}$, R_s and R_r are the stator and the rotor resistances, respectively, L_s , L_r and L_m are the stator, the rotor and the mutual inductances, respectively, i_{rd} and i_{rq} are the *d-q* components of the rotor current, v_{rd} and v_{rq} are the *d-q* components of the rotor voltage, ω_s is the synchronous angular speed, ω_r is the rotor speed.

Using the rotor currents and the stator flux orientation, the active and reactive power of the DFIG stator side can be approximated by

$$\begin{cases} P_s = -\frac{3}{2}\frac{L_m}{L_s} V_s i_{rq} \\ Q_s = \frac{3}{2}\left(\frac{V_s \varphi_s}{L_s} - \frac{L_m}{L_s} V_s i_{rd}\right) \end{cases} \quad (2)$$

where, $\varphi_s$is the stator flux.

It can be observed from the power equation (2) that the stator active power can be directly controlled through the *q*-component of the rotor current and the stator reactive power can be directly controlled through the *d*-component of the rotor current (Merabet, Eshaft, & Tanvir, 2018).

At the grid side, the current dynamics is given in the *d-q* reference frame, by

$$\begin{cases} \frac{di_d}{dt} = -\frac{R}{L} i_d + \omega i_q - \frac{V_s}{L} + \frac{1}{L} v_d \\ \frac{di_q}{dt} = -\frac{R}{L} i_q - \omega i_d + \frac{1}{L} v_q \end{cases} \quad (3)$$

where, R is the filter resistance, L is the filter inductance, i_d and i_q are the *d-q* components of the grid current, v_d and v_q are the *d-q* components of the grid converter voltage, which is also the DFIG stator voltage, and ω is the grid angular frequency.

At the grid side, the d-components of the vector control is synchronized such as $v_q = 0$. Therefore, the active power and reactive power at the grid side can be designated by

$$\begin{cases} P_g = v_d i_d \\ Q_g = - v_d i_q \end{cases} \quad (4)$$

It can be observed from the power equation (4), that the grid active power can be directly controlled through the d-component of the grid current and the grid reactive power can be directly controlled through the d-component of the grid current (Bakir, et al., 2020).

2.2. OPAL-RT

Rapid control prototyping (RCP) of the micro-grid based on the control system was done using the OPAL-RT hardware (OP5600 and OP8660) as shown in Figure 2.

OP5600, a real-time digital simulator, consists of analog and digital I / O signal modules running an RT-LAB real-time simulation software platform, a multi-core processor and FPGA. It provides real-time RCP of the controlled microstructure with low time step to achieve the best sensitivity. The processor, which makes it a powerful tool for RCP and in-loop hardware applications, is equipped with Intel Xeon QuadCore 2.40 GHz.

The OP8660 is a signal conditioning interface that expands the features of the real-time digital simulator by providing multiple input and output channels adapted to the HIL Controller and Data Collection Interface, power electronics and power systems applications. Its core contains high current and high voltage input conditioning modules that allow current and voltage to be converted to ± 10V (OPAL-RT, 2019).

The connection between OP8660, virtual environment (real time simulator OP5600) and experimental micro grid system (DFIG based wind system, inverters, inductors, grid) is shown in Figure 1.

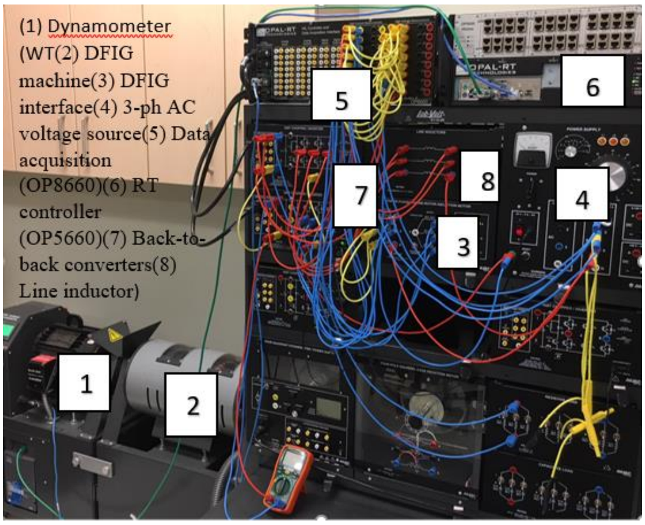

Fig.1. DFIG based wind energy system experimental setup

2.3. REAL TIME MONITORING AND CONTROL SOFTWARE

A real-time software application for measurement, testing and control has been developed in the MATLAB / Simulink environment and is integrated into RT-LAB for real-time monitoring. RT-LAB is an open real-time simulation software environment that can realize the real-time RCP of controlled micro-grid using the OP5600.

To run the model on different target processors or nodes, it is divided into two subsystems as in Figure 2:

1- The console subsystem, which must be defined with its prefix, is executed on the PC at the command station and contains user interface blocks such as scopes, screens and reference command;

2-The main subsystem that must be defined by its prefix.

It is executed in the CPU core processor of the OP5600 and contains all the calculation elements of the model, mathematical operations of the algorithms and input-output blocks. Since the two subsystems are run on different targets or nodes, communication and synchronization between them is done through RT-LAB OpComm blocks. The Simulink model of the control system is opened via RT-LAB and compiled on the real-time target (OP5600), then automatically loaded by the RT-LAB into the CPU core of the OP5600 for the main subsystem.

Finally, the subsystems of the model are executed in the CPU core of the OP5600, for the SM subsystem, and on the command station PC, in all sequencing, communication and synchronization processes for the SC subsystem to run the engine in real time, the processes RT-LAB managed by.

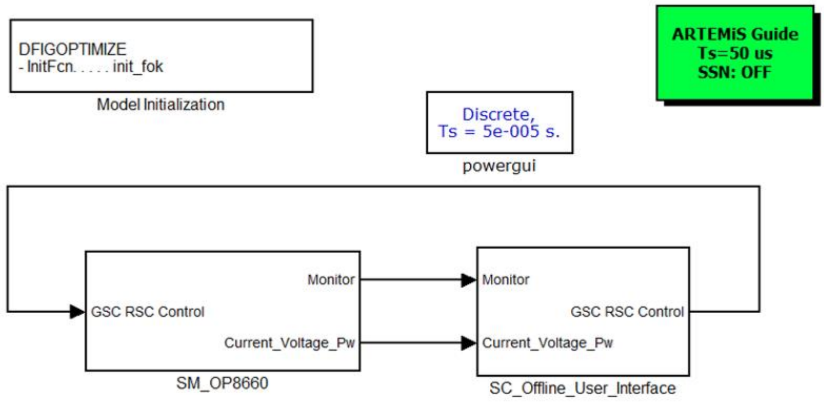

Fig.2. RT-LAB subsystems

3. Results and Discussion

3.1. REAL-TIME CURRENT, VOLTAGE, POWER SIMULATION RESULTS OF DFIG BASED WIND ENERGY SYSTEM

In this test setup, the dynamometer (wind turbine emulator) was operated at constant speed. When working from the system, the Iq stream was changed by giving a signal and depending on the results at this stage, it can be seen in Figures 3, 4 and 5 that the real-time system's mains current creates a three-phase sine signal with peak magnitudes between +8A and -8A. Rotor current produced a three-phase signal by drawing +4 A and -4 A, and it can be seen that the stator current drawn is between the peak magnitudes of +12 A and -12 A.

In Figures 6, 7 and 8, thanks to OPAL-RT technology, a real-time three-phase mains voltage with peak magnitudes between +30 V and -30 V is supplied to the system, 150 V rotor and 28 V stator voltage results are obtained. In Figures 9, 10, and 11 active and reactive power are controlled by changing and controlling the rotor q current and power profiles for stator, rotor and network are given. From the power response shown, it can be seen from Figure 11 that the active and reactive power can be controlled by changing the rotor current. In Figure 11, blue colored active power increases to balance the total while green colored reactive power decreases.

Likewise, when the Id current is changed in the system, the blue colored active power decreases to balance the total while the green reactive power increases. Active reactive powers and changes in the system are observed in this wind system by keeping the dc link voltage Vdc constant and changing the current of Id and Iq. And the effect of the change of Id and Iq on the system and the changes in the power profile can be seen. In addition, the DC-link voltage has been successfully arranged to follow a continuous reference.

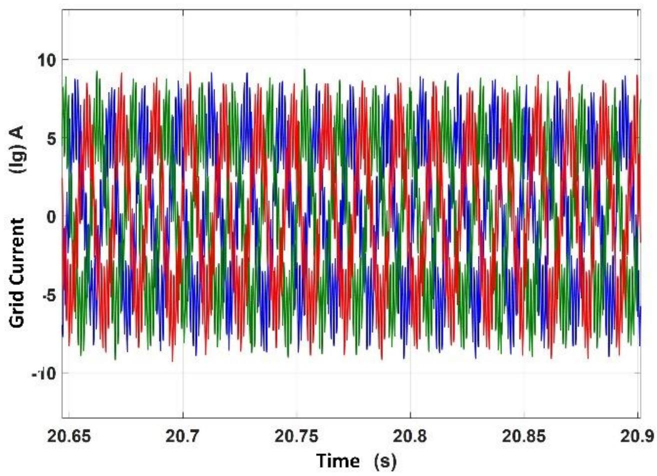

Fig.3. Grid current of the system

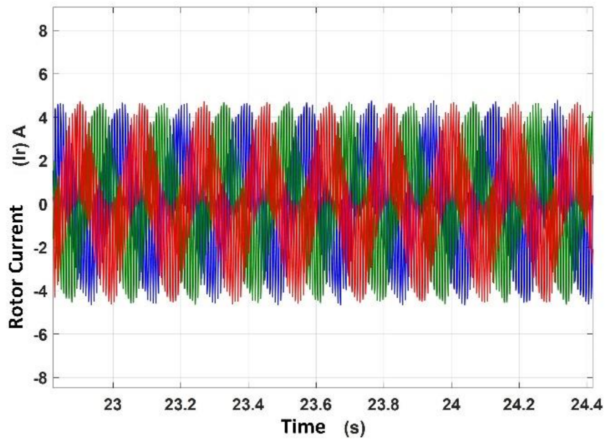

Fig.4. Rotor current of the system

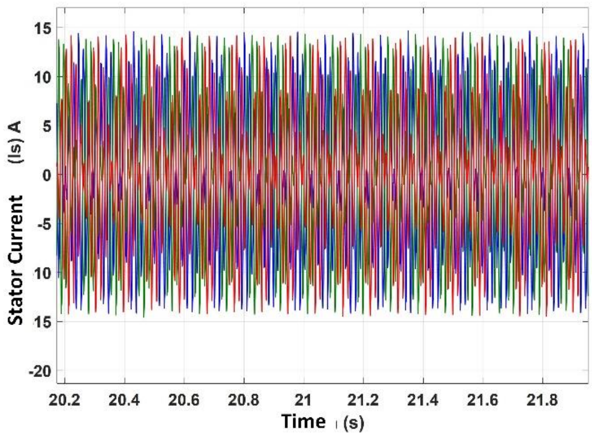

Fig.5. Stator current of the system

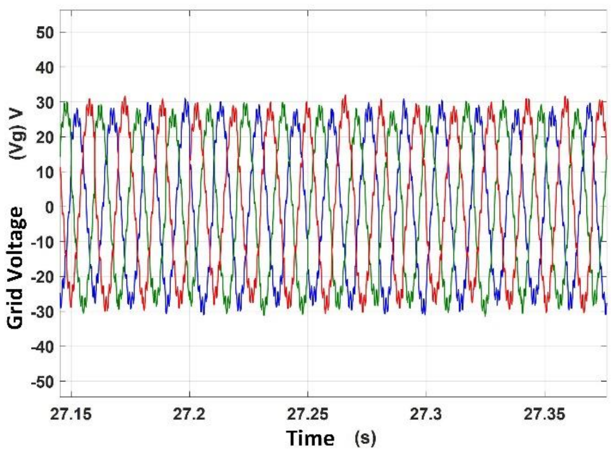

Fig.6. Grid voltage of the system

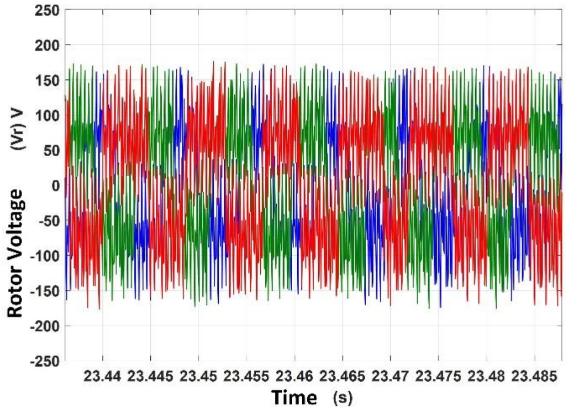

Fig.7. Rotor voltage of the system

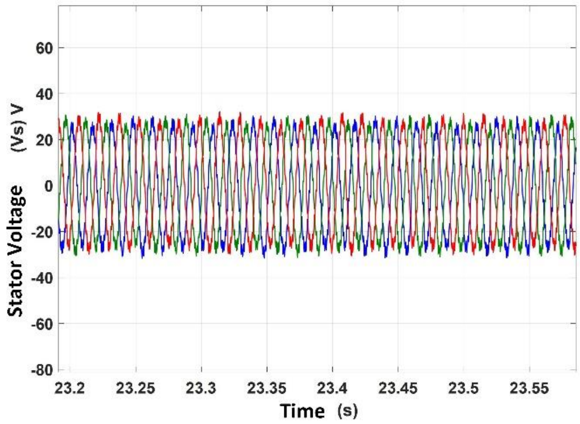

Fig.8. Stator voltage of the system

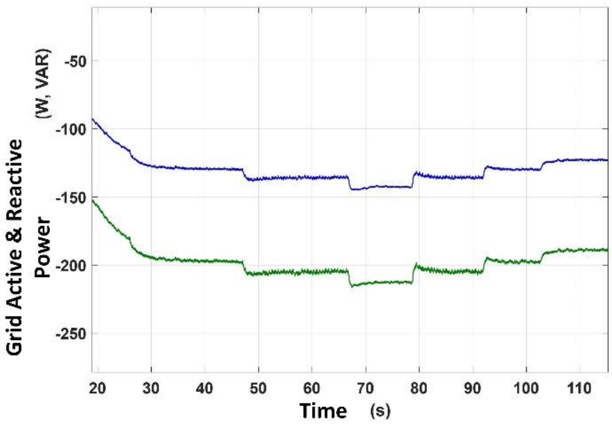

Fig.9. Grid active & reactive power of the system

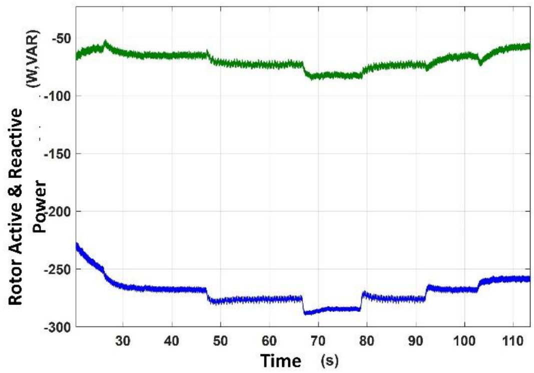

Fig. 10. Rotor active & reactive power of the system

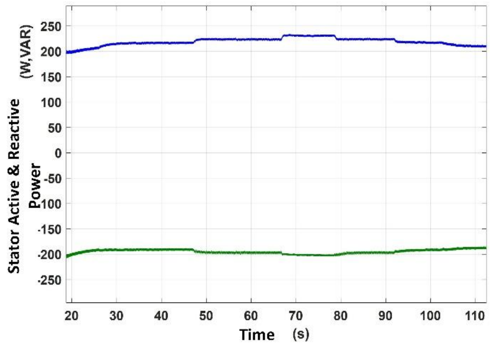

Fig. 11. Stator active & reactive power of the system

4. Conclusions and Recommendations

In this study, the model in Simulink was created in RT-LAB. DFIG-based wind system was physically installed and experimental control systems were realized with OPAL-RT technology. Control system results were obtained in real time with OPAL-RT technology. Active reactive powers and changes in the system are observed in this wind system by keeping the Vdc constant and changing the current of Id and Iq.

4. Acknowledge

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