Journal of Engineering Research, 2023, 20(2),138-148

Minimizing the Effect of Integrating Wind Farms on Transmission Power Systems

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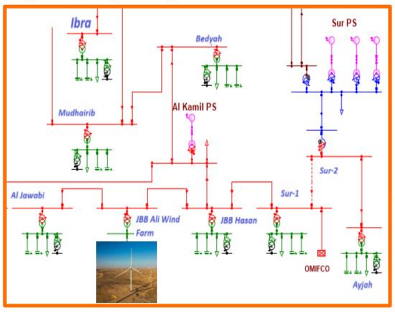
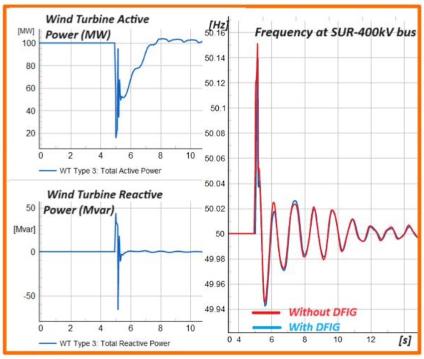
Aim

Investigating and minimizing the influence of large-scale wind energy penetration on Oman's Main Interconnected System (MIS).

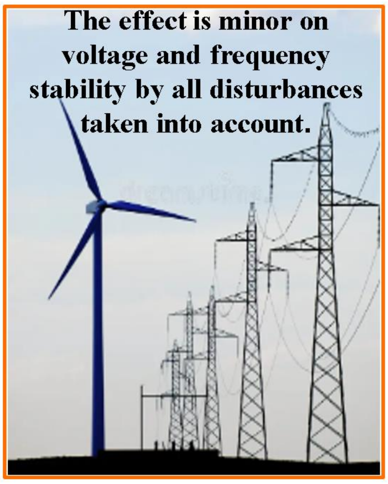


Methods



Study the impact of major faults, generator trips, and sudden load changes on MIS

Results



ABSTRACT: Expanding the renewable energy sources usage in power systems will help the government meet its energy policy goals of lowering emissions, ensuring high power supply reliability, and promoting spot markets with high competitivity. However, due to the intermittent nature of these sources, this will necessitate the mitigation of network vulnerabilities. High wind energy penetration in the grid could have an impact on the system frequency, voltage, real and reactive power response, and power quality of the system. The main objective of this paper is to investigate how the integration of wind farms in the Jalan Bani Bu Ali (JBBA) area will affect Oman's main interconnected system (MIS). Results show that the effect is minor on voltage and frequency stability by all disturbances taken into account.

الملخص: سيساعد التوسع في استخدام مصادر الطاقة المتجددة في أنظمة الطاقة الحكومية على تحقيق أهداف سياسة الطاقة الخاصة بها لخفض الانبعاثات، وضمان إمدادات طاقة موثوقة، وتعزيز الأسواق التنافسية. ومع ذلك، وبسبب الطبيعة المتقطعة لهذه المصادر، فإن هذا يستلزم التخفيف من نقاط الضعف في الشبكة. يمكن أن يكون للاختراق العالي لطاقة الرياح في الشبكة تأثير على ملف الجهد والتردد واستجابة الطاقة النشطة والمتفاعلة وجودة طاقة النظام. الهدف الأساسي من هذا البحث هو استكشاف كيفية تأثير دمج مزارع الرياح في منطقة جعلان بني بو علي (JBBA) على النظام الرئيسي المترابط (MIS) في سلطنة عمان. أظهرت النتائج أن التأثير ضئيل على ثبات الجهد والتردد من خلال جميع الاضطرابات التي تم أخذها في الاعتبار

Keywords: renewable energy; transient stability; wind turbines; MIS.

الكلمات المفتاحية: طاقة متجددة؛ الاستقرار العابر، توربينات الرياح، النظام الرئيسي المترابط (MIS).

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DOI:10.53540/tjer.vol.20iss2pp138-148

1. INTRODUCTION

Green energy is necessary for global development toward wealth and growth. Many governments around the world are trying to reduce energy prices and lower greenhouse gas emissions by employing renewable energy sources (RES). Wind and photovoltaic (PV) energy have grown considerably as of the beginning of 2022, with capacities of 845 GW and 942 GW, respectively (Reigh Walling et-al, 2015). The overall performance, stability, and reliability of transmission power systems are impacted by the complexity associated with incorporating large-scale wind farms and other renewable sources. Modern wind turbines typically use power electronic systems acting grid interfaces, either completely rated converters generators (type 4) or partially rated converters as with type-3 doubly-fed induction generators (DFIGs) enabling dynamic reactive power control. While wind energy has environmental benefits such as renewable energy, cost-effectiveness, and efficient land utilization, it also has drawbacks. Its intermittency due to wind speed variation, gearbox connections, noise pollution, and environmental effects are significant concerns. Furthermore, issues such as low energy conversion efficiency, mechanical stress, gearbox maintenance, and challenges managing active and reactive power separately prevent its seamless integration.

Voltage and frequency should be maintained at their nominal values during normal power system operation by adjusting the amount of active and reactive power generated by wind power generators. The wind power generators should have the ability to contribute to controlling both the voltage and the frequency to stabilize the system following disturbances. Power electronics converters provide the ability to completely regulate the generator's angular velocity and gain a number of advantages, including first, by harnessing the kinetic energy in the blades, the variations in wind speed may be seamlessly translated into mechanical torque and electrical power with some inertia. Power electronics converters enable increased power regulation flexibility, which enables the provision of some auxiliary services for the grid. The real power output of the wind turbines can be controlled by shutting down some turbines or changing the pitch control. If more real power is required from wind turbine farms, the wind turbines were run at a lower power level than the available power in order to have some reserve power, in case of not provided, an energy storage device may be used (El-Naggar & Erlich, 2016).

Wind turbines normally use type-1 squirrel cage induction generators (SQIG) for constant-speed turbines or type-2 for variable-speed turbines. In SQIG, the stator is directly connected to the grid in parallel with a shunt capacitor bank. However, wind power can be controlled by stall control or active stall control (Choi et al., 2022).

DFIGs are used in wind turbine applications that require a constant output power system frequency at various speeds of the generator shaft. They have windings on both the stator and rotor sides. As indicated in Figure 1, the stator is directly connected to the grid, while the rotor is connected to the grid via rotor-side power converter. The produced electrical power is delivered to the grid via both the rotor and the stator.

The advantages of this type are the ability to control its active and reactive power, the ability to maximize power point tracking, reduced mechanical stress, and a smaller converter size. DFIGs have attracted increasing attention in recent years because of various advantages, including the ability to run at different speeds (Herbert et al., 2007 and Yang et al., 2012). DFIG decouples its reactive and active power by adjusting the rotor-side converter modulation coefficient, which enhances energy conversion efficiency, wind farm power factor, and voltage stability. The impact of the line side converter controller and the DFIG-WT response during an unbalanced fault were both carefully investigated in (Pai, 1989). Wind energy integration into grids has a wide range of consequences, including frequency fluctuations, power quality issues, system stability concerns, and economic dispatch constraints (He et al., 2013; Rueda & Shewarega, 2009; Pena et al., 1996; Renewables 2022 Global Status Report). This paper aims to investigate the influence of large-scale wind energy penetration on Oman's Main Interconnected System (MIS). First, the wind model was investigated using the IEEE 39-bus system following a major fault in the power system (Salman & Teo, 2003; Sorensen et al., 2007; Sun et al., 2010; OETC, 2016). Then the impact of major faults, generator trips, and sudden load changes on the MIS was studied. Recent industrial experiences highlight the significance of investigating the real fault current contribution and system resilience when integrating large-scale wind farms in power systems with significant RES penetration (Qiao & Harley, 2008). This paper aims to minimize these effects and expedite the integration of wind farms into transmission networks.

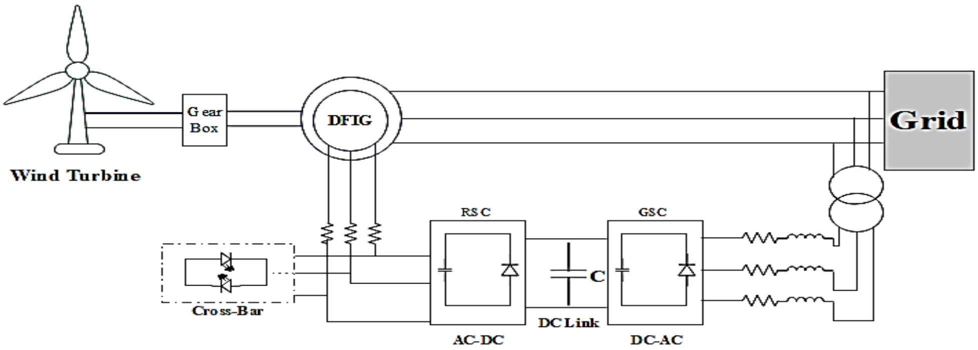

Figure 1. Doubly Fed Induction Generator (Yang et al., 2012).

2. SYSTEM MODELLING AND SIMULATION USING IEEE 39 BUS SYSTEM

The IEEE 39 Bus System offers a framework for modelling and simulating different wind farm integration scenarios and serves as a benchmark for power system studies. The model of the IEEE 39-bus system has ten machines connected to different buses as shown in Figure 2. By substituting synchronous generator #7 with a wind farm modelled by a large DFIG, a model to study the integration impact of a large wind farm on transient stability was created (Pena et al., 1996). The Power Factory DigSilent software was used to model the system in which the wind power plant at G7 has a capacity of 700 MVA. This is the equivalent of 140 DFIG-based wind turbines, each with a nominal capacity of roughly 5 MW. To prevent additional computation time, all individual units within the wind power plant were represented by a single equivalent model. A variety of simulations were carried out to evaluate the transient performance of the IEEE 39-bus system with and without wind power integration. The end of line 21–22 on bus 22 experiences a three-phase fault five seconds after the simulation begins. The fault is applied at t = 5 s and cleared after 150 ms. In the following scenario, a sizable DFIG is used to simulate the wind farm with the same capacity as generator 7 (G7). Repeating the same scenario of the fault position, the results of the simulation with and without the wind- farm are shown in Figure 3 displaying bus 36's voltage in conjunction with the wind farm. To keep the terminal voltage of the wind farm at the desired level during the fault, the active power decreases while the reactive power dramatically rises. Comparatively to a situation without a wind farm, the terminal voltage oscillation is minimized.

The voltage at bus number 36 dropped to 0.4 p.u. during the fault, and then returned to the nominal value which is presented in Figure 3. In a few cycles, the generator finally reached a steady-state condition.

The active power was reduced to zero at the time of the fault, whereas the reactive power increased dramatically to about 640 MVAR. When the fault occurred, the generator used a considerable amount of reactive power to control the voltage. However, once the fault was rectified, the voltage returned to normal.

When compared to the situation without the wind farm, there is less oscillation. Figure 4 depicts the active and reactive power of generator # 6 with and without the wind farm. It takes several cycles for the generator to achieve steady-state conditions. The results show that integrating the wind farm enhances transient performance stability and helps the system in the event of any faults or disturbances. The wind farm's controller will produce reactive power, which will contribute to the fault, before transitioning to a stable state. In conclusion, during the fault condition, the system with a wind farm performs well, and it gets back to normal conditions in a short period.

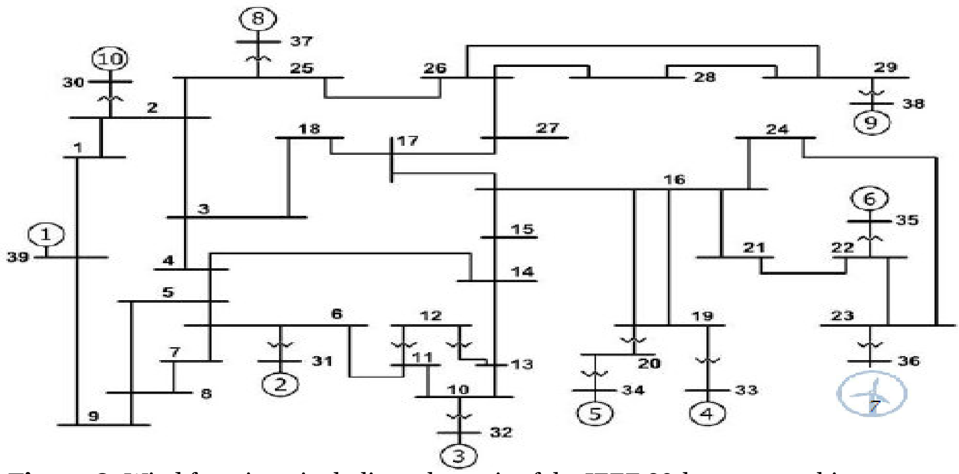

Figure 2. Wind farm in a single-line schematic of the IEEE 39-bus, ten machines system.

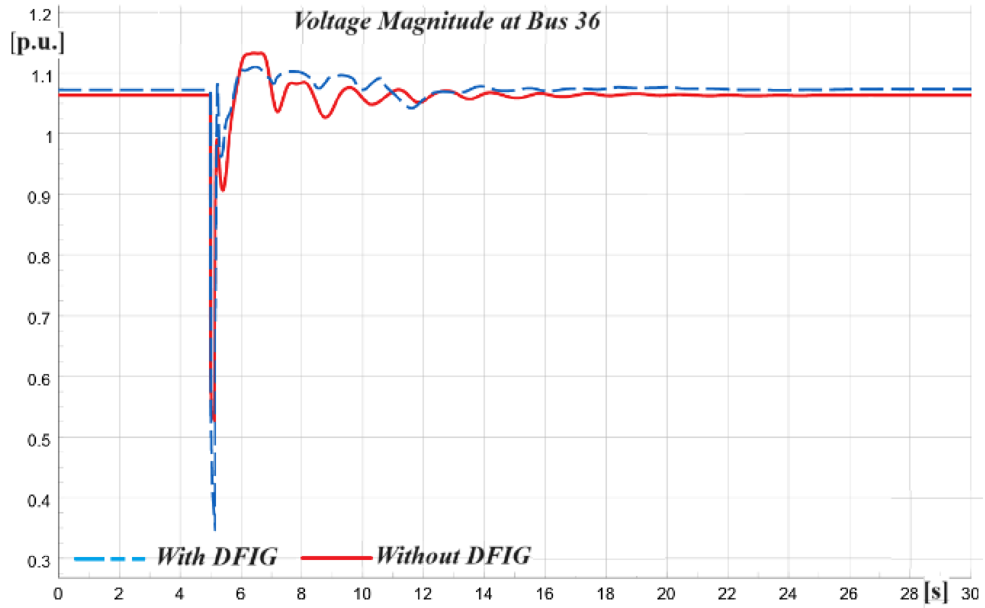

Figure 3. The terminal voltage of bus 36 without and with the wind farm

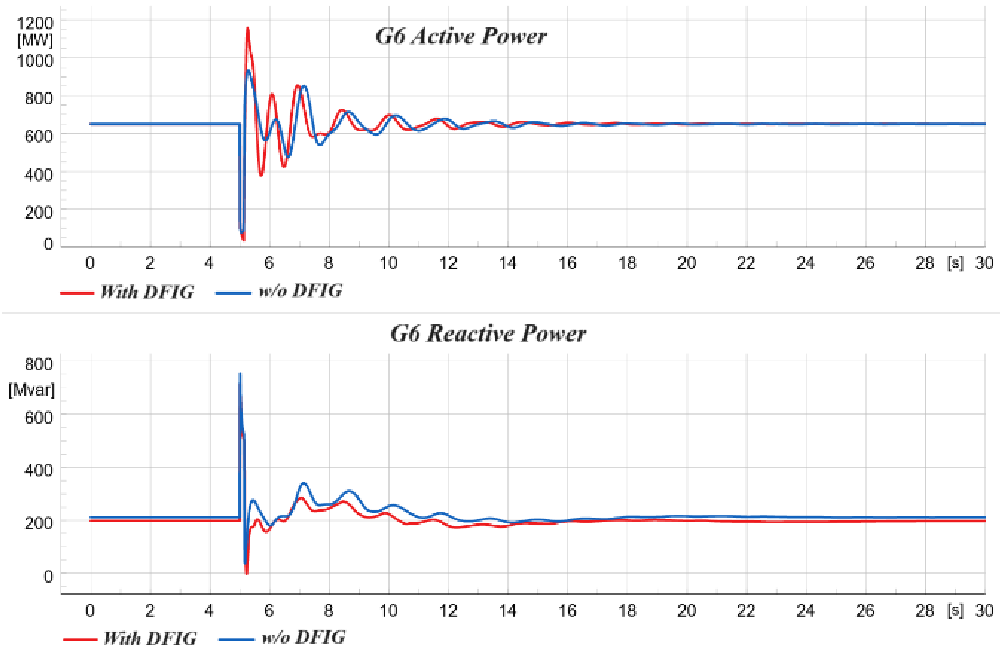

Figure 4. Generator 6's active and reactive power without (blue) and with (red) wind farm

3. SYSTEM MODELLING AND SIMULATION OF OMAN'S MAIN INTERCONNECTED SYSTEM

The power transmission system data of summer MIS 2023 were used in this study. The DigSilent MIS model has been implemented as per the OETC capability statement (2022-2026) (Chen, 2013). According to capability statement data, the generation in 2023 will be supplied by six gas-fired power plants: Barka II IPP, Barka III IPP, Sur IPP, Sohar II IPP, Sohar III IPP, and Ibri IPP, as well as one solar plant at Ibri Solar PV IPP. Table 1 shows the overall generation capacity of each station. The total system generation is 8017 MW, with 7317.3 MW provided to the load and 645.7 MW in spinning reserve.
For the peak demand of MIS in 2023, the total anticipated load (Grid+ Industrial+ Auxiliary +Desalination) is 7187MW and 2868 MVar. As a result, the system's overall losses are 184 MW and 3791 MVar. Table 2 shows the total load for each area in MIS.

Table 1 The net generation in MIS for 2023 *(Chen, 2013).*

Power Stations	Net Generating Capacity (MW)
Barka II IPP	688.50
Barka III IPP	765.50
Sohar II IPP	765.50
Sohar III IPP	1740.70
Sur IPP	2018.20
Ibri IPP	1538.50
Ibri Solar PV IPP	500.00

Table 1 Total load for distribution areas in MIS for 2023 (Chen, 2013).

Area	Total MW load	Total MVar Load
Muscat Area	2646.3	869.8
Mazoon Area	2489.2	818.2
Majan Area	1801.4	592.1

In Oman, a proposal is underway to integrate a 100 MW wind turbine situated in Jalan Bani Bu Ali (JBBA) into the Main Interconnected System (MIS). This wind turbine will utilize a doubly-fed induction Generator (DFIG). This section looks into assessing the impact of wind farm integration on the Oman MIS in the presence of a wind farm among scenarios involving a three-phase fault, the shutdown of a significant load, and the isolation of generating units. Figure 5 illustrates a segment of the MIS featuring the inclusion of a wind farm.

3.1 Al Kamil 132 kV Power Station Bus Short Circuit

A three-phase short circuit at the Al Kamil power plant, close to the JBBA wind farm was applied to investigate the system response as depicted in Figure 5. Figure 6 shows the DFIG's active and reactive power of JBB Ali wind farm. During the fault, the active power dropped close to 24 MW before returning to the nominal value once the fault cleared. Reactive power on the stator side is typically adjusted to zero. Figure 6 shows that the stator-side reactive power begins to increase because the voltage drops at the generator terminal, then adjusts the control strategy of the rotor converter which turns it into a reactive power support control strategy, and outputs reactive current to provide support for the system voltage.
During the fault, DFIG terminal voltage drops to approximately 0.25 pu (retained voltage).
When the fault is cleared after 150 ms, the system recovers stability and is eventually restored to its pre-fault value with a fast and smooth response which is presented in Figure 7.
Figure 8 illustrates that the voltages of Sur 400 kV bus which decreased during the short circuit and eventually restored to their steady state. Also, during the fault, the frequencies increased and subsequently recovered to rated values as shown in Figure 9 which are within the standard limits of OETC system parameter valued (e.g. 400 kV ±5% and 50Hz -5% +3% for less than 60 seconds).

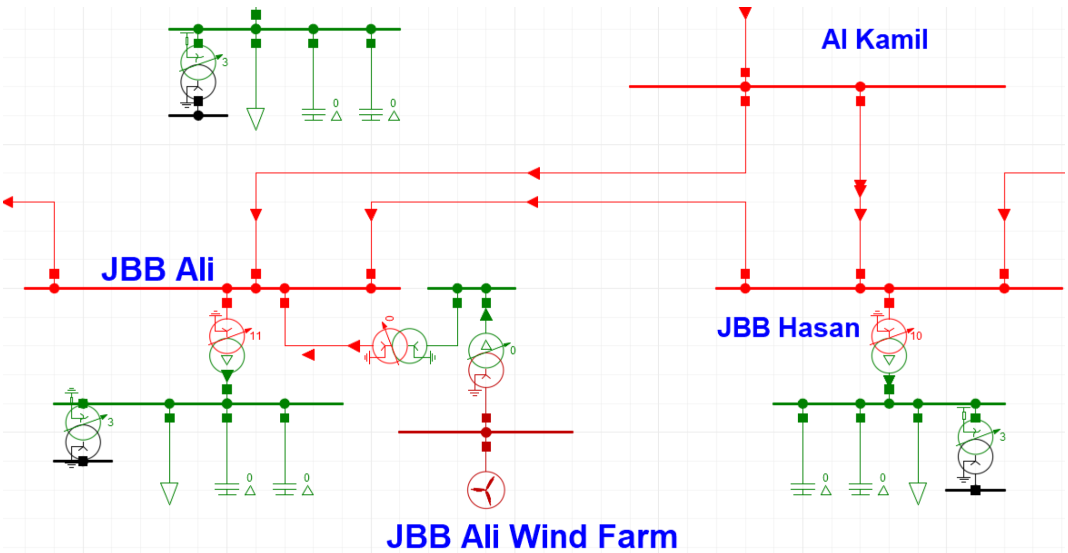

Figure 5. Part of MIS with the wind farm

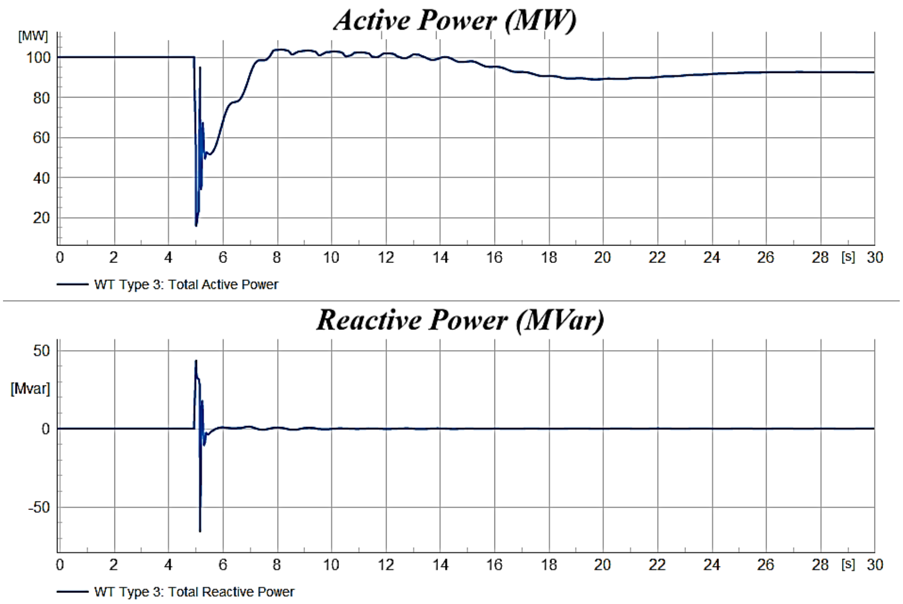

Figure 6. DFIG active and reactive power during a three-phase short circuit.

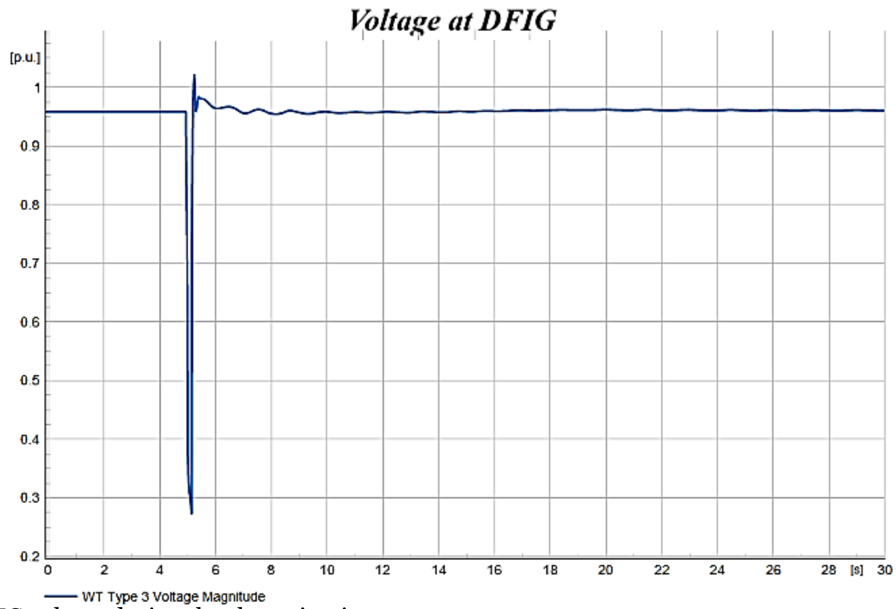

Figure 7. DFIG voltage during the short circuit.

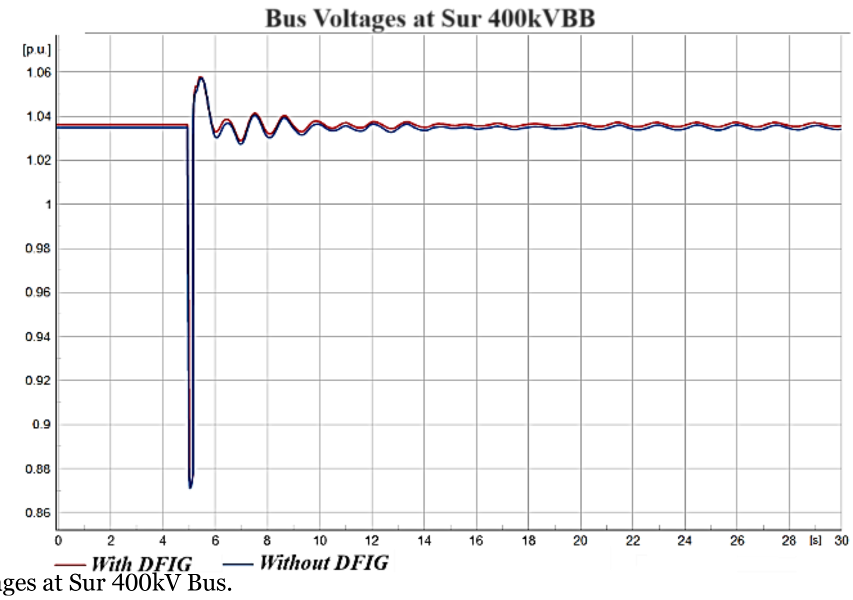

Figure 8. Voltages at Sur 400kV Bus.

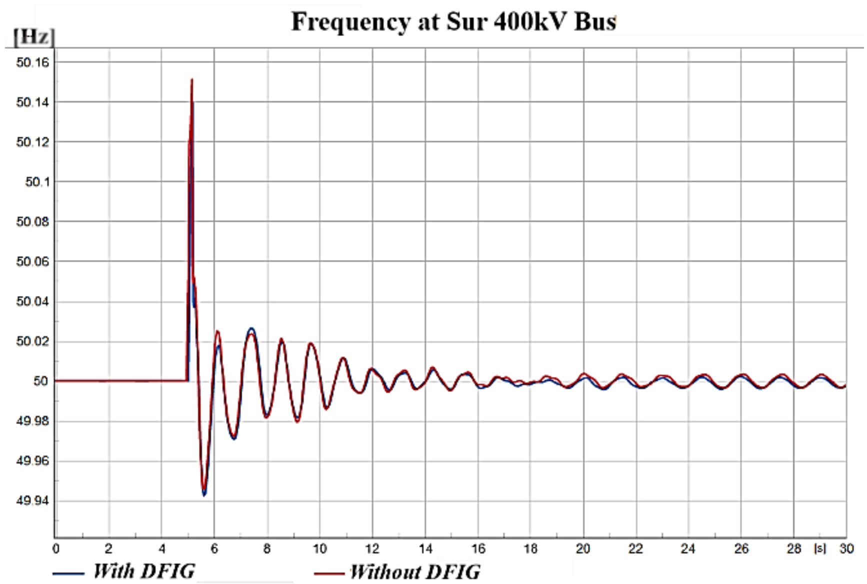

Figure 9. Frequency at Sur 400kV Bus.

3.2 Barka-3 GT1 Power Plant Shutdown

When Barka-3 GT1 power station was turned off (Figure 10), the behavior of the DFIG was examined. The reactive and active power of the DFIG is shown in Figure 11. Five seconds after the simulation started, the power station was shut off. The active power increased and remained at 100 MW after first falling to about 99.8 MW. While the reactive power reduces to -0.23 MVAR during the failure, the DFIG controllers employ reactive power to maintain their terminal voltages. Figure 12 illustrates that when the Barka-3 GT1 was shut off, the voltage also dropped and eventually reverted to 0.994 pu.

The frequency profiles of the low voltage bus of JBB Ali wind farm and Sur 400 kV bus are depicted in Figure 13. The under-frequency event was simulated for 60 seconds to show that it is less than the stretched condition of the OETC security standard.

3.3 Load Disconnection

The effect of load shedding on the DFIGs and the system was investigated by switching off a large load from the MIS (76.1 MW and 25.01 MVAR). The active power increased, which means that the DFIGs provided an extra 72.5 kW to the system. Figure 14 shows the 18.8 kVAr increase in reactive power that occurred. Figure 15 illustrates that when the large load was switched off, the voltage also increased and eventually settled to 0.999 pu.

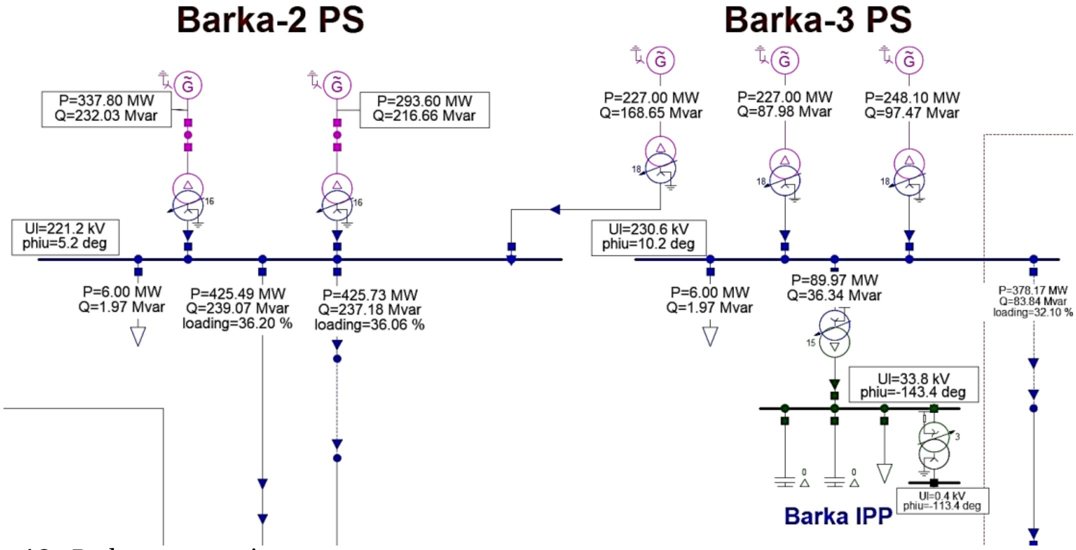

Figure 10. Barka power station.

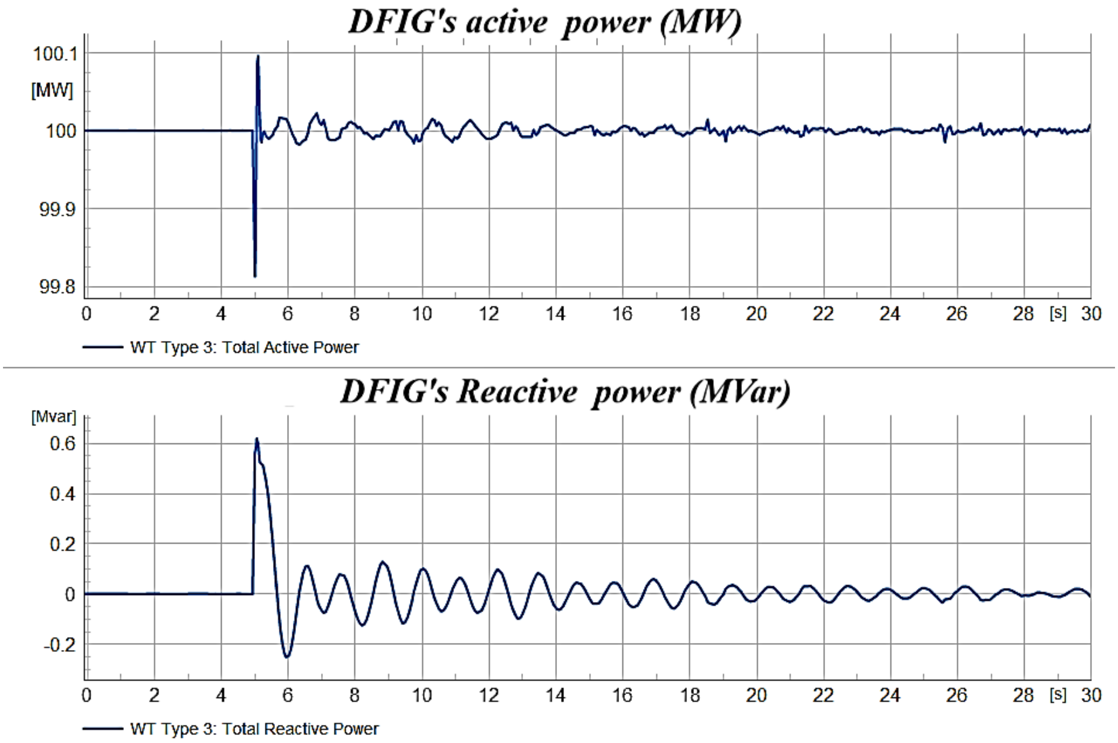

Figure 11. DFIG's active and reactive power while Barka-3 GT1 PS is turned off.

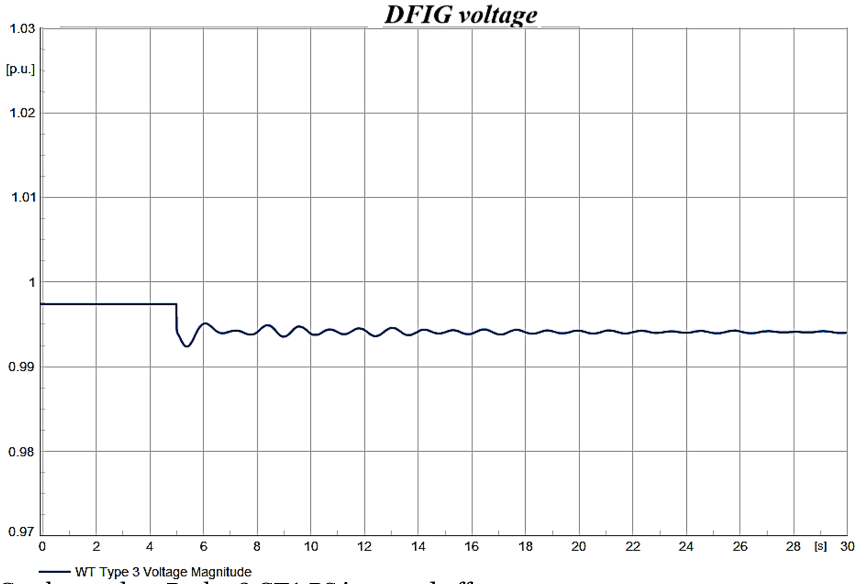

Figure 12. DFIG voltage when Barka-3 GT1 PS is turned off.

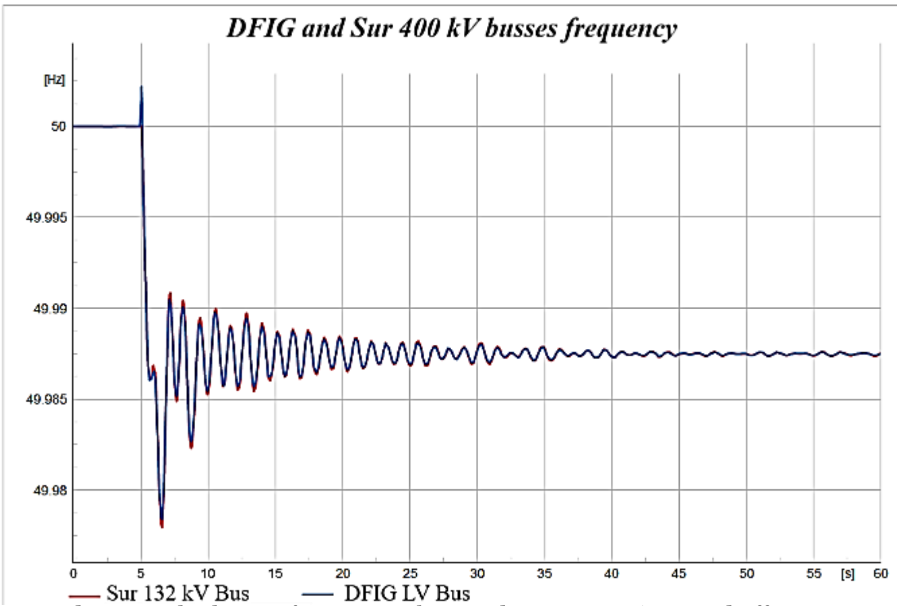

Figure 13. DFIG and Sur 400 kV busses frequency when Barka-3 GT1 PS is turned off.

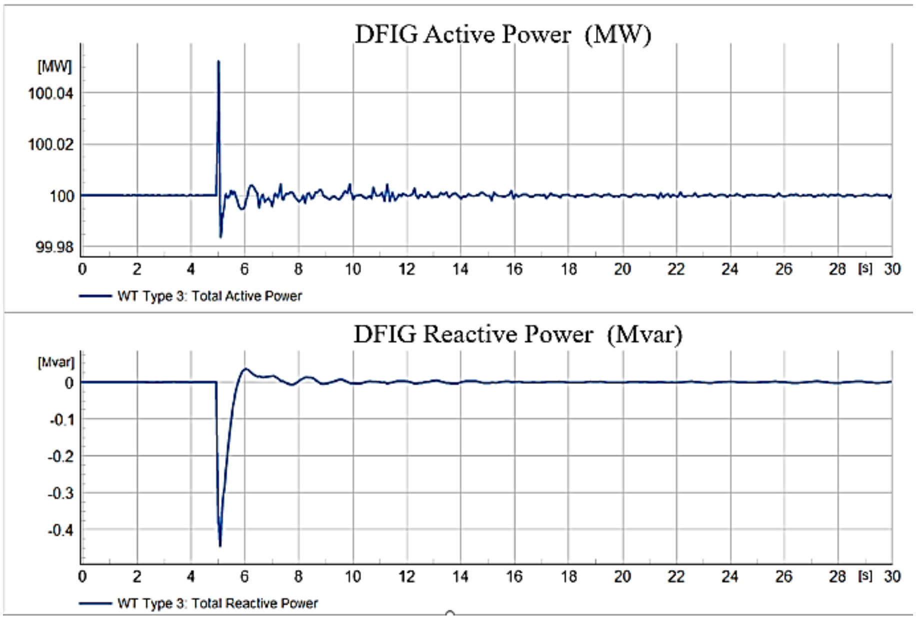

Figure 14. DFIG active and reactive power during load shedding.

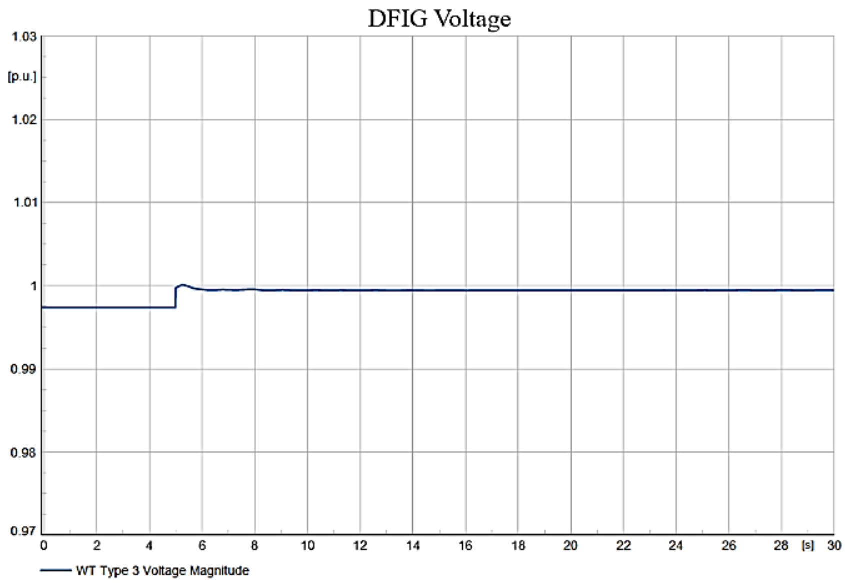

Figure 15. DFIG Voltage during load shedding.

CONCLUSIONS

This study investigated the integration of a wind farm at JBB Ali into the Oman power grid, focusing on its impact on system voltage, active and reactive power, and frequency response. The analysis, conducted using DigSilent PowerFactory software, compared scenarios with and without the wind farm under various disturbances like short circuits, load shedding, and generator tripping.

Simulations reveal that introducing wind power enhanced the grid's recovery time following disruptions, highlighting its resilience.

Overall, voltage and frequency remained steady across all simulated disturbances, indicating effective grid management. The study showed that Doubly-Fed Induction Generator (DFIG) wind turbines had a positive impact on the network, validating their suitability for OETC Oman's grid.

The results provide valuable insights into the feasibility and possible benefits of integrating wind energy into Oman's network. The study provides a road map for future studies on large-scale wind farm integration, taking into account various wind turbine technology and grid management methodologies. It informs stakeholders in Oman's energy sector on the potential benefits of renewable energy sources on grid stability and resilience.

The study requires considerable additional factors to quantify the reported improvement in transient performance and provide specific recovery timeframes. Future research could overcome the study's possible constraints of implementing a simple grid model and limited disturbance scenarios to evaluate the economic consequences of wind farm integration or enhancing grid management tactics to further boost stability.

FUNDING

The authors declare there is no funding received for conducting this research.

CONFILCT OF INTEREST

The authors state that there is no conflict of interest in this paper.

ACKNOWLEDGMENT

The authors acknowledge the technical support of Oman Electricity Transmission Company and Sultan Qaboos University.

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