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Dynamic analysis of grid-connected hybrid wind farm

Jannatul Mawa Akanto[1], Md. Kamrul Islam[1], Effat Jahan[2,3], Md. Rifat Hazari[2,3], Mohammad Abdul Mannan[2,3], Md. Abdur Rahman[2,3]

[1]Erasmus Mundus Joint MSc in Smart Cities and Communities, Faculty of Engineering, University of Mons (UMONS), Mons, Belgium
[2]Department of Electrical and Electronic Engineering, Faculty of Engineering, American International University-Bangladesh (AIUB), Dhaka, Bangladesh
[3]Center for Sustainable Energy Research (CSER), Dr. Anwarul Abedin Institute of Innovation, American International University-Bangladesh (AIUB), Dhaka, Bangladesh

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ABSTRACT

Since the last couple of years, the expansion of grid-connected wind farms (WFs) has increased dramatically. The wind turbine might be a fixed-speed squirrel cage induction generator (FSWT-SCIG) or a variable speed wind turbine with a doubly-fed induction generator (VSWT-DFIG). The main disadvantage of FSWT-SCIG is its lack of ability to adjust power quality. Inversely, the VSWT-DFIG is a competitive wind turbine technology that allows for the effective management of both active and reactive power outputs. Moreover, it has some extraordinary functionaries rather than FSWT-SCIG. However, the major downside to this system is that it only has a partial rating AC/DC/AC power converter, which is extremely expensive. Hence, to reduce the overall cost combining the implementation of VSWT-DFIG and FSWT-SCIG in a WF could be a feasible alternative. Therefore, a novel DFIG control technique is proposed in this article, which can keep the connection point voltage of the hybrid WF stable during dynamic analysis. To evaluate the proposed controller responses PSCAD/EMTDC software has been used.

Corresponding Author:

Jannatul Mawa Akanto
Erasmus Mundus Joint MSc in Smart Cities and Communities (SMACCs), Faculty of Engineering
University of Mons (UMONS)
Mons, Belgium
Email: jannatakanto@gmail.com

1. INTRODUCTION

The huge usage of fossil fuels, market volatility, and growing concern for the environment have all indicated the need for renewable and clean energy sources in recent history. Furthermore, renewable energy sources are practically unlimited, free, clean, and easily accessible. The wind market had a phenomenal year in 2019, as it installed 60.4 GW of systems, making it the second largest in history. Furthermore, the global cumulative wind power (WP) capacity reaches up to 651 GW which is highlighting 19% growth of year-over-year (YoY). Meanwhile, onshore wind new installations reached 54.2 GW, even while offshore wind recent units exceeded 6 GW, accounting for 10% of overall new installations in 2019, the fastest-growing percentage to date. Moreover, based on the Global Wind Energy Council (GWEC), nearly 355 GW of new installation will be incorporated in the following five years, with a yearly installment rate of 71 GW until 2024. Therefore, WP might satisfy up to 20% of worldwide power demand by 2030, exceeding 2010 GW. However, worldwide the WP sector gets affected because of the novel COVID-19 virus. Through these difficulties, the GWEC has determined to preserve its critical factors unaffected, and when the world will recover from this pandemic, it would take proactive measures to manage the situation [1], [2]. Stability is significantly affected by the enormous quantity of WP incorporated into the power system. All the wind farms (WFs) must need to stay in stable condition during the long run.

Fixed-speed wind turbines with squirrel cage induction generators (FSWT-SCIGs) are by far the most often employed wind turbines (WTs) since they are easy to build, robust, and most importantly they are cost-effective [3]. Despite this, the SCIG is directly tied to the electrical grid and as the voltage of a bus-connected FSWT-SCIG based WF fluctuates significantly during starting phase, a sufficient amount of reactive power is required [4], [5]. Nevertheless, at the steady state phase, SCIG requires reactive power. Hence, a capacitor bank is utilized to supply reactive power [6]. Therefore, to make the terminal voltage stable several flexible AC transmissions (FACTs) device has been used, such as static synchronous compensator (STATCOM) [7]–[11], energy capacitor system (ECS) [12], static var compensator (SVC) [13], thyristor-controlled series capacitor (TCSC) [14], static synchronous series compensator (SSSC) [15], and superconducting magnetic energy storage (SMES) [16]. Therefore, the overall expenditures have been increased.

Nevertheless, variable speed wind turbine with a doubly-fed induction generator (VSWT-DFIG) is one of the most competitive wind turbines in the wind industry. Since it has some remarkable benefits VSWT-DFIG has a massive market share in the world, such as high efficiency, lower converter rating, relatable control on active and reactive power, and lightweight [17], [18]. The control of the rotor side converter (RSC), which is commonly rated at around 30% of the generator rating when the rotor speed is between 75% and 125% under standard conditions, is predominantly responsible for these benefits [19]. Apart from this, the key disadvantage of VSWT-DFIG-based WFs is they are quite expensive due to their partial rating power electronic AC/DC/AC converter. Hence, hybrid installation of FSWT-SCIG and VSWT-DFIG has been implemented. As a result, SCIG's stability may be achieved at a cheaper cost. Consequently, the foremost objective of this study is the develop a novel DFIG control strategy that focuses on the PI controller to regulate the RSC controller's outer and inner loop in order to keep the connection point voltage of the hybrid WF stable during dynamic analysis. The following section is presented as follows, section 2 is the model of power system, section 3 is the DFIG system with the cascaded control system, section 4 is the proposed controller, section 5 is the grid-side converter (GSC) controller, section 6 is simulation analysis and discussion, and section 7 is conclusion.

2. MODEL OF POWER SYSTEM

A double circuit transmission line and transformers with voltage ratings of 0.69 kV/6.6 kV and 6.6 kV/66 kV are employed to connect the SCIG and DFIG to an infinite bus in the power system architecture illustrated in Figure 1. The required and the power rating of both WTs are 35 MW and 15 MW, respectively. The base power of the system has been chosen 100 MVA and the frequency has been chosen 50 Hz. All the essential attributes of both generators have been taken from [20].

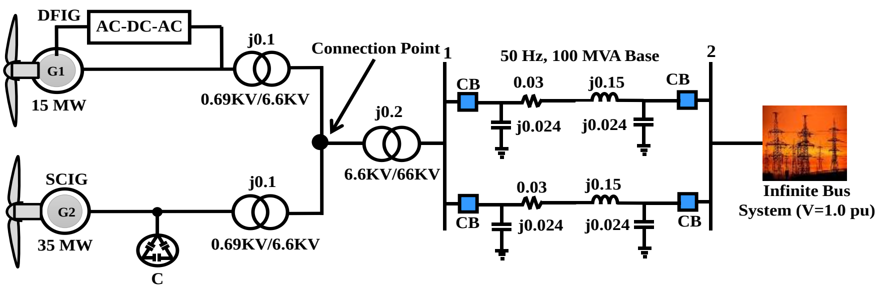

Figure 1. Power system model

3. DFIG SYSTEM WITH CASCADED CONTROLLER

Figure 2 shows the MPPT curve of DFIG system [21]. According to the available wind speed, the MPPT curve for DFIG is segmented into four functioning regions as described in the following [22]: i) minimum operating region from point A to point B, ii) optimal speed region from point B to point C, iii) maximum operating region from point C to point D, and iv) the limited speed region where the pitch controller take action. Besides, Figure 3 shows the layout of VSWT-DFIG and its controller. Aerodynamic wind turbine system with drive-train, wound rotor induction generator (WRIG), pitch angle controller, RSC, and GSC comprise up the system. Two levels of insulated gate bipolar transistors (IGBTs) are employed to regulate the RSC and GSC. However, WRIG transforms WP into electrical power. The rotor position (θ_r) and speed (ω_r) are collected from the WRIG rotor shaft. As demonstrated in Figure 3, the stator junction is directly coupled to the grid while the rotor is coupled to the grid via RSC and GSC. The power converter rating is one-third of the WRIG rating. The RSC supplies the rotor windings variable frequency excitement according to the wind speed and integrates the GSC through the transformer with the grid system. This work employs the pulse width modulation (PWM) approach, with a carrier frequency of 3.0 kHz for both converters. In the DC-Link circuit is a DC chopper. The comparator block is in charge of it. The comparator triggers the DC chopper and protects the DC-Link circuit when the DC-link voltage (V_{dc}) is 1.15 pu. The rated voltage is 1.2 kV.

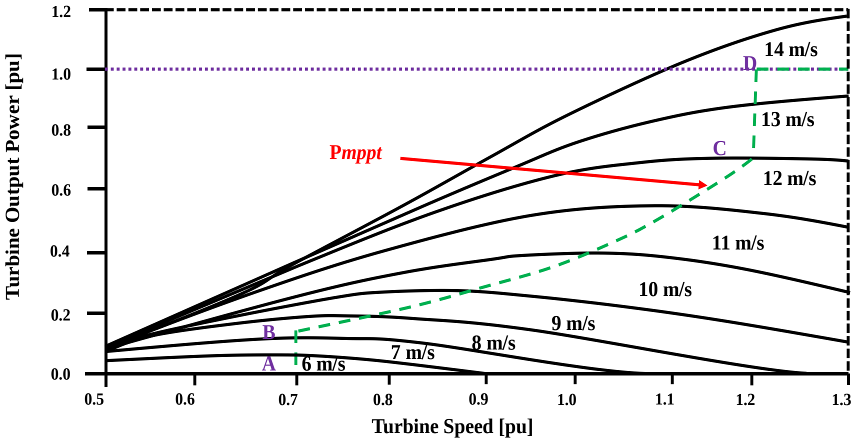

Figure 2. MPPT diagram of DFIG

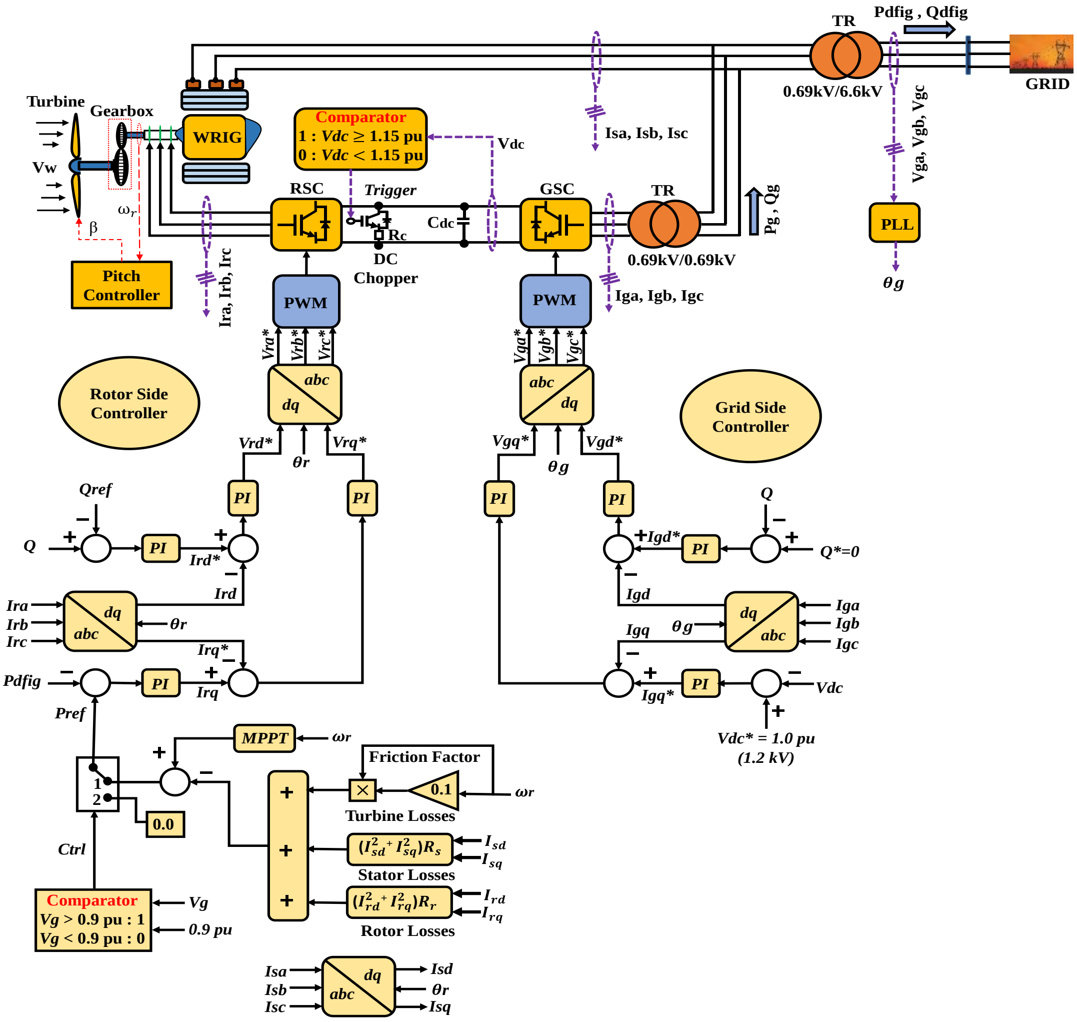

Figure 3. DFIG system with cascaded controller

In the synchronous reference frame, the DFIG system is defined. Using (1) and (2), the d and q-axis stator and rotor voltages are calculated [23].

$$\begin{cases} V_{sd} = R_s . i_{sd} + \frac{d\varphi_{sd}}{dt} - \omega_s . \varphi_{sq} \\ V_{sq} = R_s . i_{sq} + \frac{d\varphi_{sq}}{dt} + \omega_s . \varphi_{sd} \\ V_{rd} = R_r . i_{rd} + \frac{d\varphi_{rd}}{dt} - \omega_r . \varphi_{rq} \\ V_{rq} = R_r . i_{rq} + \frac{d\varphi_{rq}}{dt} + \omega_r . \varphi_{rd} \end{cases} \quad (1)$$

$$\begin{cases} \varphi_{sd} = L_{st} i_{sd} + L_m i_{rd} \\ \varphi_{sq} = L_{st} i_{sq} + L_m i_{rq} \\ \varphi_{rd} = L_{rt} i_{rd} + L_m i_{sd} \\ \varphi_{rq} = L_{rt} i_{rq} + L_m i_{sq} \end{cases} \quad (2)$$

In the (1) and (2), R_s , R_r and L_{st}, L_{rt} are represented the resistance and self-inductance of stator and rotor winding accordingly. Mutual inductance is illustrated as L_m. Also, i_{sd}, i_{sq}, i_{rd}, and i_{rq} are represented the currents of stator and rotor sequentially. Consequently, ω_r represents the angular speed of the rotor and the angular frequency of the grid is presented as ω_s.

4. PROPOSED RSC CONTROLLER

As displayed in Figure 3, the RSC is regulated by the RSC controller. Four PI controllers are used in the control system to adjust several errors. The outer loop is responsible of acquiring MPPT power from the DFIG as well as reactive power regulation. The inner loop is employed to control the *d* and *q*-axis currents. To adjust active power, losses in the turbine, rotor, and stator are taken into consideration which is displayed in the following equation to maximize reactive power supply.

$$P_s = (i^2{}_{sd} + i^2{}_{sq})R_s \quad (3)$$

$$P_r = (i^2{}_{rd} + i^2{}_{rq})R_r \quad (4)$$

$$P_{tl} = 0.01\omega_r \quad (5)$$

The stator, rotor, and turbine losses are denoted by P_s, P_r and P_{tl}, accordingly. The active power extracted can be more realistically estimated by accounting for all these losses. The voltage dip at the common coupling point is employed to regulate the reactive power. The reference reactive power was calculated as regards [24], [25].

$$Q_{ref} = S\left\{\left(\frac{V}{V_0}\right)^2 - \left(\frac{V}{V_0}\right)^{12}\right\} \quad (6)$$

Where, the rated apparent power is represented by S, the terminal voltage and pre-fault voltage (1.0 pu) of DFIG are represented by V and V_0 Besides, depending upon (6), the voltage vs reactive power features curve is displayed in Figure 4.

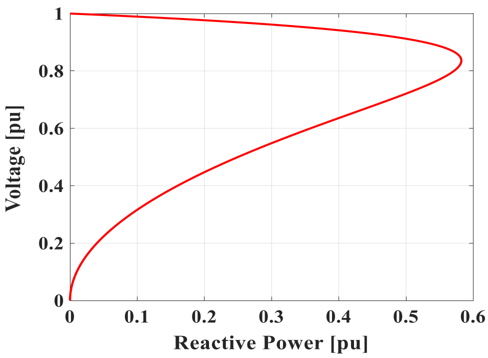

Figure 4. Voltage vs reactive power features curve

5. GSC CONTROLLER

Figure 3 additionally depicts the GSC controller, which has four PI controllers to adjust for several other error signals. Furthermore, the GSC reactive power (*Q*) and DC-link voltage (Vdc) are regulated sequentially by the d-axis (I_{gd}) and q-axis (I_{gq}) current components. In addition, the reference reactive power is zero, and the reference DC-link voltage is 1.2 kV (1.0 pu).

6. SIMULATION ANALYSIS AND DISCUSSION

The dynamic behavior of the proposed RSC controller of DFIG is illustrated and evaluated in this section. The power system represented in Figure 1 is employed to evaluate the performance. The overall simulation is executed for 100.0 s.

However, the actual wind speed for both WFs as shown in Figure 5 is recorded intending to monitor the dynamic effects of the proposed power system. Figures 6 and 7 represent the active power and reactive power response at the common coupling point (PCC). Figure 8 shows the voltage response at the PCC, and it is clearly evident that the terminal voltage is remains constant.

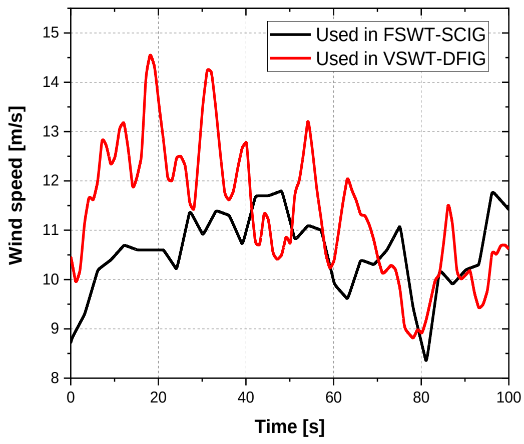

Figure 5. Wind speed for SCIG and DFIG

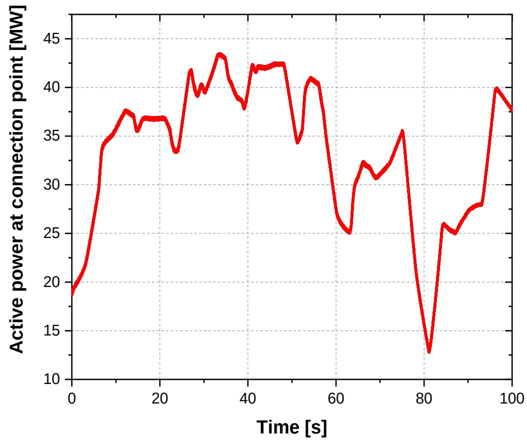

Figure 6. Active power at common coupling point (PCC)

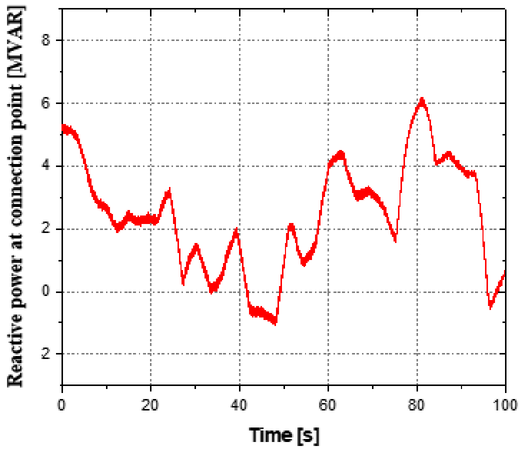

Figure 7. Reactive power at common coupling point (PCC)

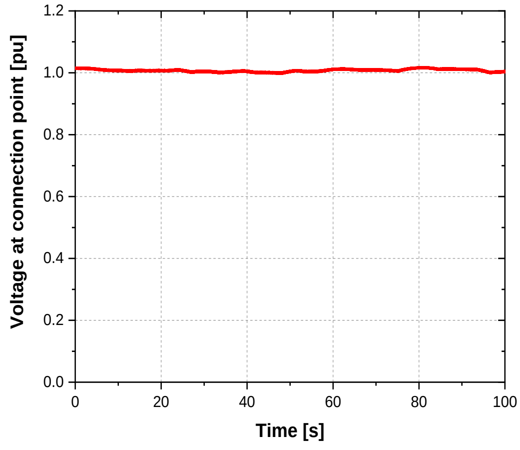

Figure 8. Voltage at common coupling point (PCC)

Hence, the system remains in stable condition. Moreover, the active power output for both WFs is displayed in Figures 9 and 10. Besides, Figures 11 and 12 depict the reactive power output for both WFs (SCIG & DFIG). Finally, Figure 13 displays the DC-link voltage of DFIG, which stays nearly steady during the whole simulation run time.

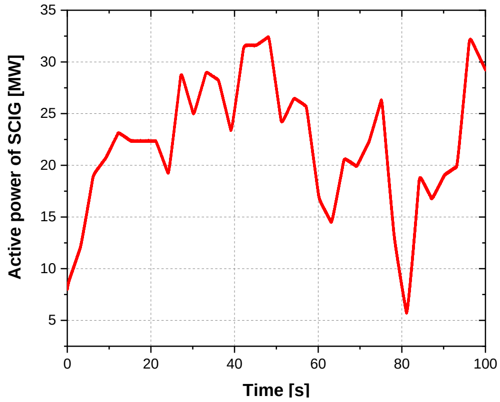

Figure 9. Active power output of SCIG

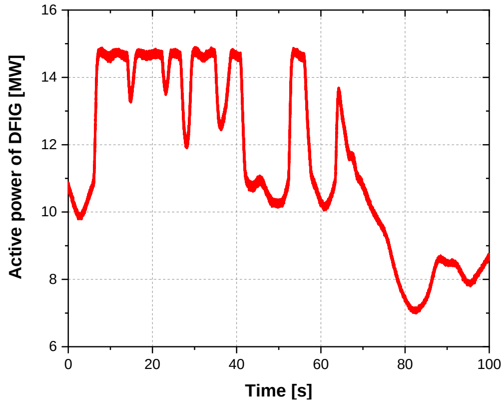

Figure 10. Active power output of DFIG

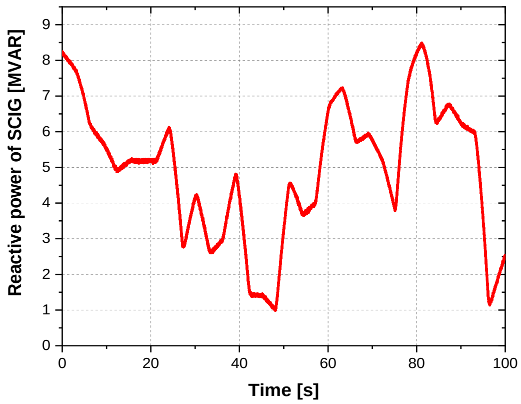

Figure 11. Reactive power output of SCIG

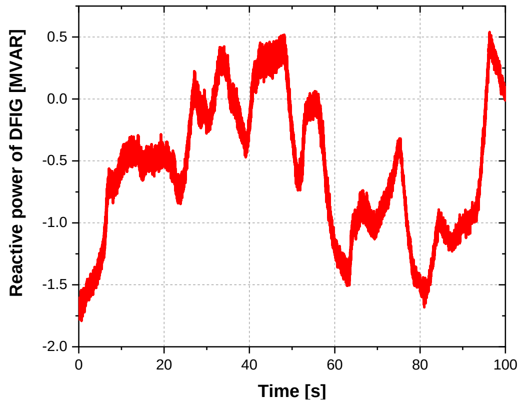

Figure 12. Reactive power output of DFIG

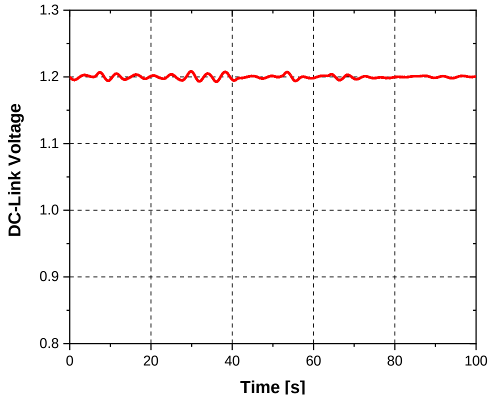

Figure 13. DC-link voltage output of DFIG

7. CONCLUSION

This study proposes a novel DFIG control system to increase the system stability of SCIG based WFs with partial integration of the DFIG WF. The total installation cost of WFs might be decreased with this hybrid WF concept. Furthermore, the simulation analysis reveals that the suggested RSC controller is capable of confirming constant terminal voltage during dynamic analysis. Hence, the proposed control scheme is ensuring system stability.

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BIOGRAPHIES OF AUTHORS

Jannatul Mawa Akanto is recently completing her Erasmus Mundus Joint Master Degree (EMJMD) in Smart Cities and Communities (SMACCs). She obtained her M.Sc. and B.Sc. Engg. Degree in Electrical and Electronic Engineering (EEE) from American International University-Bangladesh (AIUB) in 2021 and 2020 respectively. Based on her B.Sc. thesis she got the "1st Runner Up Poster Award" from AIUB. Moreover, in 2018 she has been selected as Science Crew (To Research) at AIUB Robotic Crew and in 2019 participated in one of the most prestigious competitions "The University Rover Challenge", organized by The MARS Society, Utah, USA. However, for her academic excellence, she achieved DEAN'S LIST HONOR (7 times) from AIUB and got nominated for one of the most prestigious academic honors "MAGNA CUM LAUDE" in AIUB 20th Convocation. Moreover, in 2018 she achieved 1st prize in the "Esho-Robot Banai" idea contest organized by Channel-I, Bangladesh. Her research interest is in renewable energy resources and power electronics. She can be contacted at email: jannatakanto@gmail.com.

Md. Kamrul Islam is recently completing his Erasmus Mundus Joint Master Degree (EMJMD) in Smart Cities and Communities (SMACCs). He received his M.Sc. and B.Sc. Engg. degree in Electrical and Electronic Engineering (EEE) from American International University-Bangladesh (AIUB) in 2021 and 2020 respectively. Moreover, he was working as a Teaching Assistant (TA) in the Department of Electrical and Electronic Engineering under Faculty of Engineering at AIUB. He was working as Team Captain of AIUB ROBOTIC CREW since 2019. His research interests based on renewable energy, power electronics, electrical vehicles, virtual synchronous generator, microgrid, and robotics. He is a graduate student member of IEEE. He can be contacted at email: kamrulislamczs@gmail.com.

Effat Jahan graduated from American International University-Bangladesh (AIUB) in 2013 and 2014 with a B.Sc. Engg. and an M.Sc. Engg. in Electrical and Electronic Engineering, respectively. She also achieved the Magna Cum Laude (academic honor) award for her outstanding performance in her Bachelor's degree program. Her Ph.D. degree was at the Kitami Institute of Technology (KIT) in Japan. Her Ph.D. research focuses on power system frequency stabilization, including large-scale offshore wind farms, VSC-HVDC transmission system design and analysis, and power system dynamics analysis. She is currently working as an Assistant Professor in the Electrical and Electronic Engineering Department. She can be contacted at email: effat@aiub.edu.

Md. Rifat Hazari received his B.Sc. Engg. and M.Sc. Engg. degrees in Electrical and Electronic Engineering (EEE) from American International University-Bangladesh (AIUB) in August 2013 and December 2014, respectively and Ph.D. degree in Energy Engineering from Kitami Institute of Technology (KIT), Japan, in March 2019. He served as a Lecturer and Assistant Professor in Electrical and Electronic Engineering department at AIUB. Currently, he is working as a Senior Assistant Professor in the Electrical and Electronic Engineering department at AIUB. He is also the Deputy Director of Center for Sustainable Energy Research (CSER), Dr. Anwarul Abedin Institute of Innovation, AIUB. He received the MINT (Academic Excellence) Award 2017 from KIT for the outstanding research of 2017 academic year, Best Paper Award in the Australasian Universities Power Engineering Conference 2017, Melbourne, Victoria, Australia and Best Presentation Award in the IEEJ Branch Convention 2017, Hakodate, Japan. His research interests are renewable energy systems (especially wind power and photovoltaic power systems), power system stability and control, microgrid and hybrid power systems, HVDC system, analysis and control of rotating electrical machines. Dr. Hazari is a member of IEEE. He can be contacted at email: rifat@aiub.edu.

Mohammad Abdul Mannan was born in Laxmipur, Bangladesh on January 01, 1975. He received his B. Sc. Eng. degree from Rajshahi University of Engineering and Technology (RUET former BITR), Bangladesh, in 1998, and Masters of Eng. and Dr. of Eng. degrees from Kitami Institute of Technology, Japan, in 2003 and 2006 respectively, all in electrical engineering. He then joined in the American International University Bangladesh (AIUB) as an Assistant professor in May 2006. He served in AIUB as an Associate Professor from December 2013 to November 2016. Now he is working as a Professor and Director of the Faculty of Engineering in AIUB. His research interests include electric motor drive, power electronics, power system, wind generation system and control of electric motor, power electronic converters, power system, and wind generation system. Prof. Dr. Mannan is a member of the IEB and IEEE. He can be contacted at email: mdmannan@aiub.edu.

Md. Abdur Rahman is an experienced Researcher with a demonstrated history of working in the higher education industry. He has extensive knowledge of radio frequency (RF), wireless communication, biomedical imaging, machine learning, and antenna propagation. Profound research professional with Doctor of Philosophy (Ph.D.) from Tokyo Institute of Technology University in 2013 focused on software defined radio (SDR) and has experience as a Postdoctoral Researcher in Federation University Australia from 2014, focused on Application of modern signal processing techniques in gene expressions to form gene regulatory network (GRN). His research interest is focused on RF/microwave circuits and systems, digital signal processing, biomedical image processing, nano-electronics, machine learning, wireless communication, antenna propagation. Currently, he is working as an Associate Dean in the Faculty of Engineering at American International University-Bangladesh (AIUB) and a Professor in EEE, AIUB. He can be contacted at email: arahman@aiub.edu.