BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 63 (67), Numărul 3, 2017
Secţia
ELECTROTEHNICĂ. ENERGETICĂ. ELECTRONICĂ

A COMPARATIVE STUDY OF WIND TURBINE GENERATORS OPERATING PERFORMANCE
A CASE STUDY FOR THE VIETNAMESE NINH THUAN-GRID

BY

MINH QUAN DUONG [1,*], THANH VIET DINH[1], NGOC THIEN NAM TRAN[1], GABRIELA SAVA[2] and ALEXANDER KIES[3]

[1]The University of Danang – University of Science and Technology,
Faculty of Electrical Engineering, New and Renewable Energy
in Power System Research Group, Vietnam,
[2]University Politehnica of Bucharest, Romania,
Faculty of Power Engineering
[3]Frankfurt Institute for Advanced Studies, Goethe University Frankfurt, Germany

Received: July 21, 2017
Accepted for publication: August 29, 2017

Abstract. Renewable resources are emerging rapidly and are a current trend of developing world energy. Of all renewable resources, wind is growing the fastest and can become a main source of power for future power systems. However, the grid connection of wind power can generate many issues related to stability due to grid faults. Previous studies have not shown the difference in these issues depending on the types of generators as well as the effects of these generators when integrated into an actual grid. Thus, this paper analyzes the operation as well as the possibility of overcoming a grid fault for four wind turbine generator systems integrated into the grid of Ninh Thuan province-Vietnam: Fixed-Speed Induction Generator (FSIG); Limited Variable-Speed Induction Generator (LVSIG); Doubly-Fed Induction Generator (DFIG); Permanent Magnet Synchronous Generator (PMSG). In this study, hypothetical faults are simulated in the grid to show the capabilities of these wind turbine generators with respect to power distribution and transient stability of the wind turbine generators. The simulated results show that DFIG and PMSG system have a number of outstanding advantages with fast recovery after faults as well

[*]Corresponding author: *e-mail*: dmquan@dut.udn.vn

as the voltage being always within the specified range while FSIG completely collapsed after the fault. The ability to adjust the speed makes PMSG, DFIG and LVSIG able to overcome the fault and operate more stable than FSIG.

Key words: ETAP; Mui Dinh wind power plant; renewable energy; wind energy; wind turbine generator.

1. Introduction

Over the past few years, renewable energy has been intensively studied and the deployment of renewable energy has developed dramatically worldwide according to the International Renewable Energy Agency (IRENA), which has 154 countries as members and another 26 countries in the process of joining the organization. Wind power accounts for a great proportion and has achieved the fastest growth rate among the renewable resources. However, many studies show that depending on the level of penetration, wind power can cause negative impacts on the grid: voltage instability, short-circuit current increase and frequency instability (Kim *et al.*, 2017; Abbasi *et al.*, 2017). When wind farms are connected to the grid, it is considerably more difficult to ensure the stability of the grid as well as of the entire system (Tang *et al.*, 2017; Jallad *et al.*, 2017). Wind power plants are required to provide and meet power quality requirements as given by the grid code (Circular No. 39/2015/TT-BCT of the Government of Vietnam, 2015) to ensure the reliability of the power system and supply electricity to customers. It is important to understand the source of the disturbance that affects the input energy (Zhang *et al.*, 2016; Duong *et al.*, 2014a), in order to provide methods to stabilize the output power when a fault occurs.

Many studies are being conducted to solve the limited issues of wind power plants, such as the location of wind turbines, using reactive power compensation devices. Reference (Neagu *et al.*, 2014) presents an optimization method for the off-shore wind farm turbine power grid combining a classical method and a heuristic algorithm using graph theory. A scientific research paper (Duong *et al.*, 2014b) has examined two types of wind turbine generators that have been used in recent years to show the advantages and disadvantages of each type of generator. They also predict possible requirements to increase the grid capacity, storage requirement and impacts on grid stability. Wind power plants must ensure grid stability to meet the loading demands and improve power quality. For that reason, it is crucial to research and develop wind turbine generators. Studies usually use IEEE test systems: IEEE 9 Bus System, IEEE 14 Bus System, etc. (Pillai Anju *et al.*, 2013). Otherwise their grid would have incorrect parameters.

This study examines the performance of four types of wind turbines: FSIG systems (Fixed-Speed Induction Generator) operating at fixed rotor speeds, depending on the frequency of the supply, gear ratio and structure of the generator; LVSIG (Limited Variable-Speed Induction Generator) an improved version of FSIG; DFIG (Doubly-Fed Induction Generator) and PMSG (Permanent Magnet Synchronous Generator) integrated into an actual electrical system in Vietnam. This research presents the general possibilities of exploiting wind energy for different generator systems and uses simulations based on the reality in Vietnam. The ETAP software with tools to assist in performance simulation, power flow, fault and recovery analysis is used to investigate the four wind turbine generator types. The steady and transient states are assumed when integrating these wind energy converters into the Vietnamese Ninh Thuan electricity network with realistic parameters. Finally, conclusions about the suitability of the different types of wind turbine generators for the operational requirements of the grid in Vietnam are drawn.

2. Wind Power in Vietnam and Ninh Thuan Grid

2.1. Wind Power and the Power System of Vietnam

Located in the tropical monsoon region, Vietnam has great potential for developing wind energy. The National Electricity Plan of Vietnam for 2011-2020, with a vision until 2030, prioritises the development of renewable energy sources. Accordingly, the total wind power capacity of the country is projected to increase from the current 140 MW to 800 MW by 2020 and 6,000 MW by 2030 The World Bank study (Wind Resource Atlas of Vietnam, 2011) shows that Vietnam has a large potential for wind power: more than 39 % of Vietnam's total area is estimated to have a high average annual wind speed of more than 6 m/s at 65 m height. The study also estimates the total installation potential to be around 512 GW. Major parts of the existing transmission grid are located in coastal areas, where high wind speed and high exploitable reserves make it a great advantage for wind energy to be developed and connected into the system. Table 1 shows the potential of wind power in Vietnam according to the wind atlas**.**

Table 1
The Wind Velocity in Vietnam at 80 m, AWS TruePower

Average wind speed	Lower than 4 m/s	4-5 m/s	5-6 m/s	6-7 m/s	7-8 m/s	8-9 m/s	Higher than 9m/s
Potential (MW)	956,161	708,678	404,732	24,351	2,202	200	10

According to these numbers, Vietnam has tremendous potential for wind energy (Kies *et al.*, 2017). However, bad weather conditions and natural disasters, which often occur, especially typhoons, make it difficult to ensure the stability of wind power production as well as the stability of the grid. Detailed investigations of the optimal location of the wind farms as well as the appropriate type of wind turbine generator must be carefully considered and analyzed. Currently, wind power projects are concentrated mainly in South Central Vietnam – especially in Binh Thuan, Ninh Thuan. Hence, this paper is based on the actual data collected on the regional grid Mui Dinh - Ninh Thuan power plant to simulate the process of operation when wind power penetrates the grid.

2.2. Wind Power Development Potential and the Grid Model of Ninh Thuan Province in Vietnam and Mui Dinh Wind Power Plant

The wind potential (Wind Resource Atlas of Vietnam, 2011) in Ninh Thuan province is highest in Ninh Phuoc and Thuan Nam districts, followed by Phan Rang - Thap Cham, Thuan Bac, Ninh Hai with total wind power potential of Ninh Thuan up to 10,447 MW (Fig.1). Table 2 shows the wind potential of Ninh Thuan Province at 65 m height.

Table 2

Wind Power Potential in Ninh Thuan Province at 65 m Height According to AWS TruePower

Average wind speed	Medium (6.5-7 m/s)	Relative good (7-7.5 m/s)	Good (7.5-8 m/s)	Very good (>8.0 m/s)
Potential, [MW]	24.351	2.202	200	10
Area, [ha]	109,303	74,440	55,462	21,971
% of total area	32.6	22.2	16.5	6.5

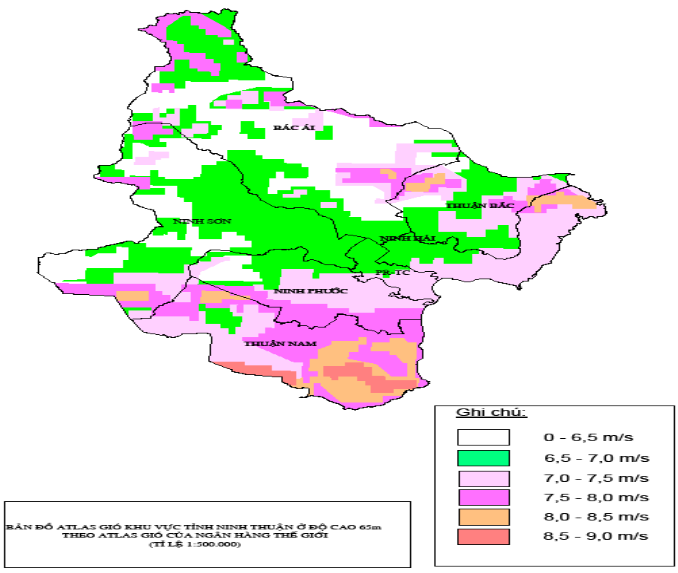


Fig. 1 - Wind atlas for Ninh Thuan province.

The ETAP software is used to simulate and analyze the operating modes of the 110 kV distribution grid in Ninh Thuan Province when connecting the Mui Dinh wind power plant. The influence of the wind power plant on the power flow, the voltage deviation at the nodes, the power losses as well as the ability to overcome faults when integrating wind power plants into the grid is analyzed.

The 110 kV grid is responsible for power transmission and for the connection of the main power suppliers. The two main power suppliers connected to this voltage level are Da Nhim Hydropower (Gen 1) with a maximum power of 40 MVA connected to Ninh Son 110 kV Bus; the area of Bac Binh Hydropower (Gen 2) with a power of 20 MVA connected to Ninh Phuoc 110kV Bus. In addition, the Ninh Thuan power grid is connected to Vietnam's electricity system via the U1 power source at the Thap Cham2 110 kV Bus. To ensure transmission efficiency and minimize losses, the Mui Dinh wind power plant (WTG) provides power to the grid through a 40 MVA transformer (22 kV to 110 kV). The parameters of the transmission lines and the transformers shown in Fig. 2 are calculated in the % unit system with a base power of 100 MVA. The load data was compiled on 06.17.2017 and was simulated in the maximum load mode with the load capacity parameters shown in Table 3 (VietNam Electricity and National Load Dispatch Centre of VietNam, 2017).

Branch Connections

CKT/Branch	Connected Bus ID		% Impedance, Pos. Seq., 100 MVA Base			
Type	From Bus	To Bus	R	X	Z	Y
Transformer	Dien gio Mui Dinh	Bus_diengio	0.63	28.74	28.75	
Line	Ninh Phuoc	Ninh Thuan 1	1.97	3.95	4.41	0.4215047
Line	Ninh Thuan 1	Dien gio Mui Dinh	0.16	0.33	0.37	0.0351832
Line	Ninh Son	Thap Cham	4.91	13.60	14.46	1.0555050
Line	Thap Cham	Dien gio Mui Dinh	3.00	6.02	6.72	0.6638919
Line	Thap Cham2	Thap Cham	2.46	4.92	5.50	0.5277536
Line	Thap Cham2	Ninh Hai	2.46	4.92	5.50	0.5277536

Fig. 2 – Parameter of Ninh Thuan grid lines.

Table 3
The Maximum Power Load of the Day 06.17.2017

Load	Nominal Voltage (kV)	Active power (MW)	Reactive power (MVAr)
Tai_Ninh Hai	110	22.4	0.4
Tai_PRTC	110	40.7	3.1
Tai_Ninh Son	110	9.4	1.4
Tai_Ninh Phuoc	110	14.3	1.5
Tai_Ninh Thuan 1	110	13.5	3.4

The purpose of the Mui Dinh wind power plant is to provide additional power to the national grid with a total installed capacity of 70 MW. The project was divided into two phases: Phase 1 started with 37.6 MW, and Phase 2 expanded the project by additional 32.4 MW. Fig. 3 shows a perspective of the wind turbines installed in the two areas at Mui Dinh from Google Earth

Fig. 3 – The layout of wind turbine phase 1 of Mui Dinh.

3. Types of Wind Turbine Generators

This turbine generator has a fixed transmission shaft speed, uses the squirrel cage induction generator (SCIG) and is directly connected to the grid through a transformer (Fig. 4). Although control power in a fixed-speed wind turbine method is varying, the fluctuating wind causes power fluctuations that lead to the fluctuation of the electric system. This fluctuation can cause voltage changes at the connection points (in case of light grid capacity), so the fixed-speed wind turbines will vary the amount of reactive power from the grid (in case of no reactive power compensation at the generator terminals). This causes a sharp increase in voltage and grid degradation (Duong *et al*., 2015).

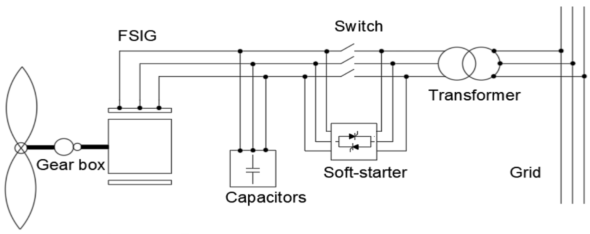


Fig. 4 - FSIG's block diagram

LVSIG (Fig. 5) uses a wound rotor induction generator (WRIG). This model uses the rotor rotation modification method to respond to the change of wind speed, its control only depends on the change of rotor resistance value. Having variable speed control via rotor resistor control, the rotor windings are an improvement compared to the FSIG. As a result, LVSIG can control the output power and catch the wind more efficiently. Rotor speed range varies between 0 ÷ 10% compared to the synchronous speed. The stator is connected to the grid via an uncontrolled rectifier and a smooth inverter. Similar to FSIG, the soft starter with limited in-rush currents gives LVSIG connections to the grid additional stability. In addition, LVSIG reduces the mechanical stresses caused by wind on the turbine (Li, 2017). However, both FSIG and LVSIG have the problem of consuming a large amount of reactive power to recover. So, complementary equipment has to be installed to compensate reactive power.

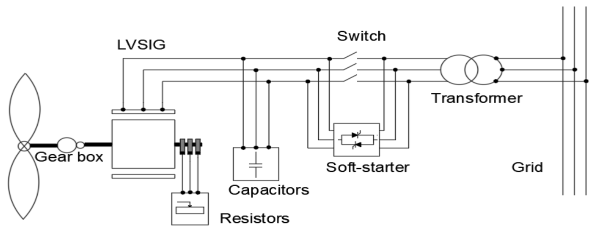


Fig. 5 – LVSIG's block diagram.

DFIG (Li, 2017) consists of a WRIG with stator windings connected directly to a constant frequency three-phase grid and a rotor winding connected to the grid via an indirect frequency inverter using the PWM method. The model is shown in Fig. 6. This system allows operation in a wide range of varying speed. There are two converters: the rotor converter and the grid converter, which are controlled independently of each other. The rotor converter controls the reactive power and by controlling the rotor current components, while the grid converter controls DC voltage. This model uses the Variable Speed - Variable Pitch control method (Duong *et al.*, 2014b).

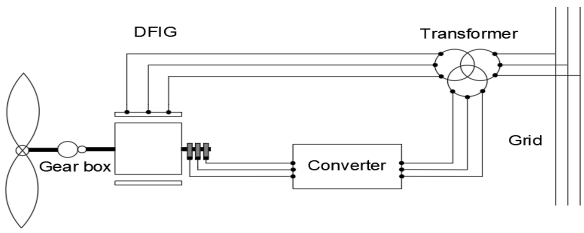


Fig. 6 - DFIG's block diagram

PMSG is used to meet all types of wind speed variations. The generator is connected to the grid via a back-to-back power converter to provide the desired frequency of power (Fig. 7). PMSG uses a permanent magnet to generate a magnetic field. The system has therefore no need for an excitation system. This system uses a variable speed control strategy. Variable-speed methods have become popular for modern wind turbines, especially at low wind speeds. The convenience of this method is the large amount extracted power, which reduces the aerodynamic load and improves the quality of power. Due to the strong development of power electronics, this model effectively controls the amount of active and reactive power (Venkata Yaramasu *et al.*, 2017).

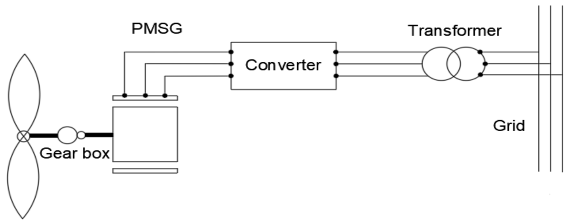
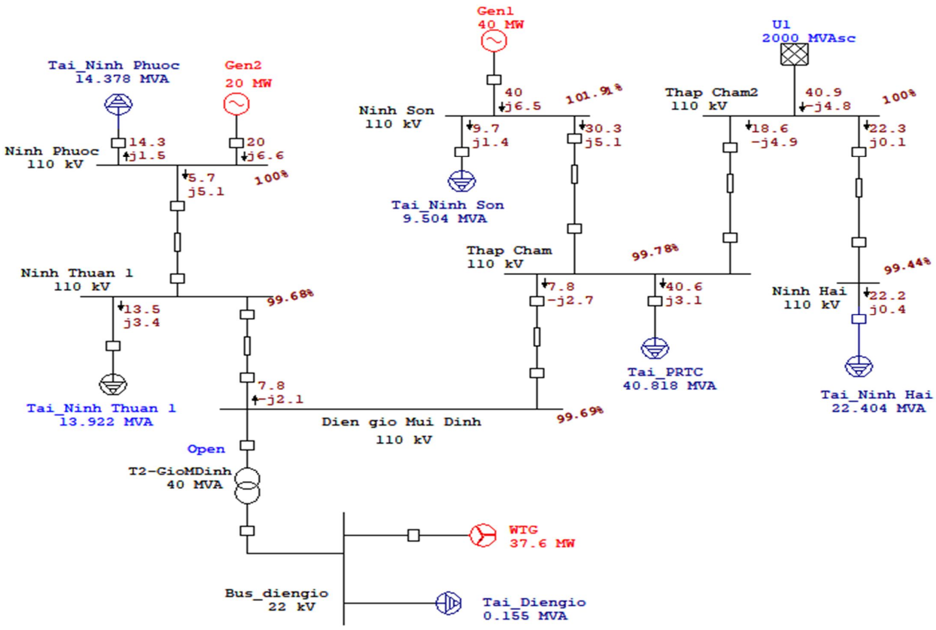


Fig. 7 – PMSG's block diagram.

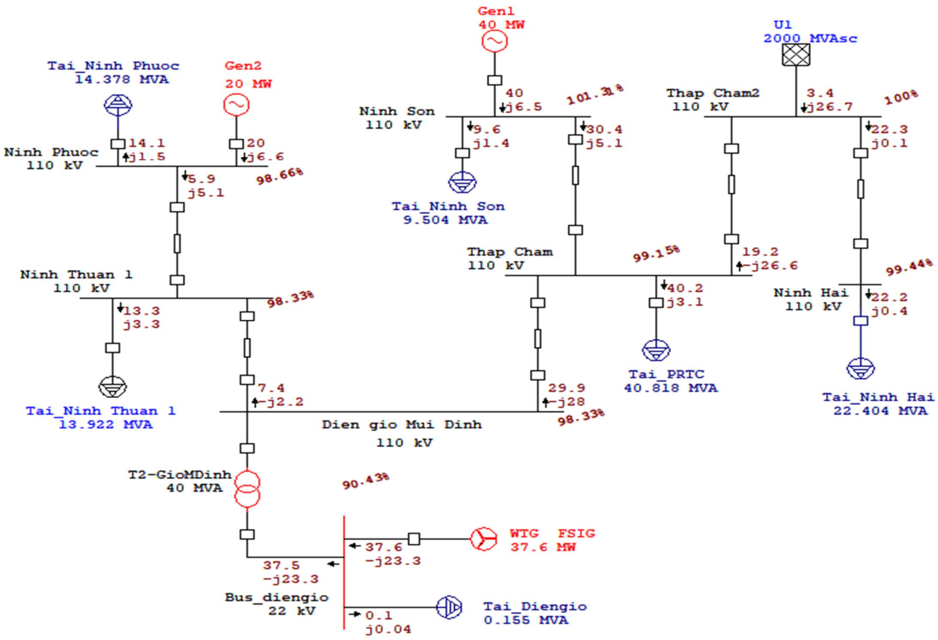
4. Simulation Results and Discussion

4.1. Steady-State Analysis

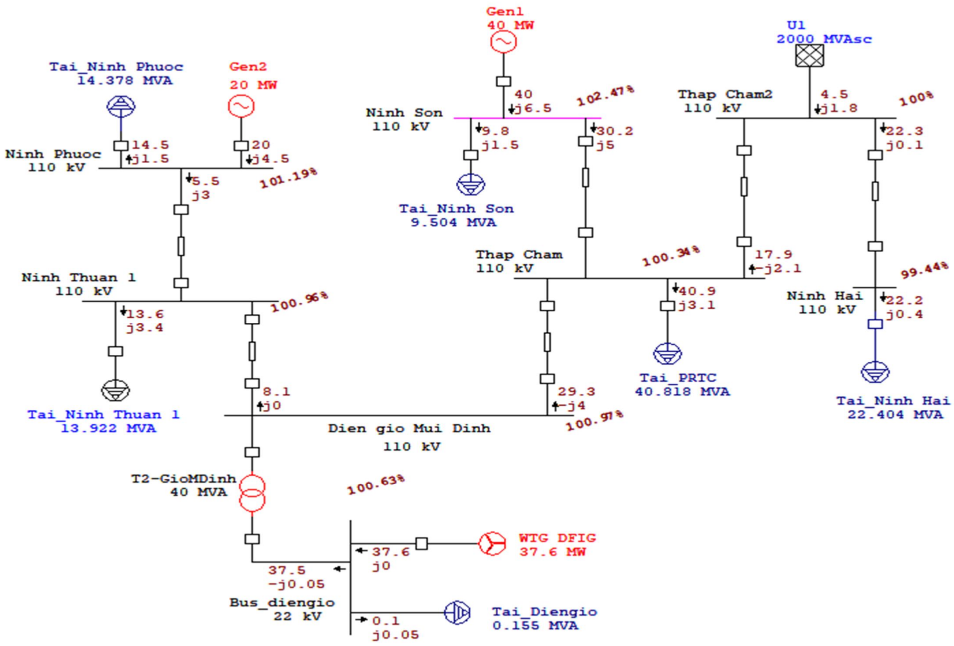
The power balance is evaluated to study the impact of wind power plants when integrated into the grid in the steady state (static mode). The distribution of power flows determines the grid stability. In this study, power flow was simulated for 5 cases: the grid without the intrusion of the Mui Dinh wind farm; the Mui Dinh Wind power source using an FSIG generator; the Mui Dinh Wind Power source using the LVSIG generator; the Mui Dinh Wind power source using the DFIG generator and the Mui Dinh Wind power source using the PMSG generator. An Enercon turbine (ENERCON turbine) is used in the simulation. The power flow results are shown in Fig. 8.



a) Without wind farm



b) The wind farm using a FSIG generator and the wind farm using a LVSIG generator



c) The wind farm using a DFIG generator and the wind farm using a PMSG generator

Fig. 8 – The power flows.

Fig. 8*a* shows the case without wind turbine penetration: the Da Nhim hydro power (Gen 1) and the Bac Binh hydro power (Gen 2) did not meet the demands of the load with a total capacity of 97.8 MW. Thus, 40.9 MW were taken from the U1 power system and 4.8 MVAr reactive power were transmitted in the grid (Table 4).

When the grid was penetrated by wind power of the FSIG and LVSIG generators, the power flow was similar, because these two asynchronous machines have the same operating principle, and LVSIG is an improved version of FISG with adjustable rotor resistor to change the speed. The weakness of these two generators is that they always consume reactive power from the grid. As can be seen from Fig. 8*b*, the wind power plant provides 37.6 MW, but also takes 23.3 MVAr from the grid to operate. As a result, the U1 system is required to provide 26.7 MVAr, but the power delivered to the grid is much less than in the case without the wind power plant in Mui Dinh. The difference amounts to around 3.4 MW.

The other cases, with DFIG and PMSG integrated into the grid, are shown in Fig. 8*c*. Those two generator types consume almost no reactive power thanks to the adjusting parts connected to the rotor. The synchronous generator PMSG almost does not need to consume power from the grid and can instead even return power back to the grid. The system offers only a small amount of 4.5 MW and 1.8 MVAr for stable operation in steady state. In addition, the DFIG and PMSG output voltage can be seen to reach a nominal value (100% equivalent to 22 kV), while the other two generators achieve only about 90 %.

It can be seen that if the grid is not connected to the wind power plant and the wind power plant uses DFIG and PMSG, the voltage values reach approximately 100%,…,102%. This allows for a smoother grid operation as well as a higher power factor (%PF) However, with the other two generators, the voltage and %PF values are lower, especially at the wind farm connection point (T2-GioMDinh), voltage values reached only about 90%.

Both the FSIG and LVSIG generators require a large amount of reactive power to operate. Hence, it is necessary to install compensating devices close to the wind power plant to increase the voltage of the bus.

Table 4

The Power Received From U1 and the Voltage at Bus_Diengio 22kV

Cases of wind farm	Power received from U1		Voltage (kV)	%PF (%)
	P_{U1}(MW)	Q_{U1}(Mvar)		
Without wind farm	40.9	–4.8	–	–
Using a FSIG and a LVSIG generator	3.4	26.7	19.89	100
Using a DFIG and a PMSG generator	4.5	1.8	22.14	85

4.2. Transient-State Analysis

Power flow analysis is not sufficient to evaluate the performance of the grid as well as the type of wind turbine generator with wind power penetration. This is because a grid does not always work in a fully steady state, it must also work in transient state. The transition is simulated for a total of 15 seconds, three-phase short-circuit faults were created at the Bus connection line between the Thap Cham Bus and Dien Gio Mui Dinh Bus at the 5th second and cleared after 150 ms. The behavior of all four generators types is again analyzed.

Fig. 9 shows the voltage response before and after the failure of the generators. Before the fault, both FSIG and LVSIG could not achieve 100% voltage, but only 90% while the DFIG and PMSG generators achieved the nominal value. Due to their ability to control the active power and the reactive power by using power converters, DFIG and PMSG can control the output voltage when they are connected to the grid. At the 5th second, when the fault occurred, the terminal voltage of all four generators went down dramatically: the terminal voltage of both DFIG and PMSG dropped to 20%, the two remaining generators dropped to 10%. 150 ms later, the FSIG terminal voltage increased to about 75% then dropped to 60% while the other three generators remained at their initial voltage values. The LVSIG takes 3 seconds to recover, while DFIG and PMSG recover almost immediately. Compared with the FSIG, LVSIG could adjust the speed through the wounded rotor, but the narrow range of regulation results in less reactive power consumption, so the voltage could recover but more time was required. The two remaining generators restored almost immediately. DFIG recovered very quickly but initially had a higher voltage overshoot than the PSMG but compensated it back to the initial value of only 0.2 seconds while PSMG needed more time.

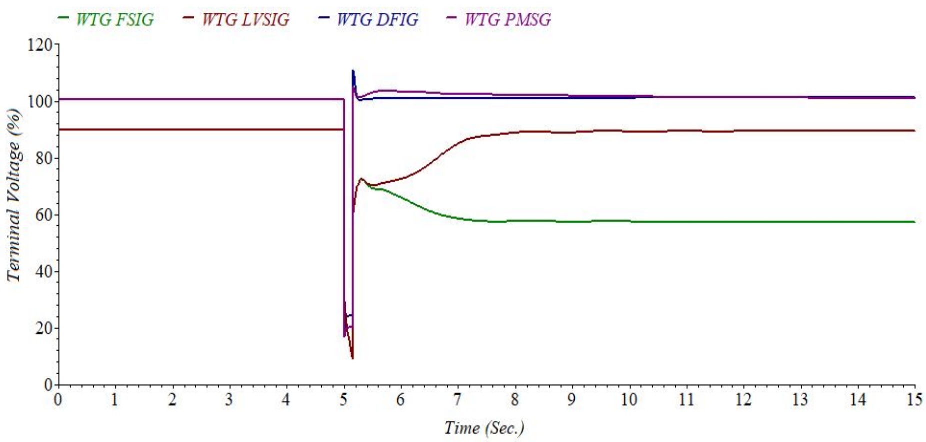


Fig. 9 – The response voltage of the 4 types of wind turbine generators.

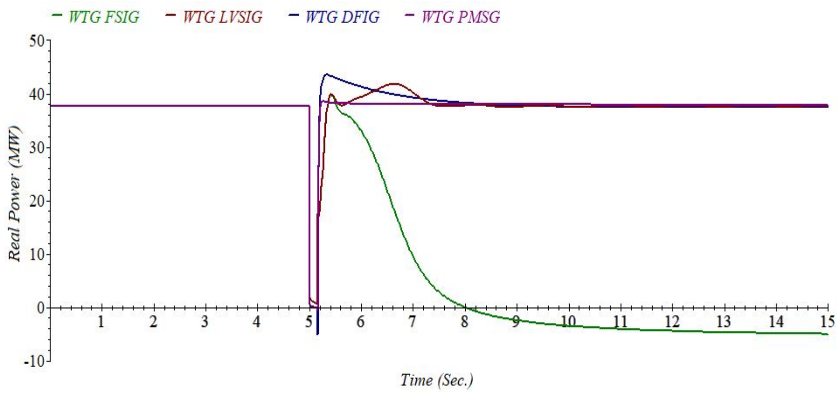


Fig. 10 – The real power characteristics of the generators.

Fig. 10 shows that before the fault, all the generators worked at the rated power of 37.6 MW. When the fault occurred, the active power of the four generators dropped sharply to zero. For the PMSG, it takes only 0.6 seconds to fully recover, showing the best performance of the four generators. Due to the support of the power converter, the two types of generator current could quickly return to their normal working value which caused the generator output power to reach the nominal value. The power of PMSG can be adjusted easily as the generator is fully connected to the converter, so the PMSG fluctuates very little and recovers quickly after the fault. For DFIG, only the rotor is connected to the converter. This makes the adjustment a little difficult and slower than for the PMSG model, taking about 4 seconds to recover completely. For LVSIG, after the fault, the power increased lower than for DFIG and PMSG, but the duration was extended to more than 5 seconds to recover. This is due to the limited rotor resistance range, so the generator current would decrease slowly after the fault and the active power would be kept at the high level and recover later. In contrast, FSIG completely collapsed when the power could not be recovered.

Before the fault, both FSIG and LVSIG consumed 23.3 MVAr of reactive power from the grid. When the fault occurred, the system voltage dropped, resulting in the power of all four generators to decrease to almost zero (Fig. 11). The electromagnetic force acting on the turbine shaft decreased while the mechanical torque of the turbine operated normally. This caused an imbalance in momentum. The change of generator power results in fluctuations in current and voltage, so that the electromagnetic momentum changes. After the fault, the two generators consume large amounts of reactive power to recover the voltage. However, only the LVSIG generator recovers, while FSIG remains unstable. FSIG consumes too much reactive power while the capacitor bank does not supply enough. In contrast, the LVSIG shows better response thanks to a better ability to adjust the speed through the change of the wounded rotor. The DFIG and PMSG continue to show stability when recovering very fast and take very small amounts of reactive power from the grid. PMSG even provides a large amount of the reactive power for the grid. This is achieved through the support of power converter devices for both DFIG and PMSG generators.

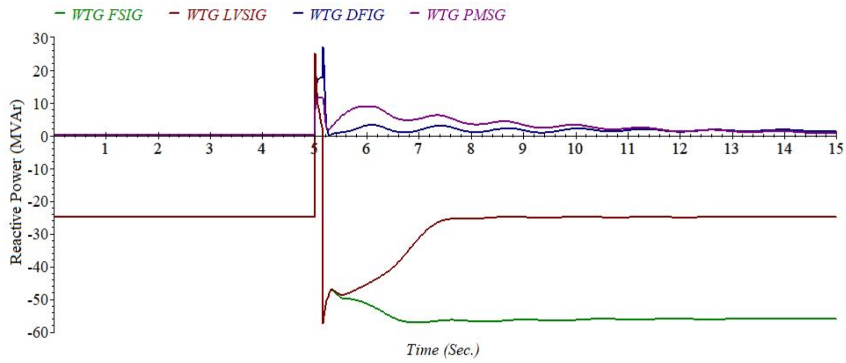


Fig. 11 - Reactive Power characteristics of the generators.

Similarly, when the fault happens, the speed of the generators tends to increase due to an imbalance of the electromechanical power. With FSIG generators excessive power leads to an increase in the generator speeds and reactive power consumption along with uncontrollable speed characteristics due to the imbalance of electromechanical power. This causes the FSIG not to be capable of recovering from the fault, which forces the generator to be cut off to ensure that the grid is able to operate. LVSIG generators can adjust the speed based on the rotor winding resistance, so that it is able to recover slowly. The other two types of generators meet power requirements thanks to the ability to adjust the speed, which balances the electromechanical power. The generator recovers in a short period of time. With the ability to adjust the speed and power, the PMSG continues to show very small speed changes and the best recovery of all generators when the fault occurs. DFIG has a greater speed variation than the PMSG, which is because DFIG only has a rotor connected to the converter and the structure is the asynchronous generator. This can be seen in Fig. 12.

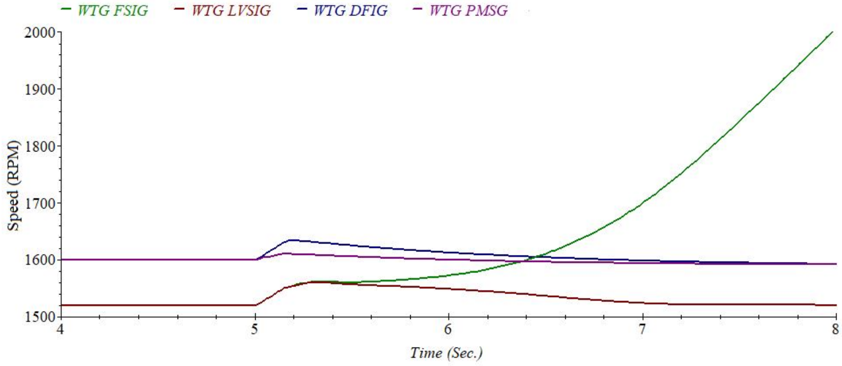


Fig. 12 – Speed of the generators.

In general, all responses occur in transition due to the fault. The DFIG and PMSG Wind Turbine Generators showed their superior ability, fast recovery and short transient time. As the FSIG cannot overcome the fault, it must be cut off from the grid, while the LVSIG shows slower recovery.

5. Conclusion

The FSIG and LVSIG turbine types absorb a large amount of reactive power from the grid, which is a cause of voltage instability. However, the LVSIG generators, with their ability to vary the rotor resistance to adjust the speed, partly improve on the FSIG's drawbacks. In fact, they still consume less reactive power from the grid than FSIG, which makes LVSIG recover faster. To reduce the amount of reactive power absorbed from the grid for the two types of generators, compensation devices can be used, such as Static VAR Compensators (SVC) or STATCOM (Static Synchronous Compensators).

DFIG and PMSG show superior performance with respect to the ability to operate as well as overcome the problem. Under the same grid conditions, the two types of generators are capable of almost instantaneous recovery, in particular, and do not need to consume reactive power from the grid when operating in steady state. PMSG generators show better ability to stabilize the speed and capacity to provide reactive power for the grid to recover voltage compared to DFIG. The grid integrated turbine generator provides higher stability and reliability. However, these types of generators are expensive.

PMSG has the problem of high construction cost. This can be remedied using the DFIG type or the development of LVSIG in combination with capacitor banks to increase the ability to overcome the fault of this type of generator. In Vietnam, renewable energy in general and wind energy in particular are increasingly developed. The Government of Vietnam has issued many policies to prioritize the development of this type of energy that shows promise of explosive growth in the future. In the term of building and developing wind power in Vietnam, with all the aforementioned advantages, we notice that the DFIG wind turbine type meets all technical requirements to ensure stable operation as well as improve the reliability of the grid. Furthermore, it is appropriate for economic conditions, while the PMSG type has even better features but at much higher costs.

Acknowledgements. This work is part of the R&D Project "Analysis of the Large Scale Integration of Renewable Power into the Future Vietnamese Power System" financed by Gesellschaft fuer Internationale Zusammenarbeit GmbH (GIZ, 2016-2018). Furthermore, Minh Quan Duong who is co-author of this research is funded by Funds for Science and Technology Development of the University of Danang under project number B2017-DN02-31.

This work has been funded by University POLITEHNICA of Bucharest, through the "Excellence Research Grants" Program, UPB – GEX 2017. Identifier: UPB- GEX2017, Ctr. No. 11/2017 (GREENHOUSE)".

REFERENCES

Abbasi M., Lam J., *A Step-up Transformer-less, ZV-ZCS High-Gain DC/DC Converter with Output Voltage Regulation Using Modular Step-up Resonant Cells for DC Grid in Wind Systems*, IEEE Journal of Emerging and Selected Topics in Power Electronics, **5**, 1102-1121 (2017).

Duong M.Q., Grimaccia F., Leva S., Mussetta M., Le K.H., *Improving Transient Stability in a Grid-Connected Squirrel-Cage Induction Generator Wind Turbine System Using a Fuzzy Logic Controller*, Energies, **8**, 6328-6349 (2015).

Duong M.Q., Grimaccia F., Leva S., Mussetta M., Ogliari E., *Pitch Angle Control Using Hybrid Controller for all Operating Regions of SCIG Wind Turbine System*, Renewable Energy, **70**, 197-203 (2014a).

Duong M.Q., Grimaccia F., Leva S., Mussetta M., Sava G., Costinas S., *Performance Analysis of Grid-Connected Wind Turbines*, U.P.B.Sci.Bull. Series C, **76**, *4*, 169-180 (2014b).

Jallad J., Mekhilef S., Mokhlis H., *Frequency Regulation Strategies in Grid Integrated Offshore Wind Turbines via VSC-HVDC Technology: A Review*, Energies, **10**, 1244 (2017).

Kies A., Schyska B., Thanh Viet D., von Bremen L., Heinemann D., Schramm S., *Large Scale Integration of Renewable Power Sources into the Vietnamese Power System*, Proc. of EGU General Assembly Conference, Vienna, Elsevier, 18972, 2017.

Kim C., Muljadi E., Chung C.C., *Coordinated Control of Wind Turbine and Energy Storage System for Reducing Wind Power Fluctuation*, Energies, **11**, 52 (2017).

Li W., *A Hybrid Fault-Tolerant Strategy for Severe Sensor Failure Scenarios in Late-Stage Offshore DFIG-WT*, Energies, **11**, 21 (2017).

Neagu B.C., Georgescu Gh., *Wind Farm Cable Route Optimization Using a Simple Approach*, 8th Internat. Conf. and Exposition on Electrical and Power Engng., EPE 2014, p. 1004-1009, Iaşi, România, 16-18 October 2014.

Pillai Anju G., Anju G. Pillai, Thomas P.C., Sreerenjini K., Sarin Baby, Tibin Joseph, Sasidharan Srecdharan, *Transient Stability Analysis of Wind Integrated Power Systems with Storage Using Central Area Controller*, Proc. of Emerging Res. Areas and Internat. Conf. on Microelectronics, Commun. a. Renewable Energy, Kanjirapally, IEEE, 1-5, 2013.

Tang Y., Dai J., Ning J., Dang J., Li Y., Tian X., *An Extended System Frequency Response Model Considering Wind Power Participation in Frequency Regulation*, Energies, **10**, 1797 (2017).

Venkata Yaramasu, Bin Wu, *Model Predictive Control of Wind Energy Conversion Systems*, ISBN: 978-1-118-98858-9, 2016.

Zhang S., Mishra Y., Shahidehpour M., *Fuzzy-Logic Based Frequency Controller for Wind Farms Augmented with Energy Storage Systems*, IEEE Trans. on Power Syst., **31**, 1595-1603 (2016).

* * * Circular No.*39*/2015/TT-BCT of the Government of Vietnam, 2015, Available online: http://www.moit.gov.vn.

* * * ENERCON turbine, Available online: https://www.enercon.de.

* * * VietNam Electricity and National Load Dispatch Centre of VietNam, 2017, Available online: http://www.evn.com.vn/ and http://www.nldc.evn.vn.t
* * * *Wind Resource Atlas of Vietnam*, 2011, Available online: https://www.esmap.org/ file-download/24912/67981.

STUDIUL COMPARATIV AL PERFORMANȚELOR DE FUNCȚIONARE A TURBINELOR EOLIENE
Studiu de caz pentru rețeaua electrică din regiunea Ninh Thuan – Vietnam

(Rezumat)

Sursele regenerabile de energie se dezvoltă rapid şi pe plan mondial reprezintă o tendință actuală de dezvoltare. Dintre toate sursele regenerabile, tehnologiile bazate pe vânt se dezvoltă cel mai rapid devenind astfel o sursă principală de energie pentru sistemele energetice viitoare. Cu toate acestea, interconectarea la rețeaua electrică a turbinelor eoliene poate genera multe probleme legate de stabilitatea rețelei în regimul tranzitoriu. Cercetările realizate până în acest moment nu au analizat, în functțe de tipul generatoarelor eoliene utilizate, modul diferit în care se pot dezvolta aceste probleme atunci când turbinele sunt integrate într-o rețea electrică existentă. Astfel, această lucrare analizează funcționarea, precum şi posibilitatea de trecere peste defect a patru tipuri de turbine eoliene integrate în rețeaua electrică din regiunea Ninh Thuan – Vietnam: generator electric asincron cu viteză fixă (Fixed-Speed Induction Generator – FSIG); generator electric asincron cu sistem semivariabil de reglare a vitezei (Limited Variable-Speed Induction Generator – LVSIG); generator electric asincron cu dublă alimentare (Doubly-Fed Induction Generator – DFIG); generatoar electric sincron cu magneți permanenți (Permanent Magnet Synchronous Generator – PMSG)**.**

În această lucrare, sunt simulate defecte ipotetice pentru a pune în evidență capabiltățile acestor turbine eoliene din punct de vedere al stabilității tranzitorii şi al circulației de puteri. Rezultatele obținute în urma simulărilor efectuate arată că turbina de tip DFIG şi PMSG prezintă un număr de avantaje remarcabile, cu revenire rapidă după apariția unor defecte, precum şi din punctul de vedere al menținerii nivelului de tensiune în limitele admisibile, în timp ce generatoarele de tip FSIG nu au capacitate de trecere peste defect. Capabilitatea de reglare a vitezei face ca generatoarele de tip PMSG, DFIG şi LVSIG să poată depăşi regimul tranzitoriu şi să funcționeze mai stabil decât generatorul de tip FSIG.