Effects of FSIG and DFIG Wind Power Plants on Ninh Thuan Power Grid, Vietnam

Minh Quan Duong[*], Thanh Viet Dinh, Van Tan Nguyen, Hong Viet Phuong Nguyen,
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Abstract— *Nowadays, the rising demand for electricity coupled with the lack of traditional forms of energy has become a global imperative. As a result, renewable energy is becoming a new development trend and is considered the best solution for electrical generation as well as environmental protection. Wind power takes the leading role with the fastest growth in renewable energy, promising to be a fundamental part of some national grids. However, there are many troubles for interconnection wind power to the main grid, especially many faults related to load flow and stability. The previous studies haven't concerned clearly the effects of different types of wind generators to actual grid integrated. In this paper, two types of wind generator including Fixed-Speed Induction Generators-FSIG and Doubly-fed induction generator –DFIG connected to Vietnam grid at Ninh Thuan province are studied in steady state as well as in Fault-Ride-Through. Fault assumptions in 2 cases steady-state and transient-stability. The results show that the DFIG could be more stable operation and faster recovery than FSIG due to its speed controller.*

Keywords— **DFIG; FSIG; Ninh Thuan-Viet Nam; Wind turbine generator.**

1. INTRODUCTION

Wind power, one of renewable energy sources, has been known as the fastest-growing energy sources all over the world [1] in the past few years. The wind power capacity summarized in Figure 1 [1] shows that the total accumulated installed wind power capacity was up to 487 GW in 2016 including about newly installed capacity of 55 MW in the year of 2016. It is predicted that the installed capacity of wind power plants over the globe will be reached 800 GW in 2021 [1]. However, extensive researches have shown that high penetration of wind power into the current power grid could causenegative effects on the grid stabilities. Such a large amount of wind power penetration may cause serious problems of power grid operation such as voltage instability, increase of fault currents and fluctuations of power frequency [2-3]. In fact, the more wind power plants are connected to the grid, the more difficult controlling the stability of the main grid as well as the whole system is [4-5]. Moreover, wind power plants are responsible not only for power supply but also for assuring the power quality required by Grid codes and the reliability for power consumers [6-7]. Figure 2 depicts a limit curve of voltage requirements according to Grid codes, which requires system faults causing a voltage drop below 15% are not allowed to exist longer than 150 ms.

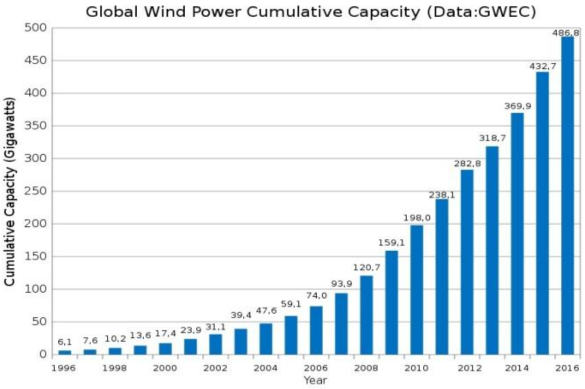

Fig.1. Total wind power capacity all over the world.

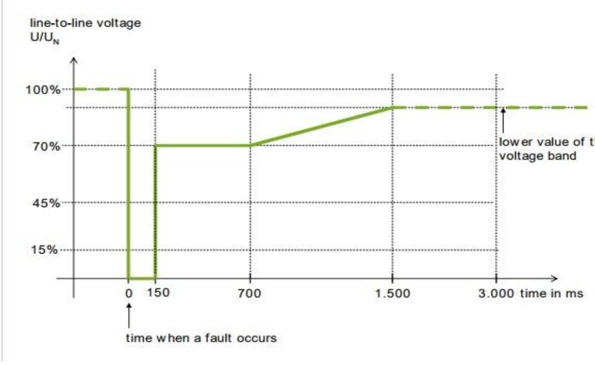

Fig.2. Limited voltage/time curve for wind power grid-on case.

For the grid–on case, extensive researches on wind turbine generators have been performed to meet the load demand with a good power quality. However, these results were only obtained from only IEEE standard grid such as 9 bus, 14 bus [8-10] or unreal model grids. This research presents effects of wind power generators to a real distribution network in Vietnam. The study focuses

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on two popular wind turbine types: FSIG (Fixed-Speed Induction Generator) and DFIG (Doubly-Fed Induction Generator) connected to Ninh Thuan distribution power system. These two wind turbine generators are simulated in ETAP simulation software to study the steady state and transient stability during their connection to Ninh Thuan distribution network. The simulated results are highly accurate as real data of network operation have been used [11]. The results shows how better wind turbine type copping with the steady state and the Fault-Ride-Through does.

2. NINH THUAN GRID:

Ninh Thuan is located in a dry area with the tropical monsoon climate. It is mostly sunny and windy during the whole year with the wind direction mostly is northeast and southwest. The average wind speed is from 3.3 to 8.9 m/s. The highest wind speed recorded in months and years is from 18 to 28 m/s. By 2020, the installed capacity of wind power plants will reach 220 MW with the corresponding produce of 482 million kWh. According to the World Bank [12], it is estimated that total potential wind power capacity in Ninh Thuan can be up to 10,447 MW. Consequently, it is identified as an important location to develop wind power plants by Vietnamese government. The wind potentials of Ninh Thuan province at the height of 65 m are summarized in Table 1.

Table 1. The potential wind velocity in Vietnam (via *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 (Over 8.0 m/s)
Potential (MW)	24.351	2.202	200	10

The ETAP software is widely used to simulate and analyze operation modes of wind power plants when they are connected to the power grid. Common analyzing methods are influences on steady state and power losses of the 110 kV grid as well as the possibility of overcoming faults. A diagram of the simulation grid based on real data provided by Electricity of Vietnam - EVN [13] is shown in Fig. 3.

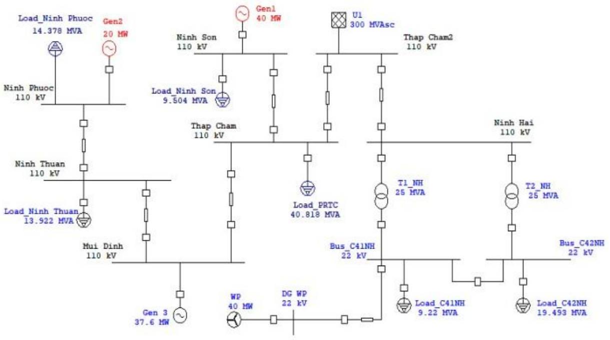

Fig.3. Ninh Thuan distribution grid map.

The studied power grid is supplied from three main sources: Da Nhim hydropower plant (Gen 1), Bac Binh hydropower plant (Gen 2) and Mui Dinh power plant (Gen 3) [14]. In addition, this grid is connected to the Vietnam national grid (U1) at Thap Cham 2 110 kV bus. The simulated wind power plant (WP) with installed capacity of 40 MVA is connected to the distribution grid of Ninh Thuan province at Ninh Hai 110kV substation. The construction plan has 2 stages: 3 turbines with nominal capacity of 7.8 MW are installed in Stage 1; the rest 13 turbines of 33.8 MW capacity is installed in Stage 2 to fulfill the total installed capacity of 40MW. The total investment of the plant is about VND1.523 trillion and is expected to be completed by October 2018.

The parameters of power sources, load capacity of the studied grid are summarized in Table 2 and 3.

Table 2. The parameter of power sources in Ninh Thuan province

ID	Rating
Gen 1	40 MW
Gen 2	20 MW
Gen 3	37,6 MW
WP	40MW

Table 3. The maximum load on Jun 17 2017

Load	Nominal Voltage (kV)	P (MW)	Q (MVAr)
Load_ PRTC	110	40.7	3.1
Load_ Ninh Son	110	9.4	1.4
Load_ Ninh Phuoc	110	14.3	1.5
Load_ Ninh Thuan	110	13.5	3.4
Load_C41 NH	22	9.2	0.6
Load_C42 NH	22	19.4	1.9

3. TWO TYPE MODELS OF WIND TUARBINE GENERATORS:

Fixed-Speed Induction Generator (FSIG):

A diagram of Fixed-Speed Induction Generator (FSIG) shown in Fig.4 has a constant speed and utilize a squirrel cage induction generator (SCIG) to work at the synchronous speed or nearly synchronous speed. It has the constant output frequency due to its capability to maintain its constant speed. [15-18].

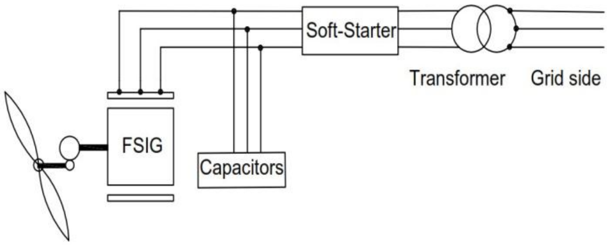

Fig.4: FSIG's Block Diagram.

Generated powers of FSIG can be modeled by following equations:

$$P_s = v_d i_d + v_q i_q \quad (1)$$

$$Q_s = v_q i_d - v_d i_q \quad (2)$$

where v_d and v_q are the voltages of generator according to the d-q axes, i_d and i_q are the currents of generator according to the d-q axes.

Doubly-Fed Induction Generator (DFIG)

DFIG includes stator windings connected directly to a constant frequency three-phase grid and rotor windings connected to the grid via an indirect frequency inverter [15], [18] as shown in Fig.5.

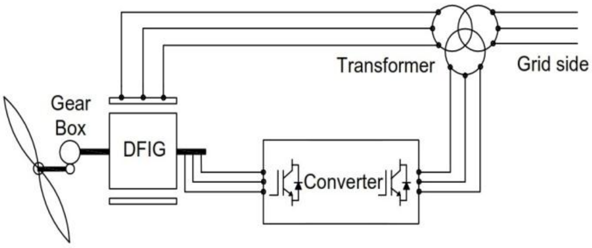

Fig.5: DFIG's Block diagram.

This mode uses the Variable Speed – Variable Pitch control method. It is increasingly popular in applying this method to the state-of-the-art DFIG wind turbines. In this method, the wind turbine is operated at variable speed with fixed pitch angle when the wind speed is below the nominal value and changeable pitch angle when it is over the nominal value.

The generated powers at the rotor side are given by:

$$P_r = v_{dr} i_{dr} + v_{qr} i_{qr} \quad (3)$$

$$Q_r = v_{qr} i_{dr} - v_{dr} i_{qr} \quad (4)$$

And the generated powers at the stator side are given by:

$$P_s = v_{ds} i_{ds} + v_{qs} i_{qs} \quad (5)$$

$$Q_s = v_{qs} i_{ds} - v_{ds} i_{qs} \quad (6)$$

The total output powers are given by:

$$P = P_s + P_r \quad (7)$$
$$Q = Q_s + Q_r \quad (8)$$

4. SIMULATION RESULTS AND DISCUSSION:

Steady-state

Power flow is one of the utmost factors to evaluate the importance of the wind power plants when they are integrated to the power grid. In this research, power flows are simulated for 3 cases: the current studied grid without WP; current studied grid with WP using an FSIG generator; current studied grid with WP using an DFIG generator. The optimal power flows and optimal voltages at simulated Buses are shown in Fig.6, Fig.7 and Fig.8.

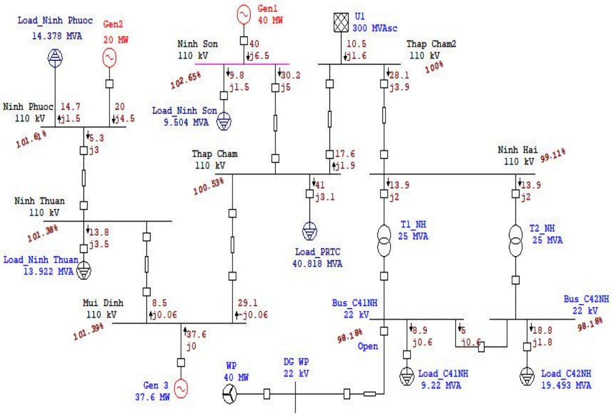

Fig 6. Current studied grid without WP.

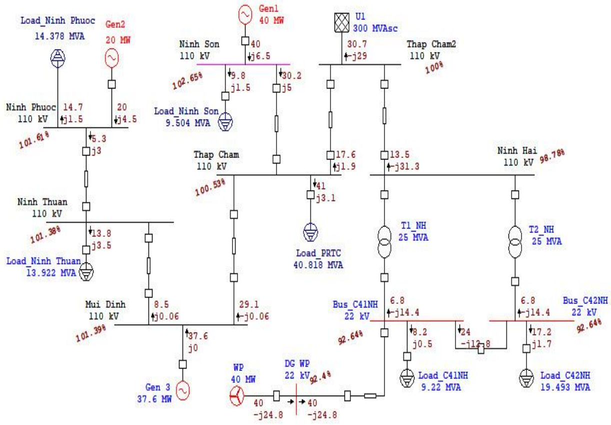

Fig.7. Studied grid with WP using FSIG generators.

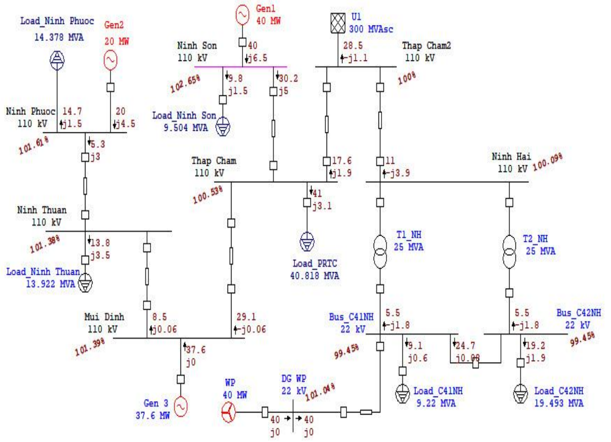

Fig.8. Studied grid with WP using DFIG generators.

The optimal power flows of the first case are detailed in Fig.6. The Nation Power Grid System of Bus U1 must supply 10.5 MW of active power and 1.6 MVAr of reactive power to fulfill the load demand. As can be seen in Fig. 6, the local supplies which are Da Nhim Hydro Power (Gen 1), Bac Binh Hydro Power (Gen 2) and Mui Dinh Hydro Power (Gen 3) are unable to meet the demand of local loads. It is inevitable to build new power sources connected to this grid to meet load demand and maintain the grid's stability and thus, wind power plants are absolutely a promising solution in this case.

For the second case, the existence of WP using FSIG generators in the studied power grid shows that requirements of local loads are fulfilled in an effective way. In addition, the national grid of Bus 1 provides 30.7 MW of active power and consumes 29 MVAr of reactive power. Fig.7 shows that when WP generates 40 MW, it also consumes 24.8 MVAr of reactive power from the studied grid. Due to the FSIG's construction which utilizes an asynchronous squirrel cage induction generator, FSIG machines always consume reactive power. This characteristic causes several troubles in maintaining the stability which is the unavoidable weakness of FSIG comparing with other types of generators.

In the last case, DFIG generators are used in the WP as shown in Fig. 8. They hardly consume or generate reactive power while they provide nominal active power of 40 MW to the connected grid. It can be explained clearly by the DFIG's ability of controlling the active power and reactive power independently via the power electronics controller connected between the Rotor and the Grid. The National Grid of Bus 1 just only provides 1.1 MVAr to operate stably in the steady state whilst receiving 28.5 MW of active power.

Regarding voltage's stability, the voltages of buses around the power plants reach high values which are approximately 98%-102% of the rated values in the first case of the studied grid without WP and the last case with WP using DFIG generators. These results bring advantages in the power grid operation processes. However, for the second case with WP using FSIG generators, the voltage values at Buses around the power plants are slightly lower (about 92,64%), and at the coupling point between WP and the studied grid, the voltage value is just 92.4% (equivalent to 20,23kV). This can be explained by huge amount of consumed reactive power of FSIG generators during their operation. Consequently, it is required to install compensate devices in the area near the wind power plants to increase the voltage values at Buses maintaining the stability of the power system.

Transient-state

During the power grid operation, it may experience the transient state due to unexpected factors. Hence, it is also important to assess the possibility to overcome system faults of these two wind turbine generator types. A three-phase fault simulator is created between Bus_WP and Bus_C41NH at the simulated time of 2 seconds. The fault is cleared after a duration of 150 ms by the line protection device. The recovery of the FSIG and DFIG generators is evaluated for a total simulation time of 5 seconds.

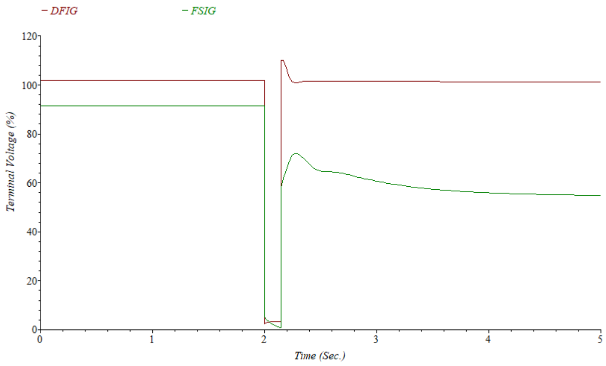

Fig.9. Response voltage of 2 types of wind turbine generator.

The voltage response of two types of generators before and after the fault is shown in Fig. 9. Before the fault occurs, the FSIG generator could not reach the rated voltage - just about 92% while the DFIG reaches 101% in the steady state. At the time of 2 seconds, the terminal voltage of the two types of machines falls dramatically when the three-phase fault occurs. While the FSIG terminal voltage drops to approximately zero, the latter generator remains at about 5%. After the fault duration of 150 ms, the DFIG generator terminal voltage almost immediately returns to its original value (after 200 ms) and remain stable afterwards. Meanwhile, the FISG terminal voltage only recovers at about 74% of the rated voltage but then decreases rapidly to 60%. This could be due to the fact that the FISG needs to consume more reactive power to recover from transient state which exceeds the grid's response in this short duration and thus, it causes the instability of the system. Such a large amount of consumed reactive power of FSIG generators can be seen in Fig.10. It is obvious that the FSIG consumes a large amount of reactive power from the grid (i.e. 25MVAr) before the fault. When the fault occurs, the generated power of the two types of generators decreases significantly as can be seen in Fig.10 due to the sudden voltage drop. At this moment, the mechanical torque of the turbine is still available but the electromagnetic torque applied to the turbine reduces dramatically which causes the torque imbalance. After the fault, FSIG generators have to receive more reactive power (the amount of reactive power consumption increases from 25MVAr to 50MVAr) to recover to normal operation whilst it lacks supporting equipment. Consequently, the FSIG fails to recover itself and drop its terminal voltage. On the other hand, the DFIG shows not only its fast recovery and stable operation after the fault, but also the generator also generates reactive power to the connected grid when the fault is over. Such a reactive power supply leads to the increase of DFIG generator terminal voltage as shown in Fig.10. It is evident that the role of integrated power electronics devices in DFIG generator systems is crucial in this case.

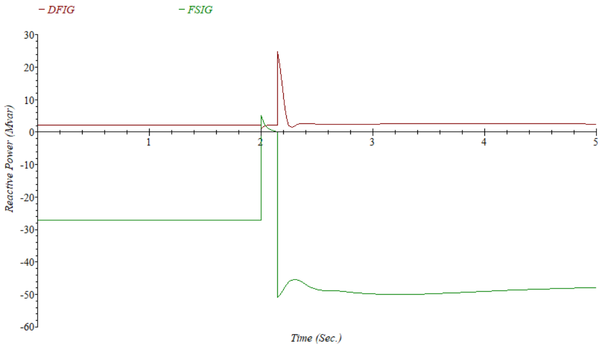

Fig.10. Reactive power characteristics of wind turbine generators.

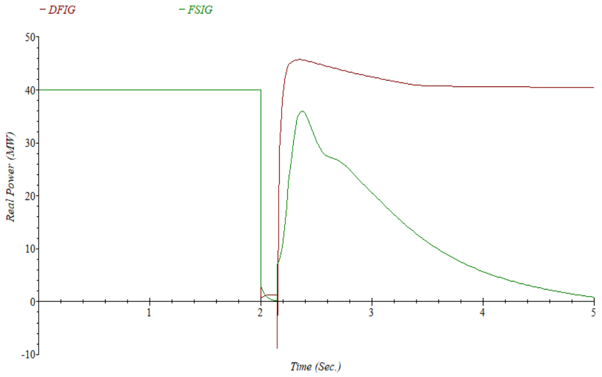

Fig. 11. Real power characteristics of wind turbine generators.

Fig.11 shows the real power characteristics of both types of generators. It is showed that two wind turbine generators operate at rated power of 40 MW before the fault. The output power of both generators decreases rapidly to zero when short-circuit is occurred. Regarding to DFIG generator, it consumes a small amount of active power from the grid to recover quickly to the initial stabilization (about 1.6 seconds) after the fault. This recovery capability is completely contrast in the case of FSIG. Since it is unable to control its rotor speed, the FISG generator only regains to the value of 36MW before it completely collapses.

Similar to the above cases, the electromechanical power imbalance in the both types of generators occurring during the fault causes a sharp increase in the terminal current. That leads to the escalation in speed of the two generators as shown in Fig.12. Thanks to the capability of speed control via the auxiliary equipment, DFIG can fulfill the power requirements and balance the power in the machine itself. As a consequence, the rotation speed is varied fairly during the fault and the machine recovers quickly after the fault. Regarding to FSIG, the generator speed increases continuously after the fault which results to an increase of reactive power absorbed by the generator. The main cause is that the FSIG cannot recover from fault situation due to the mechanical power imbalance together with the inability to control the rotor speed. Consequently, the FSIG must be disconnected from the power system to protect the generator itself as well as maintain the stable operation of the power grid.

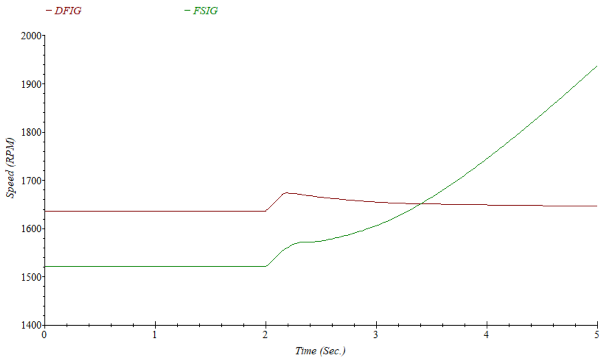

Fig.12. Speed characteristics of wind turbine generators.

In all studied cases above, the DFIG wind turbine generator always shows their remarkable fault-ride-through capability and regains the steady state quickly. Meanwhile, the FSIG generator gives completely negative results. It must be stopped and disconnected from the grid when a fault occurs to ensure stability of the system.

5. CONCLUSION

In short, WP reduces the transmission capacity of the national power system in the steady state in which the power supply to the local grid is always stable at 40MW. During its operation, the FSIG requires reactive power to operate normally. This requirement causes the increase of power losses in power grid and the voltage reduction at the coupling points as well as the reduction in power quality. To minimize these issues of FSIG, it is necessary to have the compensation equipment such as Static VAR Compressor or Static Synchronous Compensator when this type of wind power plant is connected to the grid. On the other hand, the DFIG generator shows its great capability to completely overcome these troubles.

In terms of transient stability, DFIG always shows the great capability of after-fault recovery over FSIG under the same grid condition. Thanks to the capability of adjusting the rotor speed and supplying reactive power to the grid through the power electronics converter, the output voltage and power of the DFIG generator are recovered quickly and maintain the stable condition during its operation after the fault. Hence, it is proved that the power grid integrated with wind turbine DFIG generator has higher reliability. On the other hand, all the responses from the FSIG shows that it completely collapses after fault due to the inability to adjust the generator speed as well as the excessive consumption of reactive power. Consequently, the FSIG must be shut down to ensure its safety issues and grid stability.

This research presents the comprehensive performance analysis of the FSIG and DFIG in two operation states to compare the advantages and disadvantages of each machine type. As a result, it is suggested that DFIG generators should be used rather than FSIG machines during wind power development in Vietnam due to its capability of fulfilling all technical requirements to ensure stable operation together with improving the reliability of the power grid.

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