INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
Mohamed A. Hazzaa et al., Vol.14, No.4, December, 2024

Maintaining System Stability with High Penetration of Wind Energy via Fault Ride Through (FRT) Criteria Development (System Operator Perspective)

Mohamed A. Hazzaa[*+], Sayed H. A. El-Banna[**], Dalal H. M. Helmi[*]

[*]Egyptian Electricity Holding Company, Ministry of Electricity and Renewable Energy, Cairo, Egypt

[**]Electrical Engineering Department, Faculty of Engineering, Al-Azhar University, Cairo, Egypt

e_mohamed2312@yahoo.com, sayedelbanna@hotmail.com, dalal_helmi@yahoo.com

[+]Corresponding author; Mohamed A. Hazzaa (e_mohamed2312@yahoo.com)

Received: 20.07.2023 Accepted:08.09.2023

Abstract- With the swift expansion of using renewable energies, especially wind parks, and its integration into the current transmission systems, the challenges that face the electric power system are becoming an interest. These challenges represent the stability and reliability of the power system due to suddenly cutting off wind energy from the system which requires setting robust grid requirements. Modern grid codes oblige wind generator manufacturers and operators to make technology with special control (ride-through disturbances) to minimize the disconnection of huge power generation due to transient disturbances. One of the most substantial grid incorporation requirements for wind energy is the fault ride-through (FRT). Until lately, the concentration was for the sake of the evolution of various wind turbine generator technologies to promote the FRT capabilities of wind parks without transmission system characteristics taking into consideration (e.g. contingencies, current protection schemes, system configurations…etc.).This paper presents the development of FRT criteria according to the characteristics of the Egyptian case under study for any wind parks intending to be linked with a high voltage transmission grid and also the effects on various types of protection due to the high penetration of wind energy according to the type of wind generator's technology. Dynamic studies on Egyptian Case modeling have been done which has a particular nature in that wind resources are highly concentrated in a specific region and no conventional power plants exist in such a specific region, also, the wind parks are interconnected to the load by a long extra high voltage (EHV) transmission line. Aggregated modeling of technologies of diverse wind generators in wind parks with studying various scenarios of disturbances has been done. The DIgSILENT_Power Factory software has been used for simulation to achieve the goal of the study.

Keywords: FRT, Wind Energy, S.C analysis, DIgSILENT_Power Factory, Doubly Fed Induction Generator (DFIG), FSIG

1. Introduction

Due to Global Warming, all countries around the world trend towards large-scale renewable energy resources to protect the environment through minimizing carbon radiation. As a result, of the high penetration of renewable energy the system operators face many challenges to maintain their grids stable and reliable. Renewable energy resources have acceptance compared with non-renewable energy [1– 6]. Wind power has become among the important new technologies inside electrical systems. Over the latter few years, energy generated from wind parks has been raised speedily. Wind energy has lately gained high importance in all countries worldwide and is considered among the essential renewable sources which give us both friendly environment and lower-cost power. As reported in Global Wind Energy Report 2023, it is foreseen to add more than 680 GW of novel installations offshore and onshore wind power in the upcoming five years up to 2027– which is about 136 GW of new constructions per year [7].

Referring to the New & Renewable Energy Authority's latter yearly report issued, the Republic of Egypt targets reaching around 42% of gross power generated from renewable by 2035 inclusive of 14% from wind.

Result to highly increase of wind energy in the power system; the grids face many challenges to ensure their stability and security. All of these because wind power is unstable (choppy) and available just over specific durations of the day. So, generation from wind may decline or be disconnected unexpectedly. Also, one of the other unparalleled matters concerning wind energy technology in Egypt is that most high wind velocity regions are located in the Gulf of Suez (at 280 km distance from the loads) and on two banks of the Nile River. Due to the high penetration of wind power concentrated in specific regions of the country and not geographically spread into the network all over the country and is integrated at definite points to high voltage power systems. All of this leads to several challenges and additional operational constraints. A grid code is a technical framework to be followed by transmission system operators (TSOs) and power plant operators; it intends to maintain grid reliability. Though in multiple countries, most desired grid codes regarding the integration of renewable energy have been specified, they are continuously upgraded as new control technologies are developed. In the following, some examples of previous research work tackling those challenges.

References [8, 9] define the wind-power integration rules of 12 countries, including Denmark, Ireland, the UK, and Germany. Therefore, the requirements of those countries for wind power integration into their national transmission grids. These requirements include reactive power control, frequency regulation, fault ride-through, power quality, and communication scheme Also, various issues like offshore wind parks, the ramp-rate limits, forecasting, and the future trends of grid codes.

Ref [10] presents a smart fault ride-through criterion for Wind parks that use Doubly Fed Induction Generators (DFIG) to achieve control in the real and reactive power throughout disturbances happening in the network. This leads to DFIG controlling the rotor and grid side converters during disturbances through its work in a smooth way, injecting reactive power to the network and reducing strain on power electronic converters therefore fulfilling stability for the grid. In ref [11- 13] a novel vigorous and efficient control design to alleviate voltage drops in a grid-integrated doubly fed induction generator (DFIG) wind energy conversion system without any further hardware in the system has been presented.

Ref [14, 15] presents a control scheme called swap which has suggested for permanent magnet synchronous generator-based wind parks grid-connected. During voltage dips at the point of common coupling (PCC), this scheme converts the wind turbine operation from maximum power point tracking (MPPT) mode to LVRT mode. The grid synchronization occurs by controlling active power to agree with grid current limits with reactive power injection to the grid according to the sag value. Moreover, the proposed technique uses the inertia of the generator rotor to store excess energy during voltage sags.

The important functions of protection schemes represent avoiding potential damage caused by incident faults and reducing the effects of these abnormal conditions on the other sound parts of the grid, consequently, limiting the negative impacts of faults on the service continuity and system stability and therefore, enhancing the reliability and dependability of entire power system. Till now wind parks utilize normal and non-integrated protection schemes which not convenient with their particular nature. Also, researches related to wind parks protection are still limited. The fault component-based protections are largely used in transmission systems protection, which is reliable when the positive and negative sequence impedances are nearly equal. But in power systems integrated with renewable energies, there is a difference between these impedances. So, it is important to study the adaptability of fault component protection [16- 18]. A modern communication-based duple time-current-voltage tripping (Dual−TCV) characteristic for directional overcurrent-based relays (DOCRs) which takes into consideration the FRT criteria of wind parks through taking rapid procedures for fault clearing in high voltage transmission systems, also digital overcurrent protection with non-standard characteristic [19- 22]. With increased connection of generation from wind within tightly interconnected grids, this can lead to gradually breakdown for the entire electric system. So, networks operators should set vigorous requirements within the grid code to ensure the integrity of the system.

The main contribution of this study focuses on avoiding disconnecting wind turbine generators during disturbances for a certain time through providing a FRT profile suitable to the characteristics and protection schemes of the power system under study and also, studying the effects on various types of protection due to the high penetration of wind energy according to the kind of wind generator's technology.

2. Technologies of Wind Turbine Generator & Ride Through Criterion

There are several kinds of wind generator technology worldwide fixed and variable speed (e.g. SCIG Type 1, 2 – DFIG Type 3 – FSFC Type 4). Currently, Egypt has approximately 1600 MW of wind parks in service and uses SCIG (Type 1, 2) – DFIG (Type3) technologies shown in Figure 1, and it targets to arrive around 42% renewable by 2035 including 14% from wind energy. Except for the control and technology strategies diversity according to every manufacturer, several dynamic and transient generator responses exist, even when making the differentiation in the same technology. So, a general model for a chosen technology isn't adequate to prove if the response of wind units achieves the grid code constraints, so it's a prerequisite to possess particular models as system operator demand [23].

Figure 2 shows the response of different technologies of turbine-generators under short circuit conditions on generator terminals. The foremost commonly used protection types in the case of large wind parks are distance, differential, and overcurrent protection schemes. These kinds of protection require various sensitive requirements to discover disturbance and send a signal to the protection device to work and isolate faults. Most modern protection necessitates a minimum current value (I pick up) to work. If the value of the short circuit current arriving at the protection relay is less than its lowest set value, the relay might not operate, and the fault stays unmonitored.

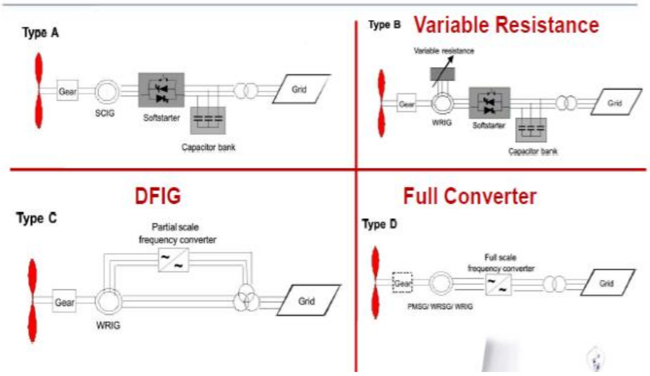


Fig.1. Wind Turbine Generator (WTG) classification based on applied technology [24]

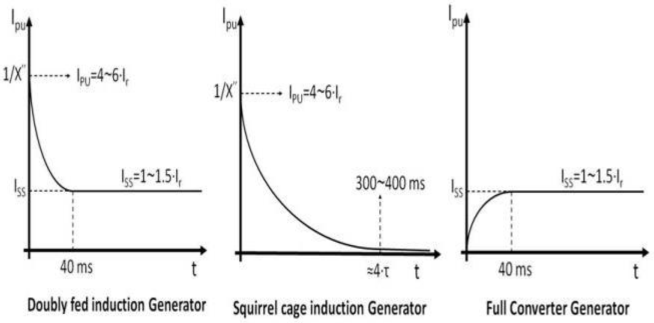
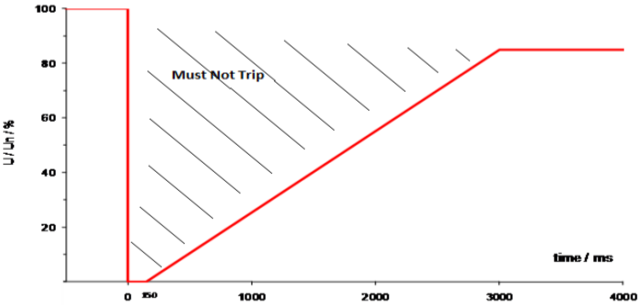


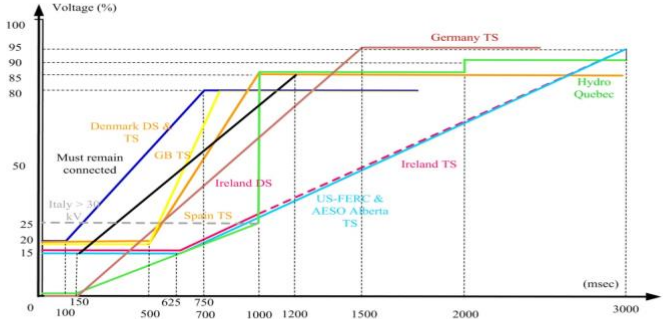
Fig.2. Generalized Fault Current Response of Wind Generators [23]

If a wind plant doesn't supply enough short circuit current as expected, the protection device may not sense the disturbance. Note, that Type-1 & Type-2 are considered the same because during simulation the resistance of the rotor is fixed [23].

Transmission grid codes set the technical requirements which should be achieved when connecting large-scale wind parks into the EHV power system. These grid codes stipulate that wind technologies should assist the control of transmission system's frequency and voltage, remarkably as worked in conventional plants, and also guarantee wind parks response during exceptional operating conditions of the system (like in status of voltage dips). The prime general requirements include FRT criteria, extended limits of voltage and frequency variance, control of active power, frequency, reactive power, power factor, and voltage organization abilities [25- 28]. Grid codes set the responsibilities of the wind park operators and the technical needs that wind turbine technology has to achieve to be interconnected to the high voltage system. Network code restrictions vary from one system to another and concentrate on the testing ways applied within the investigation of fault ride-through criteria of the turbine power plant and their response during a network disturbance. Fast growth in wind generation planned to be connected to the transmission system has driven the necessity to evolve rigorous code requirements for wind turbine plants to maintain the stability and security of electric systems. Owing to the varieties of technologies found in large wind parks increase the challenges regarding their ability to in-feed the short circuit location by enough fault current to boost the network during faults and make protection relays able to feel the fault and isolate the faulted area. References [19], [29- 33] show the challenges of large-scale renewable energies integration in power grids referring to different kinds of ride-through capabilities used in turbine Generator technologies. One of the various existed protections known as crowbars protection which comprises low-ohmic resistors that enter via electronic components to the rotor loop to dominate the high rotor current throughout the disturbance. The FRT profile as stated in the Egyptian wind code [34] and also, FRT profiles for many countries everywhere worldwide according to their grid codes [35] are shown in Figure 3.



(a) Fault ride through profile for Egyptian Wind Farm [34]



(b) Fault ride through profile for many countries [35]
Fig.3. FRT characteristics in Egyptian Grid Code and Worldwide

3. Case Study

3.1 Case Study characterization

A case study on a portion of the Egyptian electric grid has been simulated. The substantial objective of this research is to develop a fault ride-through (FRT) that suits with the state of the Egyptian High Voltage transmission grid. Also, the characteristics of different types of wind turbine generators during the disturbances, and the protection requirements due to large-scale wind parks integration have been modeled. Z1, Z2, Sho, Ga-Elz 220kV, and B-west 500kV substations are very near to areas where most of the large-scale wind generation concentrates. These wind parks are installed and concentrated at the Gulf of Suez (280 km distant from the load Centre) and are distributed on two banks of the Nile River. To formulate a FRT criterion convenient with a specific network, it is vital to understand the characteristics of that network. In this case study, a weak network where distant wind parks are connected to the EHV system has been chosen. All wind parks concentrate in specific regions far away from load center and aren't distributed over the entire network. To grasp the performance of different WTG technologies, a case study has been modeled to perform a comparative study for several WTG types. To assure an equitable principle of differentiation, all types of WTG are connected identically for similar network conditions. For developing all models, these different turbines models are collected as aggregated models (which means that wind park would be modeled by one equivalent model representing the entire wind park) using DIgSILENT_Power Factory software. A robust external grid with an elevated level of short-circuited has been used. Also, currently, there's no traditional generation near wind parks. The grid has 500 kV and 220 kV voltage levels. Some kinds of wind generators like SCIG (Types 1 & 2) and DFIG (Type 3) have been utilized.

There are diverse factors which may affect WTG characteristics and therefore, the short circuit current, e.g. short-circuit capacity of WTG, the long distance of WTG to the Point of Common Coupling (PCC), power system protection characteristics, level of voltage at the connection point, and power system characteristics at that faulted area of the network. To evaluate the fault ride-through capability used for each kind of Wind Park, there is a need to combine the voltage profiles of closed bus bars during the worst disturbance situation. The voltage profiles for these bus bars, i.e. Z1 (220kV), Z2 (220kV), Sho 220kV, Ga-Elz 220kV, and B-west 500kV are displayed for all five scenarios.

3.2 Wind Parks Modeling and Simulation

In this case study, 220 kV and 500 kV lines, distance protection (zone-based protection, and main protection with signaling) have been used five scenarios of three-phase faults have been simulated. The fault time in case of protection depending on the zone is 120 ms for zone-1 and 400 ms for zone-2 and for main protection is 120ms. For understanding and analyzing the performance of enormous wind parks regarding the WTG technology utilized, this study has been executed. So, the resultant fault current from every wind generator and voltage curves of each bus bar under study have been registered. The prime objective of the research is to develop a fault ride-through (FRT) that is appropriate to the state of the network under study. The reasons that have driven to evolve study cases of weak and independent connections are the nature of this case where just wind energy is connected to PCC and there are no traditional power plants near to this region. This study includes five different contingencies as follows: -

3.3 Results & Discussion

3.3.1 At normal operation:

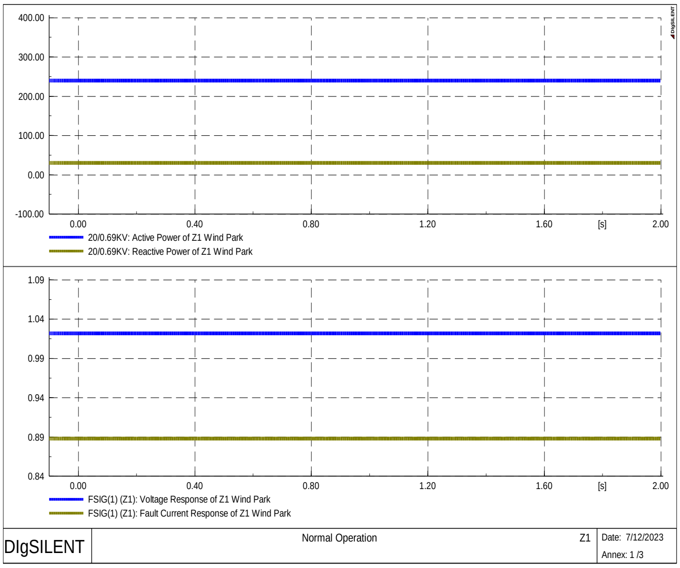


Fig.4. P, Q, V, and I at normal operation

3.3.2 Contingency one (F1)

A 3-phase short circuit on Z1-Ga_1 (220kv) high voltage transmission line has been implemented close to substation Z1 (220kV) at a distance of about 10%. This transmission line is protected by a zone-based protection scheme (distance protection without signaling). The voltage profile of the bus bars under study is indicated in Figure 6.

By looking at Figure 6, it is observed that the worst voltage level is on Z1 (220kV) prior Zone-1 protection works. The second bus bar affected is Z2 (220kV) then sho (220kV). The voltage at Z1 (220kV) and Z2 (220kV) gets back to 17% and 23% of its normal value after Zone1 protection is worked respectively. After Zone-2 protection works and the fault is fully removed, the voltage restores its value as soon as possible and gets back to its normal value.

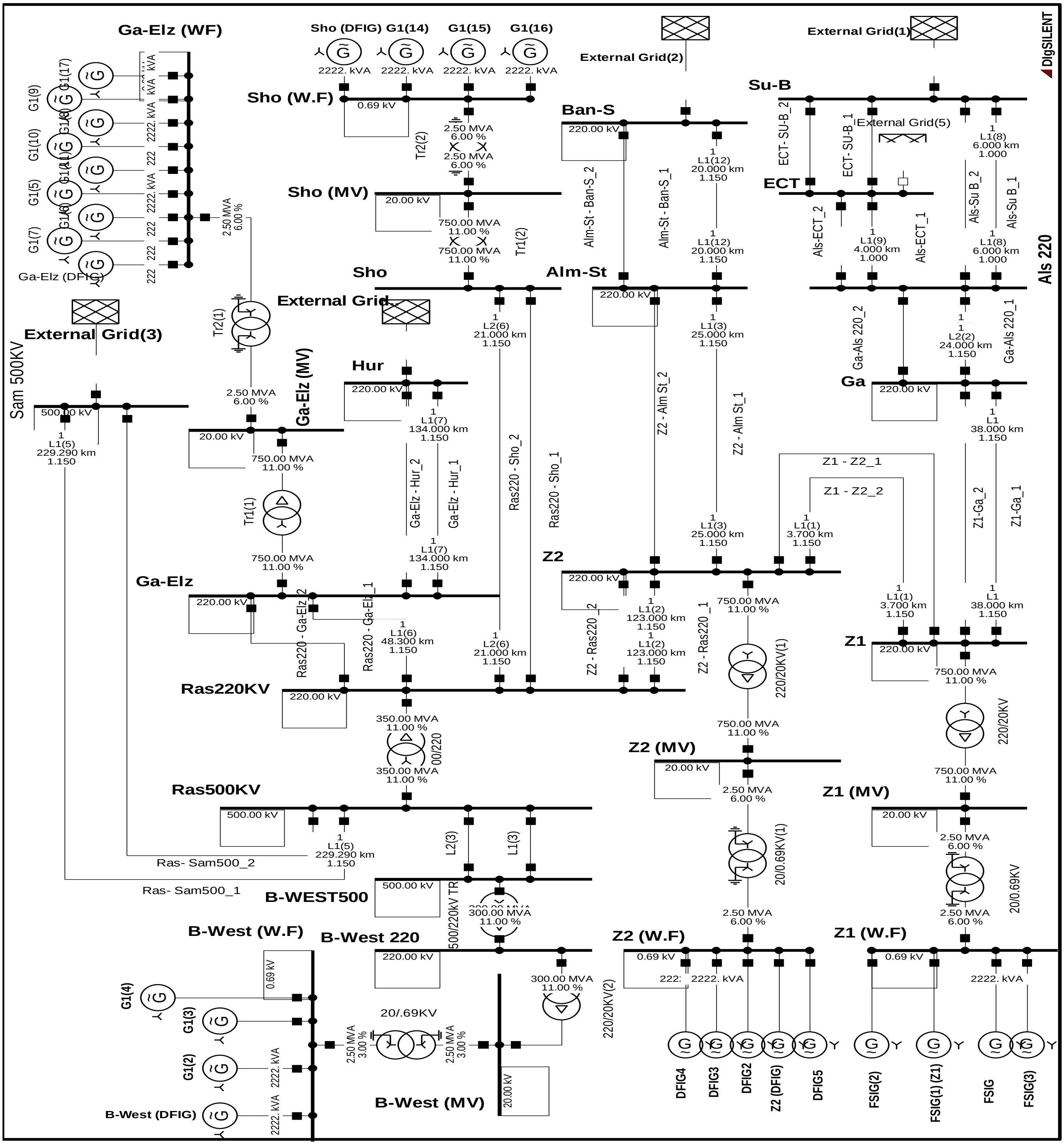


Fig.5. Case study for the wind parks connected to the Extra High Voltage (EHV) transmission grid

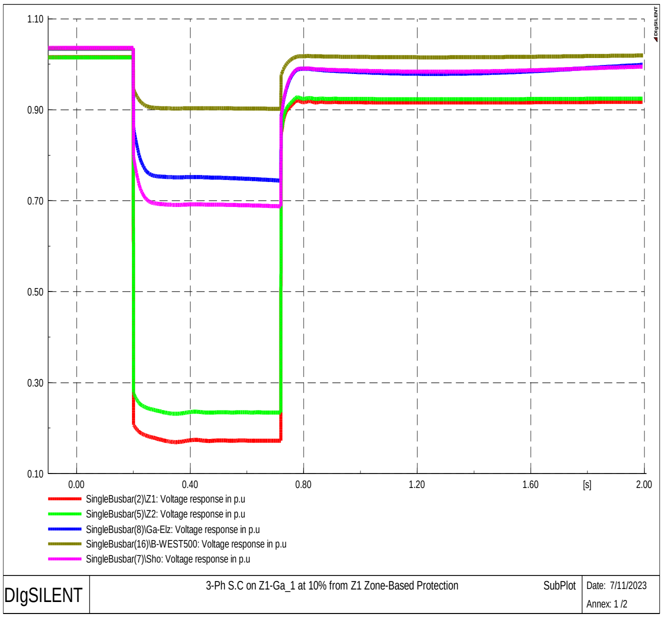


Fig.6. The voltage response of different bus bars under study

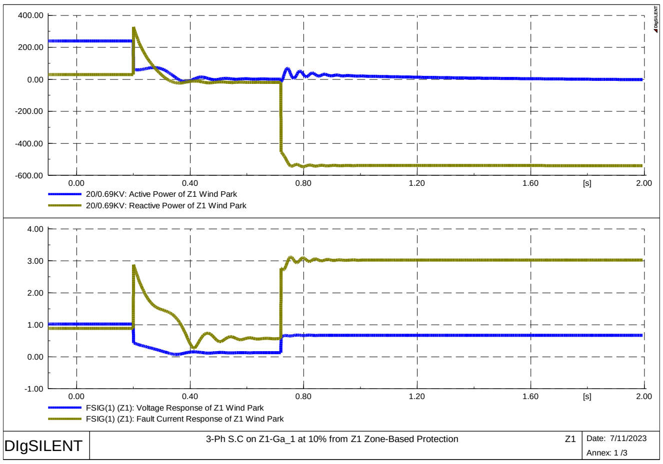


Fig.7. The active & reactive power output, voltage & current response of Z1 W.F

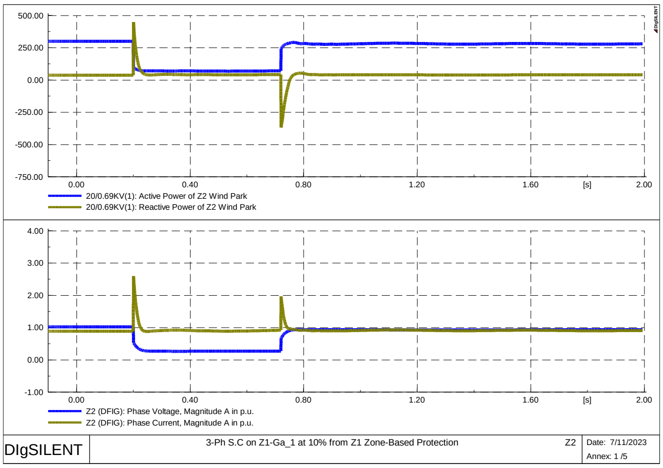


Fig.8. The active & reactive power output, voltage & current response of Z2 W.F

Figure 7 shows the active and reactive power, voltage, and current response of (FSIG) respectively during and post isolating the fault. Figure 8 shows the active and reactive power, voltage, and current response of (DFIG) respectively while and after clearing of the fault.

3.3.3 Contingency two (F2)

A 3-phase Short Circuit on Z2 –Alm-St_2 (220kV) high voltage transmission line has been implemented close to substation Z2 (220kV) at a distance of about 10%. This transmission line is protected by a zone-based protection scheme. The voltage profile of the bus bars under study is shown in Figure 9.

From the curve in Figure 9, it is observed that the worst voltage level is on Z2 (220kv) prior Zone-1 protection works. The next station affected is Z1 (220kV) then sho (220kv). The voltage at Z2 (220kV) and Z1 (220kV) get back to 12% and 15% of its normal value after Zone1 protection is worked respectively. After Zone 2 protection works and the fault is fully removed, the value of voltage is restored as soon as possible and gets back to its normal value.

The active and reactive power, voltage, and current response of (FSIG) respectively during and post-clearing of the fault are shown in Figure 10. Figure 11 shows the active and reactive power, voltage, and current response of (DFIG) respectively while and after fault clearing.

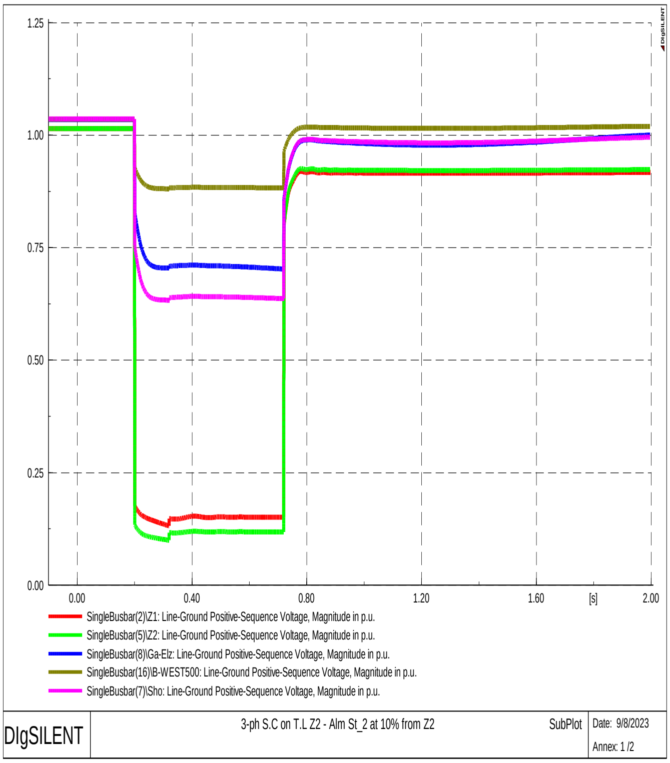


Fig.9. The voltage response of different bus bars under study

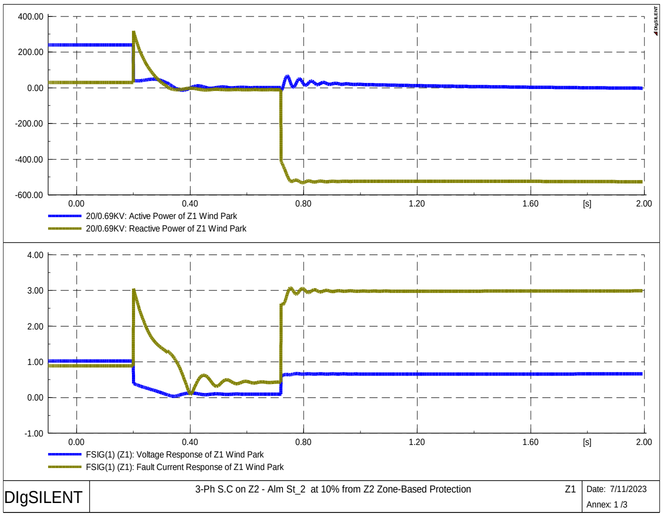


Fig.10. The active & reactive power output, voltage & current response of Z1 W.F

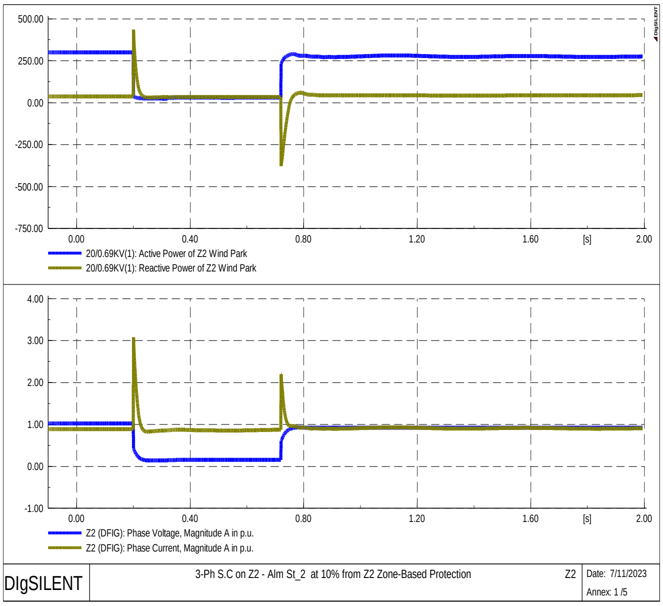


Fig.11. The active & reactive power output, voltage & current response of Z2 W.F

3.3.4 Contingency three (F3)

A 3-phase Short Circuit on Ras-Sho_1 (220kV) high voltage transmission line has been implemented close to substation sho (220kV) at a distance of about 10%. This transmission line is protected by a Zone-based protection scheme. The voltage profile of the bus bars under study is indicated in Figure 12.

From the curve in Figure 12, it is observed that the worst voltage level is on Sho (220kV) substation prior Zone-1 protection working. The next station affected is Ga-Elz (220kV) then B-West (500kV). The voltage at Sho (220kV) and Ga-Elz (220kV) gets back to 4.1% and 54% of their normal value after Zone1 protection is worked respectively. After Zone 2 protection works and the fault is fully removed, the value of voltage is restored as soon as possible and gets back to its normal value.

Figure 13 shows the real and reactive power, voltage, and current response of DFIG in sho W.F respectively while and after fault clearing. Figure 14 shows the real and reactive power, voltage, and current response of DFIG in Ga-Elz W.F respectively while and after fault clearing.

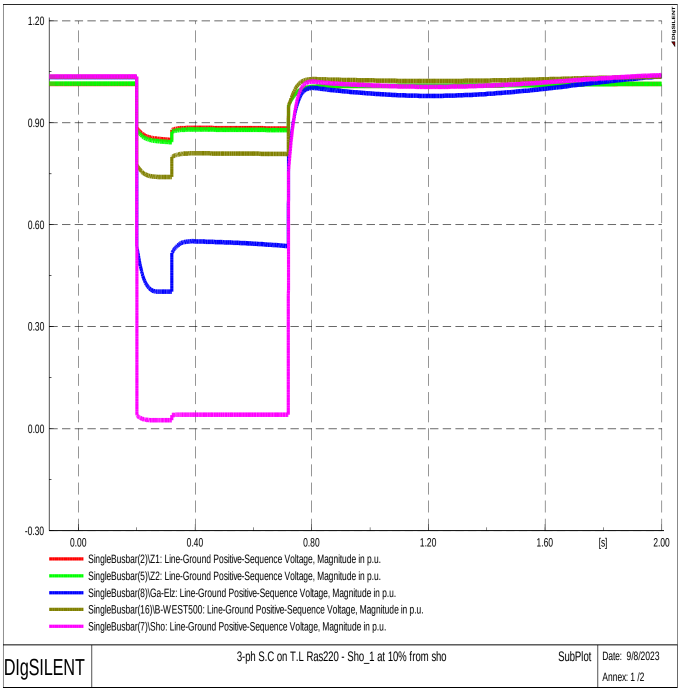


Fig.12. The voltage response of different bus bars under study

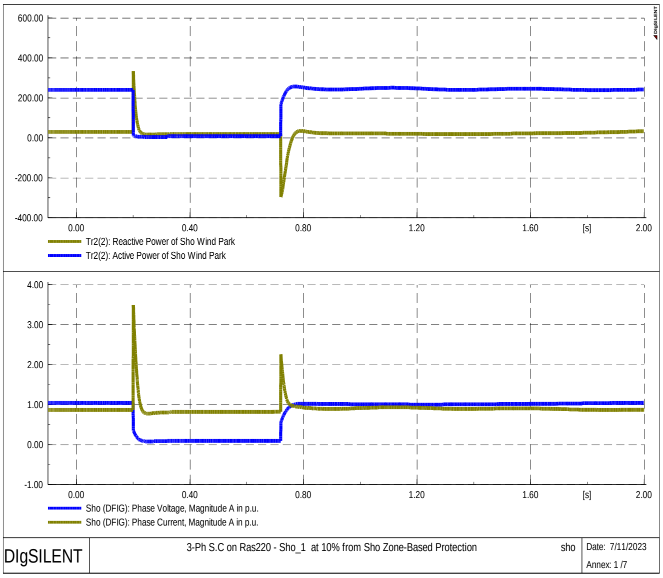


Fig.13. The active & reactive power output, voltage & current response of sho W.F

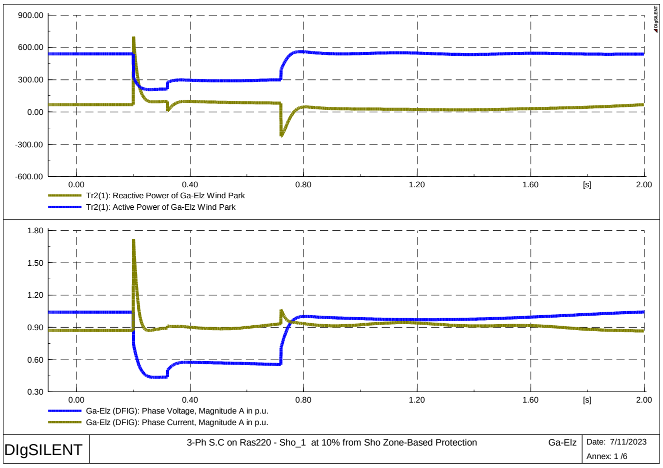


Fig.14. The active & reactive power output, voltage & current response of Ga-Elz W.F

3.3.5 *Contingency four (F4)*

A 3-phase Short Circuit on Ras-Ga-Elz_2 (220kV) high voltage transmission line has been implemented close to Substation Ga-Elz (220kV) at a distance of about 10%.This transmission line is protected by a Zone-based protection scheme. The voltage profile of the bus bars under study is indicated in Figure 15.

By looking at the curve in Figure 15, it is observed that the worst voltage level is on Ga-Elz (220kV) prior Zone-1 protection works. The following bus bar affected is Sho (220kV) then B-West (500kV). The voltage at Ga-Elz (220kV) and Sho (220kV) gets back to 8.9% and 61% of its normal value after Zone-1 protection is worked respectively. After Zone-2 protection working and the fault is fully removed, the value of voltage is restored as soon as possible and gets back to its normal value.

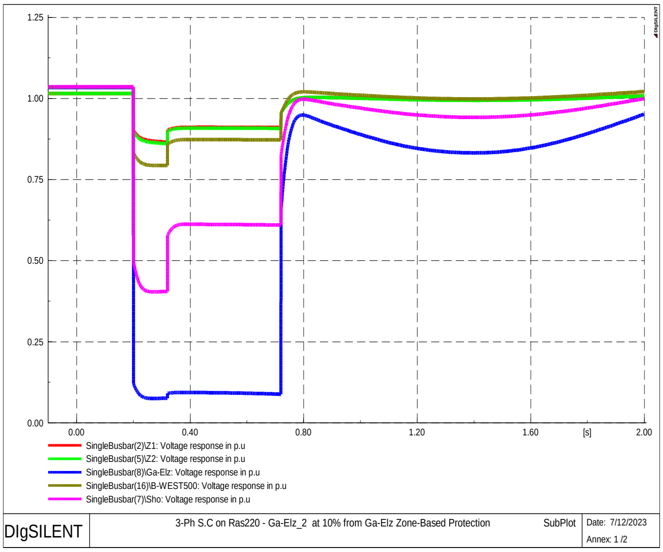


Fig.15. The voltage response of different bus bars under study

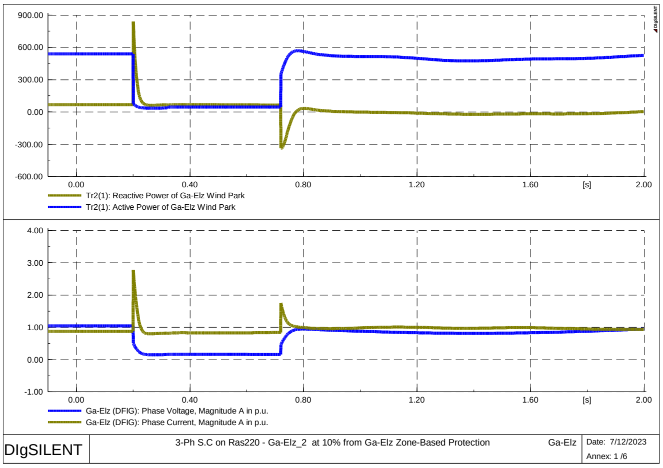


Fig.16. The active & reactive power output, voltage &current response of Ga-Elz W.F

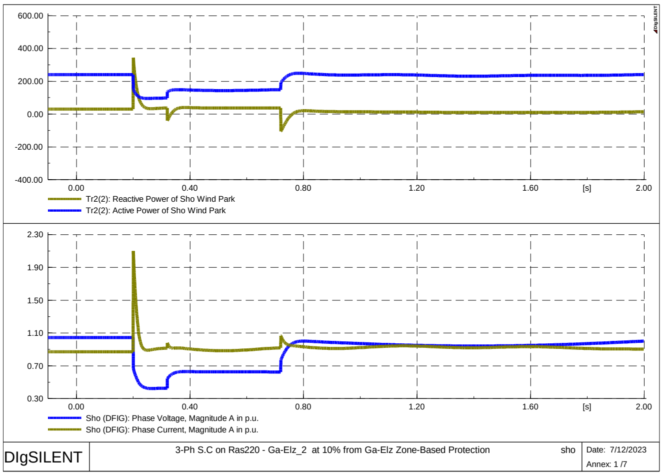


Fig.17. The active & reactive power output, voltage & current response of sho W.F

Figure 16 shows the real and reactive power, voltage, and current response of DFIG in Ga-Elz W.F respectively while and after fault clearing. Figure 17 indicates the real and reactive power, voltage, and current response of DFIG in Sho W.F respectively while and after fault clearing.

3.3.6 *Contingency five (F5)*

A 3-phase Short Circuit on Ras-Sam500_1 (500kV) high voltage transmission line has been implemented close to substation Ras (500kV) at a distance of about 10%. A signaling protection scheme (distance protection with signaling) is applied to this line. The voltage profile of the bus bars under study is indicated in Figure 18.

By looking at the curves in Figure 18, it is observed that the worst voltage level is on B-West (500kV) and reaches 10.4% of its nominal value. The following bus affected is Sho (220kV) then Ga-Elz (220kV). After protection works and the fault is fully removed, the voltage restores rapidly and gets back to its normal value.

Figure 19 indicates the real and reactive power, voltage, and current response of DFIG in B-West W.F respectively while and after fault clearing. Figure 20 shows the real and reactive power, voltage, and current response of DFIG in Sho W.F respectively while and after fault clearing.

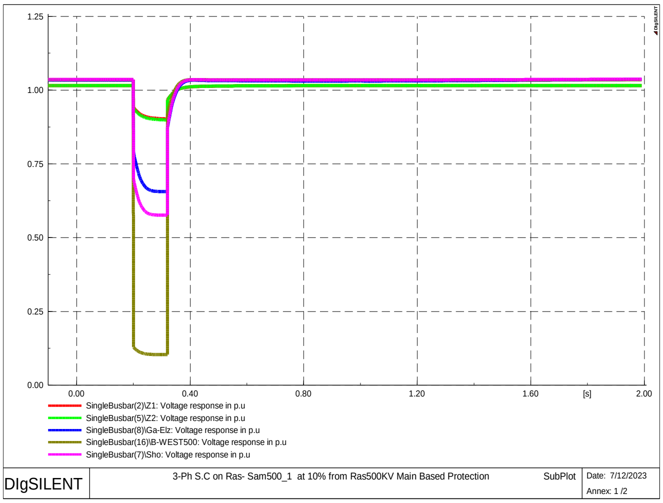


Fig.18. The voltage response of different bus bars under study

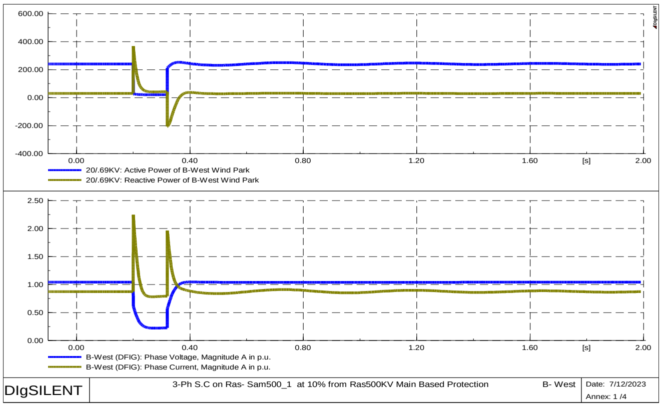


Fig.19. The active & reactive power output, voltage & current response of B-West W.F

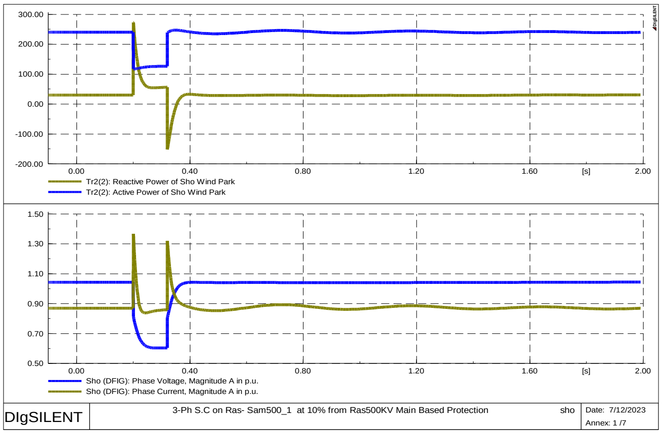


Fig.20. The active & reactive power output, voltage & current response of sho W.F

220 and 500 KV transmission voltages are levels of voltages used in the network under study. Five bus bars and various kinds of protection schemes were selected. Five contingencies have been formed. Finally, different voltage profiles in figures 6, 9, 12, 15, and 18 could be incorporated with each other to gain the singular ultimate voltage duration profile suitable to the current study case and should be obliged for all generation companies desire connecting to the high voltage power system achieving this curve.

3.3.7 *Reactive Power Injection to Support the electrical system during disturbances*

One of the utmost important things is grid support during disturbances, especially in weak grid regions. Reactive power absorption from the Grid could take place in most of the older kinds of wind turbine generator technologies and therefore, need supplemental compensation devices at the wind power plant, during the disturbances. It is observed from Figure7&10 that the reactive power dips sorely during the disturbances additionally, the FSIG sucks a reactive power from the network, therefore, effects on the voltage level at the point of common coupling. Serious events may happen because of excess voltage dip at PCC that may drive to blackout or partial black-out. Figures 8, 11, and 13 show the variance between FSIG and DFIG regarding the reactive power support.

3.3.8 *Effects of diverse generator technologies on protective relays*

The chart below presents the summary of protection performance issues for WTG technologies. After studying the current responses of DFIG (Type-3) technology obtained in Figures 8, 11, 13, and 14 found that distance relays may not face any problems due to the inception current value being high sufficient to make distance protection work in the first Zone. After a little time, the current declines rapidly to a rated value, capable of realizing second Zone and third Zone activation. Differential protection will not counter any issues due to the capability of the initial current to activate the relay. Over- current protection may counter problems due to time delays for protection coordination and the decaying response of WTG.

On the other side after examination of the current response of FSIG (Type 1, 2) technology shown in Figures 7 and 10, it's noted that distance relays may not face any problems due to the initial current value being high enough to make distance relays work in Zone-1. But after a little time, the current declines rapidly to a small value not sufficient to fulfill Zone-2 and Zone-3 working. Differential protection will not have any issues due to the capability of the initial current to activate the relay. Over-current protection will face problems due to time delays in protection coordination

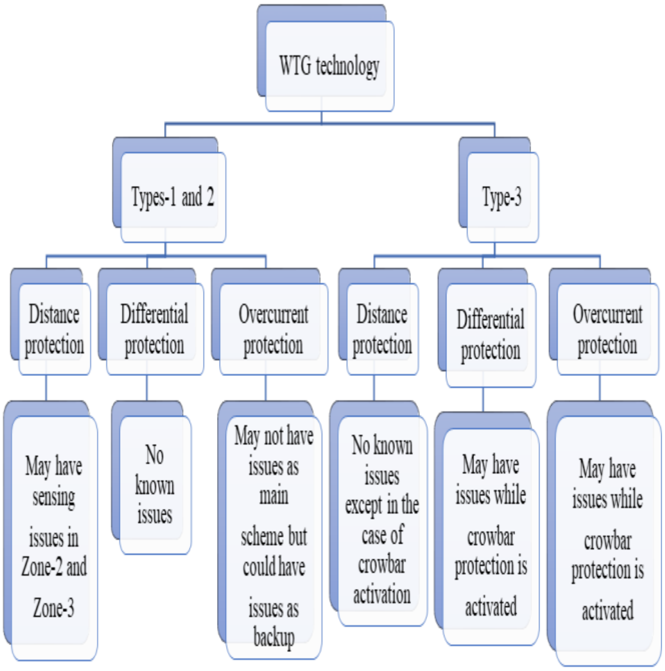


Fig.21. Summary of protection performance issues for WTG technologies

Also, after studying the requirements of the Grid Code, it is noted that the FRT requirements are not totally coordinated with under voltage protection as indicated in figure 22 i.e. for some specific cases, the under-voltage relay may trip before the FRT requirement is completely fulfilled.

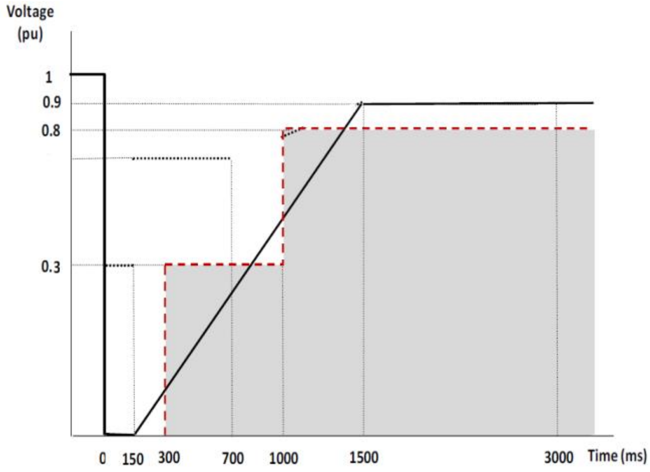


Fig.22. Under voltage and FRT co-ordination in Egypt

4. Conclusions

Due to the growing wind energy connected to the electric system, the decrease in cutting off large wind parks is requisite to retain a power system that is reliable and stable as possible. So, supporting the control system of wind park's turbines with adequate Fault Ride Through (FRT) suitable to power system characteristics, its contingencies, and characteristics of the current protection system, is highly significant.

This research focused on the impact of the connection of huge wind parks to the power system and also, the development of FRT criteria for every wind generation intended to be incorporated with the high voltage power system through dynamic studies on the Egyptian case model where wind speed is high in a specific area and no conventional generation in that regions, additionally, the wind energy linked to the load via long transmission line. Representing wind parks as aggregated models containing various wind generator technologies has been done along with studying various kinds of disturbances.

The Results obtained from the study have been used to analyze the voltage levels at various bus bars to obtain the ultimate voltage versus time curve which is adequate with the network state under study, its contingencies, and current protection system characteristics. The study has shown that the DFIG technology used is better than FSIG technology especially during and after fault clearing because the FSIG technologies affect the protection relays.

Also, the research showed that the grid code should be reviewed considering the total usage of Fault Ride Through features that existed within DFIG and ensuring the total integral among these features and protective relay settings. Therefore, a review of the grid code should be accomplished. Our recommendation for the future works is enhancement of the simulation model using real system events captured by disturbance records to improve the model capabilities. In addition, use different wind turbine models from various wind turbine suppliers at different renewable energy penetration levels to ensure these turbines comply with code requirements.

References

[1] N. Ahire, S. Paul, Z. H. Rather, "Enhancement of Transmission Systems Operational Condition in a Large-Scale Wind Integrated Power Systems Against Extreme Weather Events",10th International Conference on Smart Grid(icSmartGrid),DOI:10.1109/icSmartGrid55722.2022.9848779, Turkey, 27-29 June 2022.

[2] I. N. Muisyo, C. M. Muriithi, and S. I. Kamau, "Enhancing low voltage ride through capability of grid connected DFIG based WECS using WCA-PSO tuned STATCOM controller," Heliyon, DOI: 10.1016/j.heliyon.2022.e09999, vol. 8, no. 8, 2022.

[3] F. M. Gebru, B. Khan, and H. H. Alhelou, "Analyzing low voltage ride through capability of doubly fed induction generator based wind turbine", Comput. Electr Eng, DOI: 10.1016/j.compeleceng.2020.106727vol. 86, 2020.

[4] J. X. Jin, R. H. Yang, R. T. Zhang, Y. J. Fan, Q. Xie, and X. Y. Chen, “Combined low voltage ride through and power smoothing control for DFIG/PMSG hybrid wind energy conversion system employing a SMES-based AC-DC unified power quality conditioner,” International Journal of Electr. Power Energy System, DOI: 10.1016/j.ijepes.2020.106733, vol. 128, 2021.

[5] R. Hiremath and T. Moger, “Comprehensive review on low voltage ride through capability of wind turbine generators,” Int. Trans. Electr. Energy Syst., 2020, DOI: 10.1002/2050-7038.12524, vol. 30, no. 10, pp. 1–39.

[6] Z. Chen, S. Member, J. M. Guerrero, and F. Blaabjerg, “A review of the state of the art of power electronics for wind turbines,” IEEE, Trans. Power Electronics, DOI: 10.1109/TPEL, vol. 24, no. 8, pp.1859-1875.

[7] GWEC, “Global Wind Energy Council, Global wind report 2022,” Wind energy Technol., p. 75, 2022, [Online]. Available: https://gwec.net/global-wind-report-2022/.

[8] Y. K. Wu, S. M. Chang, and P. Mandal, “Grid-Connected Wind Power Plants: A Survey on the Integration Requirements in Modern Grid Codes”, IEEE Transactions on Industry Applications, DOI: 10.1109/TIA.2019.2934081, vol. 55, no. 6, pp. 5584 - 5593, 2019.

[9] T. K. Vrana, D. Flynn, E. Gomez-Lazaro, J. Kiviluoma, D. Marcel, N. Cutululis, J. C. Smith “Wind power within European grid codes: Evolution, status and outlook”, Wiley Interdisciplinary Reviews: Energy and Environment, DOI: 10.1002/wene.285, vol. 7, no. 3, 2018.

[10] C. R. Raghavendran, J. P. Roselyn, and D. Devaraj, “Development and performance analysis of intelligent fault ride through control scheme in the dynamic behaviour of grid connected DFIG based wind systems”, Energy Reports, DOI: 10.1016/j.egyr.2020.07.015, vol. 6, pp. 2560–2576, 2020.

[11] S. A. E. M. Ardjoun, M. Denai, and M. Abid, “A robust power control strategy to enhance LVRT capability of grid-connected DFIG-based wind energy systems”, Wind Energy, DOI: 10.1002/WE.2325, vol. 22, no. 6, pp. 834–847, Jun. 2019.

[12] M. Colak, and S. Balci, " Intelligent Techniques to Connect Renewable Energy Sources to the Grid: A review", 9th International Conference on Smart Grid, pp. 179-185, 2021.

[13] E. Bekiroglu, M. D. Yazar, "Improving Fault Ride Through Capability of DFIG with Fuzzy Logic Controlled Crowbar Protection", 11th International Conference on Renewable Energy Research and Application (ICRERA), Turkey, 18-21 September 2022.

[14] R. A. Ibrahim, and N. E. Zakzouk, “A PMSG Wind Energy System Featuring Low Voltage Ride Through via Mode Shift Control”, Appl. Sci, DOI: 10.3390/app12030964, vol. 12, no. 3, 2022.

[15] M. Colak, I. Cetinbas, and M Demirtas, " Fuzzy Logic and Artificial Neural Network Based Grid-Interactive Systems for Renewable Energy Sources: A Review", 9th International Conference on Smart Grid, pp. 186-191, 2021.

[16] C. Q. Wang, G. B. Song, and Q. Y. Shen, “Adaptability analysis for fault component protection under large scale wind power penetration”, 12th IET Int Conference. Dev. Power Syst. Prot. DPSP 2014, Copenhagen, pp. 1–4, 31 March - 03 April 2014.

[17] J. Wang, “Impact on Power System Protection by a Large Penetration of Renewable Energy Sources”, 18th Wind Integration Workshop, October 2019.

[18] M. A. Mostafa, E. A. El-Hay, and M. M. ELkholy, "Recent Trends in Wind Energy Conversion System with Grid Integration Based on Soft Computing Methods: Comprehensive Review", Archives of Computational Methods in Engineering, Springer, doi.org/10.1007/s11831-022-09842-4, Netherlands, vol. 30, no. 3, pp. 1439–1478, 2023.

[19] V. Telukunta, J. Pradhan, A. Agrawal, M. Singh, and S. G. Srivani, “Protection challenges under bulk penetration of renewable energy resources in power systems: A review”, CSEE J. Power Energy Syst, DOI: 10.17775/cseejpes.2017.00030, vol. 3, no. 4, pp. 365–379, 2017.

[20] A. Sajadi, L. Strezoski, K. Clark, M. Prica, and K. A. Loparo, “Transmission system protection screening for integration of offshore wind power plants”, Renew. Energy, DOI: 10.1016/j.renene.2018.02.070, vol. 125, pp. 225–233, 2018.

[21] M. A. Aftab, S. M. S. Hussain, I. Ali, and T. S. Ustun, “Dynamic protection of power systems with high penetration of renewables: A review of the traveling wave based fault location techniques”, Int. J. Electr. Power Energy Syst., DOI: 10.1016/j.ijepes.2019.105410, vol. 114, January 2020.

[22] H. C. Kiliçkiran, İ. Şengör, H. Akdemir, B. Kekezoğlu, O. Erdinç, and N. G. Paterakis, “Power system protection with digital overcurrent relays: A review of non-standard characteristics”, Electr. Power Syst. Res., DOI: 10.1016/j.epsr.2018.07.008, vol. 164, pp. 89–102, July 2018.

[23] G. M. ZUBIRI, S. L. BARBA, “Impact on the power system protection of high penetration of wind farms technology", CIGRE 2010, pp. 1–9, 2010.

[24] S. J. N. Cisneiros, M. J Botelho, D. O. C Brazil, F. C Medeiros “New challenges caused by the new energy

sources in the Brazilian power system", CIGRE Sess., 45th Int. Conf. Large High Volt. Electr. Syst. 2014, August 2014.

[25] M. Tsili, and S. Papathanassiou, "A review of grid code technical requirements for wind farms", IET Renew. Power Gener., DOI: 10.1049/IET-RPG.2008.0070, vol. 3, no. 3, pp. 308–332, 2009.

[26] B. S. Rajpurohit, S. N. Singh, and L. Wang, "Electric Grid Connection and System Operational Aspect of Wind Power Generation", Green Energy Technol., DOI: 10.1007/978-1-4471-2201-2_12, vol. 78, pp. 267–293, 2012.

[27] M. Mohseni, S. M. Islam "Review of international grid codes for wind power integration: Diversity, technology and a case for global standard", Elsevier, DOI.org/10.1016/j.rser.2012.03.039, Vol. 16, No. 6, pp. 3876-3890, August 2012.

[28] V. Mishra, R. D. Shukla, and P. Gupta, " An Approach towards Application of Semiconductor Electronics Converters in Autonomous DFIM Based Wind Energy Generation System: A Review", International Journal Of Smart Grid, Vol.3, No.3, PP. 152-162.

[29] S. D. Ahmed, F. S. M. Al-Ismail, M. Shafiullah, F. A. Al-Sulaiman, and I. M. El-Amin, "Grid Integration Challenges of Wind Energy: A Review", IEEE Access, DOI: 10.1109/ACCESS.2020.2964896, vol. 8, pp. 10857–10878, 2020.

[30] B. Shakerighadi, N. Johansson, R. Eriksson, P. Mitra, A. Bolzoni, A. Clark, and H. Nee "An overview of stability challenges for power-electronic-dominated power systems: The grid-forming approach", IET Gener. Transm. Distrib., DOI: 10.1049/gtd2.12430, vol. 17, no. 2, pp. 284 – 306, 2023.

[31] N. Holjevac, T. Baškarad, J. Đaković, M. Krpan, M. Zidar, and I. Kuzle, "Challenges of high renewable energy sources integration in power systems—the case of croatia", Energies, DOI: 10.3390/EN14041047, vol. 14, no. 4, 2021.

[32] S. Impram, S. Varbak Nese, and B. Oral, "Challenges of renewable energy penetration on power system flexibility: A survey", Energy Strateg. Rev., DOI: 10.1016/j.esr.2020.100539, vol. 31, p. 100539, August 2020.

[33] S. T. Meraj, S. S. Yu, M. S. Rahman, K. Hasan, M. S. H. Lipu, and H. Trinh, "Energy management schemes, challenges and impacts of emerging inverter technology for renewable energy integration towards grid decarbonization", J. Clean. Prod., DOI: 10.1016/J.JCLEPRO.2023.137002, vol. 405, Jun. 2023.

[34] S. H. E. Abdel Aleem, A. Y. Abdelaziz, and A. F. Zobaa, Egyptian Grid Code of Wind Farms and Power Quality, Handb. Distrib. Gener. Electr. Power Technol. Econ. Environ. Impacts, DOI: 10.1007/978-3-319-51343-0_7, pp. 227–245, Jan. 2017.

[35] A. M. Moheb, E. A. El-Hay, and A. A. El-Fergany, "Comprehensive Review on Fault Ride-Through Requirements of Renewable Hybrid Microgrids", Energies, DOI: 10.3390/en15186785, vol. 15, no. 18, 2022.