Impact of Wind Integration on National Transmission Network

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Abstract. Due to the scarcity of fossil fuels and their increasing prices, adoption of renewable resources has become inevitable. Wind energy is being recognized as a potential renewable source of bulk power generation in Pakistan, just as across the world. The wind corridor located from Hyderabad to Keti Bandar has an immense potential for power generation, with two windfarms already in operation and many more planned. A stability analysis of installed and potential Wind Turbines Generators (WTG) type needs to be performed, to analyse the impact of power injection from wind turbines on the voltage level and grid stability of the power network. This analysis can further help to identify appropriate integration location and suitable wind turbine generator for AC network support. This paper presents the analysis of network strength at the point of wind the turbine generator's connection and a comparison of wind turbine generators to support the AC network, which will be useful for identification of suitable type of WTG for reliable operation of integrated system.

Keywords: Wind power integration · Network strength · Wind turbine generators · Stability analysis

1 Introduction

The generation deficit in Pakistan has peaked to 6000 MW in recent years, mainly due to over relaying on conventional resources of energy generation. The installed capacity of the country at the end of 2010 was 21,455 MW of which 31 % was hydro, 67 % thermal (gas & oil), 2 % nuclear and 0.1 % coal. However, due to seasonal variation of water flow it further decreases to 15,254 MW in winter [1]. Presently, this seasonal variation put a large burden on thermal generation due to the absence of renewable generation. This gap can be well filled by harnessing the vast wind resources located across different parts of the country.

According to the wind resource studies carried out by National Renewable Energy Laboratories (NREL) [2], Pakistan has a potential of more than 131,800 MW of wind energy across the country. The Alternative Energy Development Board (AEDB) has so

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Table 1. Least cost generation plan [1]

	2010–11		2029–30	
	(MW)	(%)	(MW)	(%)
Hydro	6,555	31	41,546	37
Thermal-gas	6,571	31	12,015	11
Thermal-oil	7,838	37	6,855	6
Thermal-coal	30	0.1	37,774	34
Bagasse & Bio Waste Plant	0	0	100	0.1
Nuclear	461	2	6,947	6
Wind	0	0	5,400	5
Import	0	0	2,000	2
Total	21,455	100	112,639	100

far allocated land to more than eighteen (18) Independent Power Producers (IPPS) for wind power generation projects of 50 MW each. Twelve 50 MW wind power projects have completed feasibility studies. The plans are to achieve up to 1,800 MW from wind energy by the end of 2020 and a total of 5,400 MW from wind energy sources by 2030, shown in Table 1.

2 Related Work

Comprehensive studies have been performed for the integration of wind power into existing transmission network throughout the world, namely National Renewable Energy Laboratory in United States, Hydro-Quebec in Canada and Risø DTU National Laboratory for Sustainable Energy, in Denmark, Europe, considering both the technological and regional implementation aspects of the topic. Very few studies have been performed in the context of Pakistan. A regional study has been performed in [3], showing the need of regional interconnection for renewable energy integration and future energy security in SAARC countries. [4] presents the statistics of energy mix of sustainable energy option available for Pakistan. The evaluation of wind energy potentials at Keti Bander in particular is presented in [5]. The energy management from the renewable resources in energy deficit network is discussed in [6]. A co-ordination study of wind power and hydro power generation is performed in [7], mainly considering the loading capacity of transmission lines. However, no study has been performed to analyze the dynamic stability analysis of wind power integration into the power system network.

This study presents the stability analysis of the installed and potential Wind Turbine Generator (WTG) types, to analyze the impact of the power injection from wind turbines regarding the voltage level and grid stability of the power network. The existing transmission system has been designed for conventional power generation which is composed of synchronous generators, which can support the stability of the transmission system by providing inertia responses, oscillation damping, synchronizing power, short-circuit capability and voltage backup during faults. In contrast, wind turbine generators (WTGs) are characterized mainly as fixed speed and variable speed induction generators, doubly fed induction generators and full scale synchronous generators, which are very different from those of conventional generators. This paper presents a comparison of the grid support provided by different WTGs types to identify the most suitable type WTG at each location. A stability analysis of the 50 MW planned wind power project (WPP) is performed on the high wind potential site Jhampir, using PSCAD/EMTDC simulation software [8]. Different WTG concepts are simulated with given grid strength and wind speed at the location to determine the impact of wind turbine generators on the integrated grid. Dynamic analysis is performed to evaluate performance in accordance with the grid code description. Geo-spatial Toolkit map from NREL [9] shown in Fig. 1 is used to analyze the predicted average monthly wind speed in m/s at the location and the HOMER utility is used to obtain the frequency distribution at the locations.

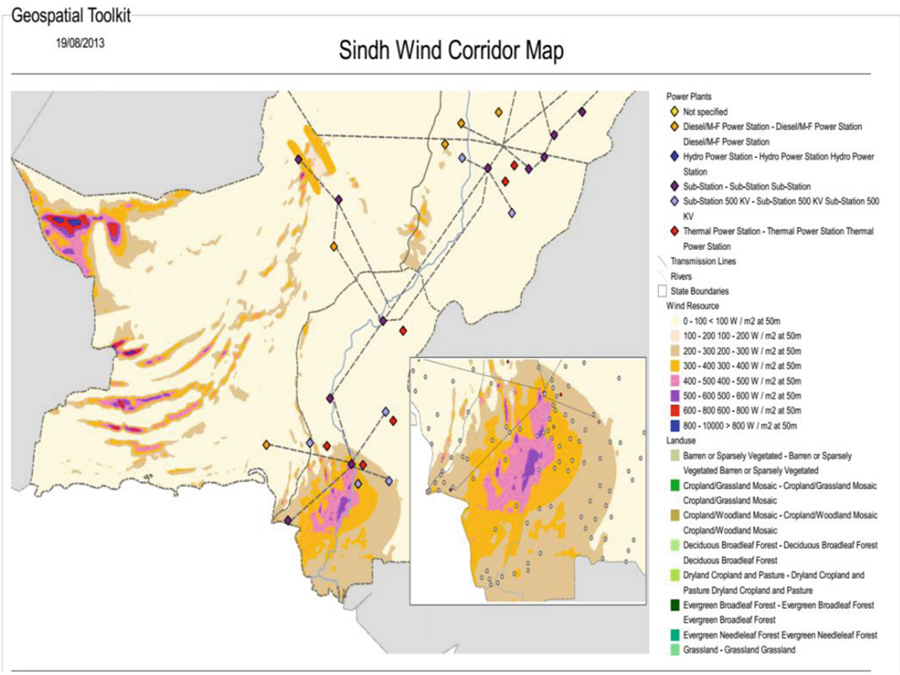

Fig. 1. Sindh wind corridor map (NREL) [9]

3 System Modelling

3.1 Wind Turbine Generator (WTG) Technologies

A wind turbine generator system is typically comprised of the turbine blades and rotor hub assembly to capture power from the wind, a drive-train to step-up the speed from low spinning turbine shaft to the high speed generator, and a generator as an electromechanical energy converter. WTGs are classified mainly into four types [10], according to their speed control characteristics, i.e., Type 1: Fixed speed wind turbines (SCIG), Type 2: Variable slip wind turbines (OSIG), Type 3: Double feed induction generator (DFIG) wind turbines, and Type 4: Full converter wind turbines (PMSG).

The fixed speed wind turbine is the most basic type turbine employed in wind energy market. It consists of a squirrel-cage induction machine (SCIG) directly connected to the grid and operates with very little variability in turbine rotor speed. It is very robust and reliable in operation but inefficient power capture capability and high reactive power consumption are its main disadvantages. Some of them do not even have pitch control capability. The remaining three types come under the broad category of variable speed turbines, as they are designed to operate over a wide range of rotor speed. Most of them also have the pitching controllability. Pitch and speed controllability enables them to capture more energy over a wide range of wind speed than fixed speed wind turbines. Type 2 wind turbines, the Opti-slip Induction Generator, employs dynamic rotor resistance to control the rotor resistance of the machine and provides variable slip operation up to 10 %. However, power is lost in the resistance. To overcome this disadvantage, the Type 3 wind turbine Double-Fed Induction Generator (DFIG) is designed with a back-to-back AC/DC/AC converter in the rotor circuit to recover the slip energy. As the converter only handles power in the rotor circuit, it does not have to be rated at machine full output power, which makes it more economical. Flux vector control employed in the converter enables decoupled control of active and reactive power, which also helps in maximizing power extraction and support to the grid. The type 4 wind turbine employs a fully rated AC/DC/AC converter to connect the generator to the grid. As there is no direct connection to the grid, so an induction or synchronous generator can be used to obtain variable speed operation with independent real and reactive power control. The most common configuration is the permanent magnet synchronous generator (PMSG). The details of universal manufacture-independent models recommended for wind power interconnection studies of all four types is described in [11].

3.2 Aggregated Wind Power Plant Model

In practice wind power plant (WPP) is comprised of a number of wind turbine generators (WTGs) of the same type. A WTG is usually rated at low voltage output (690 V). Voltage is stepped up to the medium voltage collector system (22 kV) by a transformer located at each WTG. Many closely located WTGs are connected in parallel in a group. Several of these groups are connected to the mains feeder, and several feeders are connected to a substation where the voltage is stepped up to transmission level (132 kV).

In many cases, it is desire able to model the WPP close to the actual implementation, but it may not be practical to model in detail each WTG and collector system for the WPP's power system integration studies. However, when the response to grid disturbances is required, dynamic models of the generator and related controls need to be implemented to know the turbine response. In this study an aggregated single turbine representation is taken to represent a 50 MW WPP comprising 33 units of 1.5 MW WTGs and low voltage pad-mounted transformers in a simplified manner, shown in Fig. 2.

Fig. 2. Single turbine representation of WPP

3.3 Power System Representation

For WPP integration studies, detailed representation of the whole network may not be practical and would involve excessive computational cost and time. So the actual system of the NTDC 132 kV grid shown in Fig. 3 is represented as an infinite bus connected to the PCC through equivalent impedance (Z_{grid}) of the system as shown in Fig. 2. This can be the most important parameter the network strength of the system. An important characteristic of determining the strength of the network is the short circuit ratio (SCR), connected with WPP of rated power $S_{N\ WT}$, can be defined as [10, 12]:

$$SCR = \frac{SCC}{S_{NWT}} = \frac{V_G^2}{Z_{grid}.S_{NWT}} \tag{1}$$

The SSC is the short circuit capacity which depends on voltage levels (V_G) and total power capability at the PCC. The SSC of the power grid is given in the National Power System Expansion Plan (NPSEP) [1]. Hence, the equivalent impedance of the grid (Z_{grid}) can be determined at the PCC as:

$$Z_{grid} = \frac{V_G^2}{SCC} \tag{2}$$

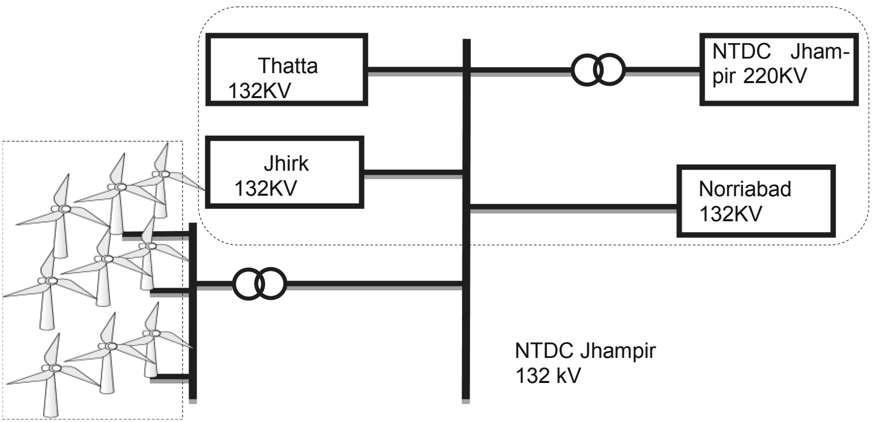

Fig. 3. Single line diagram of 132 kV Jhampir grid

4 Dynamic Simulation Results

4.1 Fixed Speed Wind Turbines

Figure 4 shows the dynamic behavior of the 50 MW WPP comprising fixed speed wind turbine (SCIG) following a rigid three phase fault for 200 ms at the PCC (132 kV) bus. The average wind speed is taken as 10 m/s at the location. The terminal and phase voltage of the wind turbine falls to zero during the fault and resumes to normal after the fault clearance Fig. 4(c) and (e). The electrical power and torque reduces to zero for the duration of the fault Fig. 4(b) and (g), while generator speed increases Fig. 4(d). When the fault is cleared at t = 10.20 s huge reactive power is drawn for excitation of the SCIG, along with the inrush current shown in Fig. 4(e) and (i). The wind turbine recovers to its normal condition 200 ms after fault clearance.

4.2 Variable-Slip Wind Turbines

Figure 5 shows the dynamic performance of the 50 MW WPP comprising variable slip wind turbines (OSIG) during rigid three phase fault at the PCC (132 kV) for 200 ms at average wind speed of 10 m/s. The dynamic behavior of the OSIG wind turbine appears to be the same as for the fixed speed turbine, except that power can be regulated to rated values in the event of higher wind speeds. The wind turbine system draws high reactive power for excitation of the induction generator, Fig. 5(f), after fault clearance and starts to supply active power, Fig. 5(a). The terminal voltage builds up, Fig. 5(c) and speed reduces down to the pre-fault value, Fig. 5(e).

4.3 Double-Feed Induction Generator Wind Turbines

Figure 6 shows the dynamic performance of the 50 MW WPP comprising double-fed induction generators (DFIG) during three phase rigid fault at the PCC (132 kV) bus. The average speed of 10 m/s is assumed with a fault of 200 ms. The wind turbine supplies active power to the grid from both stator and rotor sides. A low voltage protection is applied to avoid the very high rotor current during the fault, which blocks the rotor side converter. This compares the rms line voltage with a pre-set value of voltage dip and blocks the rotor side converter. The DFIG behaves as a squirrel cage induction generator and starts to draw huge reactive power, Fig. 6(g). After the fault clearance terminal voltage builds up and the rotor side converter is unblocked.

4.4 Permanent Magnet Synchronous Generator Wind Turbines

Figure 7 shows the dynamic performance of the 50 MW WPP comprising permanent magnet synchronous generators (PMSG) during a three phase rigid fault at the PCC (132 kV) bus. The fault is simulated for 100 ms and average wind speed is taken as 10 m/s. As observed previously in the dynamic behaviour of Type 1, 2 and 3 systems in Figs. 4, 5 and 6 respectively, the grid voltage drops significantly because of high

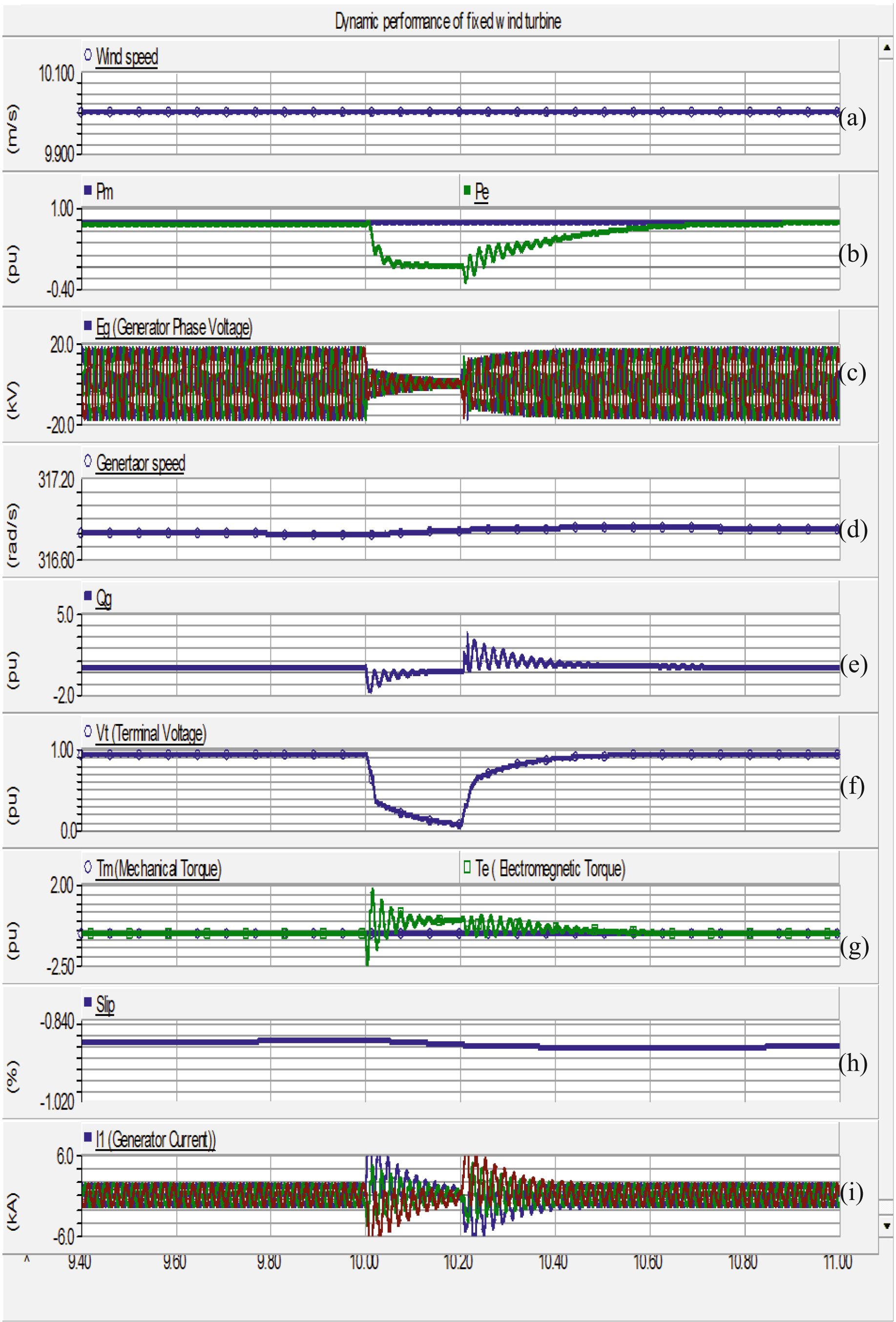

Fig. 4. Dynamic behavior of fixed speed wind turbine WPP

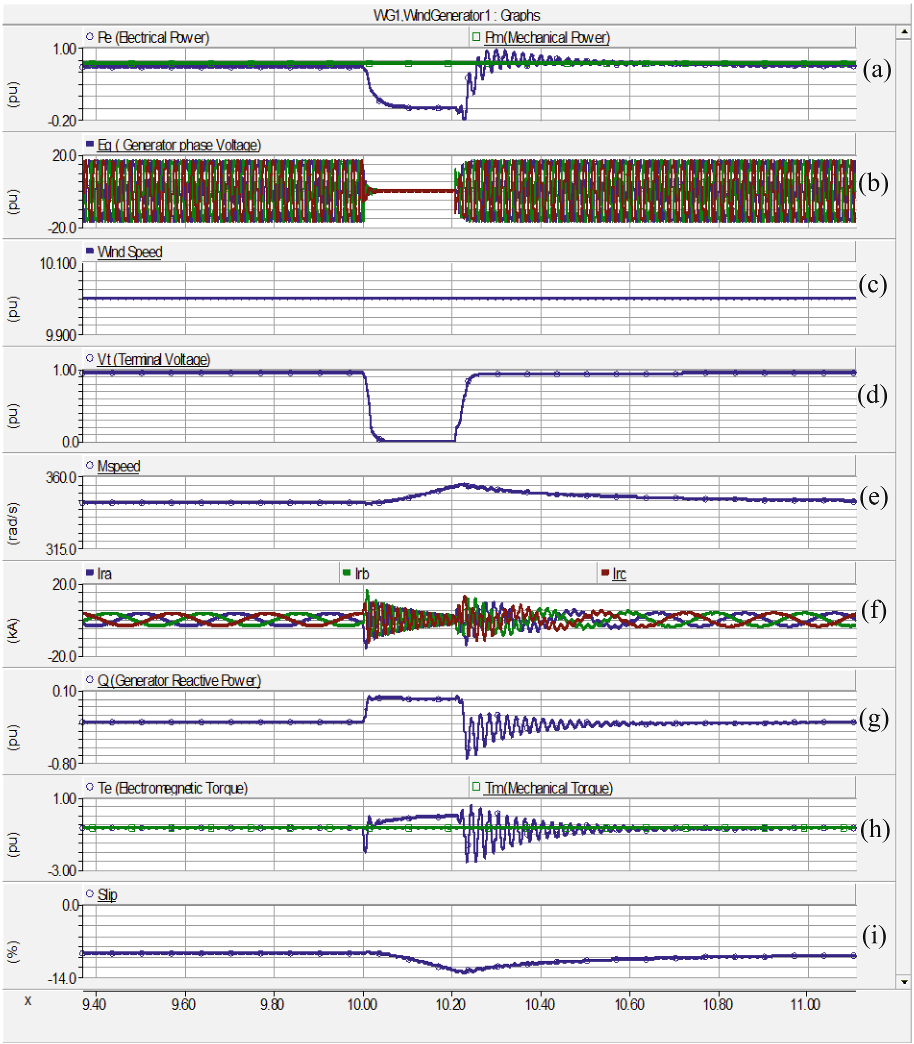

Fig. 5. Dynamic performance of variable slip wind turbine WPP

reactive power consumption by the induction generator. They have limited capability to inject reactive power into the PCC for supporting the voltage and cannot provide the necessary reactive power to raise voltage, whereas the PMSG control system attempts to raise the voltage by producing maximum available reactive power Fig. 7(d).

5 Low Voltage Ride Through (LVRT) Characteristics

One of the most important aspects of grid code compliance of WPP is Low Voltage Ride Through (LVRT) capability characterises. The Fig. 8 shows the LVRT requirement in

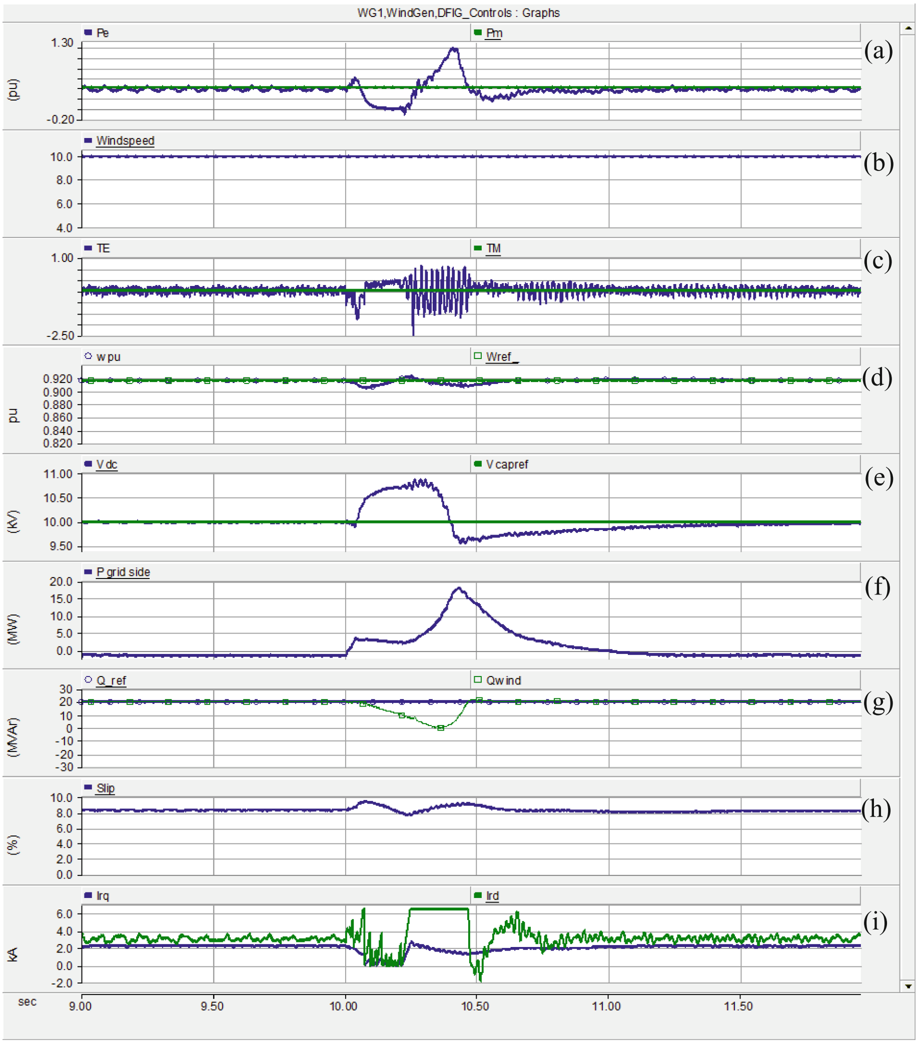

Fig. 6. Dynamic performance of DFIG WPP

German grid code. With the performance of further dynamic response analysis by varying voltage dip level at the PCC and fault duration, LVRT characteristics of each WPP type can be obtained, which can further confirm the grid code compliance of each type.

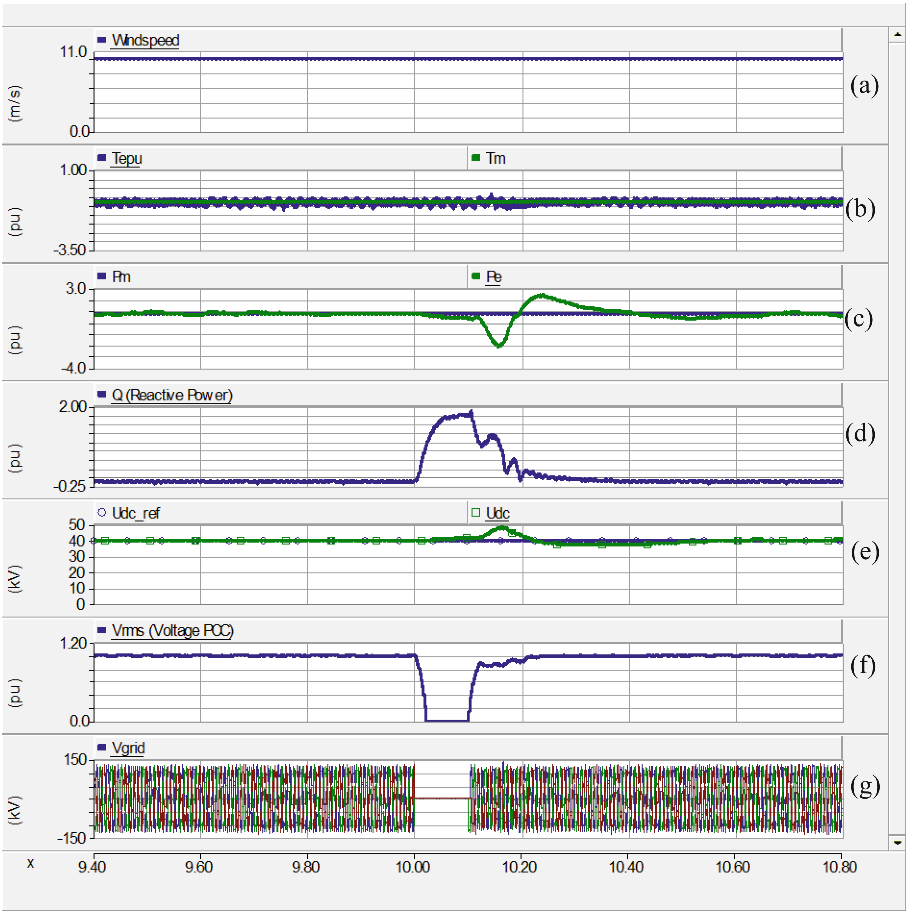

Fig. 7. Dynamic performance of PMSG WP

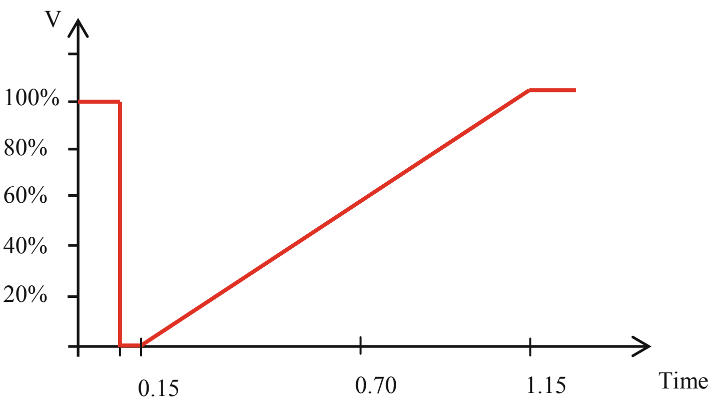

Fig. 8. VRT requirement in German grid code [13]

6 Conclusion

This paper presents the comparison of grid supportability of different WTGs types at the actual strength of the grid to identify the suitable type of WTG for the proposed location of Hyderabad-Keti Bander wind corridor. The active and reactive power controllability analysis of different WTGs types is performed to obtain the comparison of voltage and frequency maintaining capability within the prescribed range of rated values at the point of common coupling (PCC) in normal operation. The simulation result obtained shows that, Type 1, 2 and 3 systems, the grid voltage drops significantly because of high reactive power consumption by the induction generator. They have limited capability to inject reactive power into the PCC for supporting the voltage and cannot provide the necessary reactive power to raise voltage without addition protection and control. Whereas Type 4 (PMSG) wind turbines attempt to raise the voltage by producing maximum available reactive power. To further confirm with grid code compliance LVRT characteristic analysis is suggested to be performed.

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References

1. Inc, S.-L.I.: National power system expansion plan. National Transmission and Despatch Company Limited. Final report 32 (2011)
2. Elliott, D.: Wind resource assessment and mapping for Afghanistan and Pakistan. National Renewable Energy Laboratory. Golden, Color, USA (2011)
3. Rashid, T.H.M.S., Islam, R.: Prospects of renewable energy resources and regional grid integration for future energy security & development in SAARC countries. IJRET **2**(1), 43–51 (2013)
4. Asif, M.: Sustainable energy options for Pakistan. Renew. Sustain. Energy Rev. **13**, 903–909 (2009)
5. Ullah, I., Chaudhry, Q.-Z., Chipperfield, A.J.: An evaluation of wind energy potential at Kati Bandar. Pakistan. Renew. Sustain. Energy Rev. **14**, 856–861 (2010)
6. Aamir, M., Poncela, J.: Impact analysis of renewable energy in national grids for energy deficit countries. Commun. Comput. Inf. Sci. Second IMT, **218**, 1–9 (2012)
7. Awan, S.: Hydro and wind power integration: a case study of Dargai station in Pakistan. Energy Power Eng. **4**, 203–209 (2012)
8. User's guide (PSCAD) Power System Computer Aided Design (2010)
9. User manual Geospatial Toolkit (2010). www.nrel.gov/international/geospatial_toolkits
10. Ackermann, T.: Wind Power in Power Systems. Wiley, Chichester (2005)
11. Singh, M., Surya, S.: Dynamic models for wind turbines and wind power plants. National Renewable Energy Laboratory (2011)
12. Grunau, S., Fuchs, F.: Effect of wind-energy power injection into weak grids. In: Proceedings of EWEA Conference (2012)
13. Altın, M., Goksu, O.: Overview of recent grid codes for wind power integration. In: 12th International Conference Optimization of Electrical and Electronic Equipment, OPTIM, pp. 1152–1160 (2010)

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