A Review on Wind Energy Conversion System using Double Fed Induction Machine (DFIM)

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***Abstract* — This paper presents a specific wind energy conversion system based on doubly fed induction generator for Voltage fluctuation (sags and swells), interruptions of output power, total harmonic distortion and many other different types of distortion are the main issue of the wind based power system and these power quality problem. Now days, wind power technology has been growing widely. With the incorporation of Wind turbines together with the electrical grid, it is necessary for the system operators to know the behaviour of wind turbine under all the operating Many areas of interest in the power system such as calculation of wind speed, modelling, control and stability analysis of the wind system connected with electric grids are of importance in the modern power system. The problem related to the various effects of wind energy when integrated with the power system on the stability of the system is gaining more interest of researchers because of increasing of its penetration level. In this paper literature review on various effects of wind power incorporation on the power system stability and several methods for the enhancement of the small signal stability of wind system integrated with electric grid is presented.**

Index Terms:– Wind Energy Conversion System (WECS) Wind Power (WP), Wind Turbine Generators (WTG), Doubly Fed Induction Generator (DFIG), Voltage sag, Real and reactive power.

I. Introduction

In this time, renewable energy resources are gaining more attention in electrical power sectors due to efforts of reduce the usage of fossil fuels to generate the electrical energy [1]. So that the wind power in modern era has become the most established sources in generating the electricity amongst all the renewable sources because of its promising technical and economic prospects to each other types of renewable source. At this time wind power generation has continued to increase globally. With the latest wind annual report it is stated that in 2016 around 398 GW is installed all over the world which can sufficiently supply 4% of world's electricity demand [2]. And it will continue to grow approximately 24% per year globally. With the worldwide rise of generation of electricity through wind turbines, the impact on the electric utility grids has also increased.

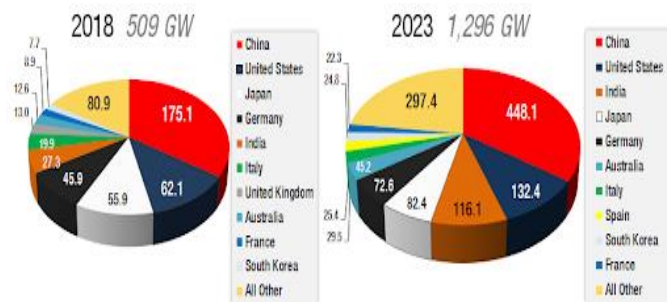

Fig. 1 Percentage share of top 10 countries in terms of cumulative capacity

By the end of 2015, six countries including China (145362 MW), Spain (23,025 MW), Germany (44,947 MW), USA (74,471 MW), India (25,088 MW) and UK (13,603 MW) had over 10,000 MW of the installed capacity [3]. New installations declined to 54.9 GW in 2016 and 53.5 GW in 2017. In 2018, 60.9 GW of new installations were expected but only 51.3 GW were installed at year end. In 2019, the Global Wind Energy Council (GWEC) forecasts 65.4 GW of new installations. For 2023, the forecast for new installations is 58.7 GW and a total installed capacity of 903.0 GW.

In Asia, India is the second leading wind market, offering abundant prospects for international as well as domestic players. India is now amongst the top five countries for wind power installed capacity worldwide. The total renewable energy installation connected with the electric grid in India attained almost 33,792 MW. In the starting of 2015, Wind power is about 11% of total installed capacity of 260.8 GW and about 66.5% of total renewable energy capacity.

With the boosting of penetration level of wind power, the importance to make sure that the wind power penetration does not have effect on security, power quality, stability & reliability of every network of power system under all operating conditions also increased. The effect of wind power generators is insignificant on stability of power system when implemented in small scale. With the rise of the penetration level, the power system's dynamic performance may be influenced. In the power system sectors variable-speed WTs which uses DFIGs are gaining more importance amongst several wind generation technologies owing to low investment, great energy transfer capacity and adaptable control. Before connecting the DFIG to the grid, its detailed design and full stability analysis is essential. This paper provides a literature review on several models DFIGs for wind energy conversion systems (WECS) and then analysis, effects and methods for enhancement of stability of wind power systems connected to electric grid performed by various authors. The remaining paper is arranged as subsequent sections. Section II reports the detail of DFIG and its modeling. Section III gives the brief study to power system small signal stability. The methods of stability enhancement in WECS are summarized in Section IV. And, conclusions are provided in section V.

II. DFIG MODELING FOR STABILITY ANALYSIS

Wind turbines machine may be categorized as follows:

- Fixed speed WTs- which works at a constant speed which is set by the operator and induction generator is used shown in figure 2.
- Variable speed wind turbines- make use of DFIG or else permanent magnet synchronous machine (PMSM) shown in figure 3.

In brief, WT model may be principally classified in three elements namely, generator, mechanical drives, control systems and converters. The modeling of the generators is having more important.

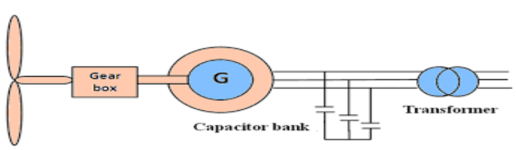

Fig. 2 Schematic diagram of Constant-speed WT

In this paper the fundamental arrangement of a DFIG based WECS attached with electric grid. WT and DFIG are joined mechanically through gearbox and coupling shaft. But in DFIG, the stator windings are having a direct connection with electric grid and through back-to-back variable frequency voltage source based converters, the rotor windings are connected. The power generation of DFIG can be optimized and stability may be improved by employing a rotor side converter (RSC).

Both of the converters used in this configuration can be modeled in the same way like four-quadrant Pulse- width modulation (PWM) converters. The flow of power from/to the rotor and stator of DFIG might be controlled both in direction and magnitude by adjusting the switching of Insulated-gate bipolar transistors (IGBT).As a result of which, the electrical power at fixed frequency and voltage may be generated on stator terminals and can be injected within the electric grid over extensive operating range. The DFIG may be assumed to be a conventional Induction generator having a rotor voltage which is non-zero.

Simulations of DFIG based WTS has been studied within many papers [4] [5] [6][7].

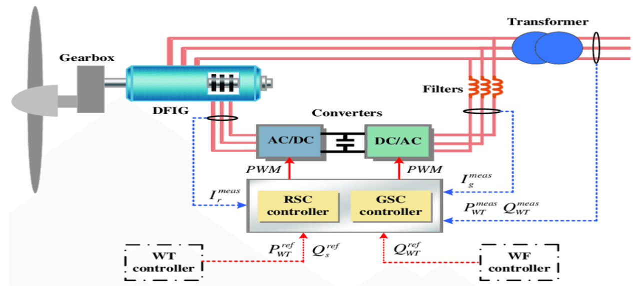

Fig. 3 Schematic diagram of DFIG based WT

DFIG can be modelled by using following mathematical equations [8]

$$V_{ds} = R_s i_{ds} + \frac{d\psi ds}{dt} - \omega_s \psi qs \quad (1)$$

$$V_{qs} = R_s iq_s + \frac{d\psi qs}{dt} - \omega_s \psi ds \quad (2)$$

$$V_{dr} = R_s i_{dr} + \frac{d\psi dr}{dt} - (\omega_s - \omega_r)\, \psi qr \quad (3)$$

$$V_{qr} = R_s i_{qr} + \frac{d\psi qr}{dt} - (\omega_s - \omega_r)\, \psi dr \quad (4)$$

And

$$\psi ds = L_s i_{ds} + L_m i_{dr} \quad (5)$$

$$\psi qs = L_s i_{qs} + L_m i_{qr} \quad (6)$$

$$\psi dr = Lr i_{dr} + L_m i_{dr} \quad (7)$$

$$\psi qr = Lr i_{qr} + L_m i_{qr} \quad (8)$$

where V, i, R, L and ψ are voltages, currents, resistance, winding inductance and flux linkage across winding respectively [21].

$$\text{Slip, } s = \frac{\omega s - \omega r}{\omega s} \quad (9)$$

Where ω_s and ω_r are represent the synchronous speed and rotor speed in (rad/s).

Electromagnetic torque

$$T_{em} = X_m(i_{dr} i_{qs} - i_{qr} i_{ds}) \quad (10)$$

In a given DFIG model which useful for the study of transient stability. This model has taken into account two assumptions:

(i):- Electromagnetic transients in the branch linking the grid & inverters and stator are neglected,

(ii):- By neglecting the current control loop dynamics, the current control can be taken into account as instantaneous value. MATLAB software is used for the study [9].

The studied the DFIG modelling and modelling of converters for stability analysis. A reduced- order model of DFIG is developed to facilitate proficient computation, which limits the calculation of the fundamental component of frequency [10]. In this paper improved model is presented which allows considering the alternating component of rotor current that is essential for initiation of the crowbar operation. Various appropriate models of RSCs and GSCs in addition to dc-link are presented which has considered all four possible modes of operation. For studies of power system simulation the model which is presented is useful.

An extension in which DC-components of stator are ignored with not ever-increasing the modelling and simulation efforts significantly have been presented in [12]. Simulation results, which explain the performance of DFIGM and related control systems during fault conditions, are also provided in this paper. In this publication, modelling of the grid is done by algebraic equations so that we can get better simulation results than the alternative calculations of instantaneous values based on full order models for both grid as well as DFIM.

In [13], the steady-state behaviour of DFIG based WECS in MATLAB has been analysed. Various characteristics of DFIG, including real and reactive-power over speed and torque-speed characteristics simulation is done. From the simulation results, the operating characteristics of DFIG are examined. From simulation results, it can be clearly said that by injecting rotor voltage of DFIG, its characteristics are affected. The overall modelling and simulation of DFIG based WTS which is attached with the grid has been reported in [14]. Modelling and simulation of complete system is done in MATAB/ Simulink such that it may become suitable for modelling and simulation of various configurations type of induction generator [14].

The dynamic performance of grid connected DFIG based WT with the occurrence of disturbances has been presented in reference [15]. In which for studying the WTG response to voltage sags, frequency control, and voltage control and variations of wind, DFIG model has been presented and used. The investigated that accurate models of generator are required for analysing the influence of installation of DFIG on operation and control of power system[16]. A third and fifth order generator models have been illustrated and WT control is studied in this research paper. The functioning of DFIG during network fault is also studied. In [17, 18], by neglecting the DFIG's stator flux dynamics, a third- order model is suggested which offers a correct mean value [16] however some of the DFIG main dynamics are also neglected. In [19], added up the energy storage system to the DFIG based WTS, owing to the irregularity of power generation through wind. With a bi-directional DC/DC power converter in DFIG based WTS, a battery is provided to the DC link of converters. To get the smooth output power with wind variations, the energy storage device can be controlled.

III. SMALL SIGNAL STABILITY

Power system small signal stability has been perfectly explained in [12], [21].

The problem of small signal instability mainly occurs because of the lacking of damping torque that can lead to increasing amplitude of the rotor oscillations. The system stability may be characterized by Eigen values of the matrix of system. The reflection of variations in the working environment of the power system can be seen in the Eigen values of the state matrix of the system's state matrix [1]. By inspecting the sensitivity of the Eigen values concerning system parameter variations, the effect on the dynamics of whole system may be analysed. The dynamic performance of DFIG may be significantly influenced by the variable-speed WTG which constitutes power electronic converters. The effect of DFIG on small signal stability is reported in [18].

In reference [20], the DFIG's full order model with series GSC is provided. By considering the linear zed model, the stability of this system has been examined. This model is useful whenever there is imbalance of grid voltage. To minimize the effects of stator flux oscillations and voltage unbalance, the arrangement shown in this research paper can be a better substitution.

The sub/super-synchronous operation of DFIG system has been presented in [11].

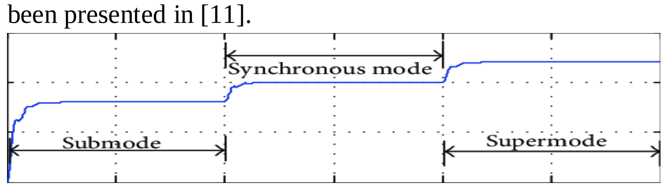

Fig. 3 Sub/super-synchronous operation

For the DFIG-based WTS, the influence of damping controller on several ways of operation is studied in this paper. And in sub/super- synchronous method, the effectiveness of damping controller is also examined. A direct drive permanent generator (DDPMG) based WT model along with associated controllers has been presented in [6]. From this model, SSSA model is obtained. The influence of improved adaptation of DFIG based WECS on the small signal stability of single machine infinite bus (SMIB) is investigated in [12]. SSSA of large scale DFIG-based variable speed WTs integration is addressed in [19].

IV. METHODS OF STABILITY ENHANCEMENT

In reference [17], a model is built to examine the dynamic response of DFIG based WECS when integrated with power system during several grid faults. The DFIG integrated WT model is built in Simulink in MATLAB and the simulations of the model are studied when grid faults occurs.

The small scalar capacity wind farm do not carry great effect on modelling of load, hence making use of ZIP model (constant impedance, constant current and constant power) in parallel with model of the load induction motor is appropriate[10]. The parallel use of ZIP model with model of induction generator may provide more precise results [3]. For studying the dynamics behaviour of grid- connected system during disturbance, modelling and simulation of a DFIG-based WECS are done. The simulation results show the capability of DFIG to regain terminal voltage after fault occurrence in grids[13]. The DFIG's response to various disturbances and the consequent action of the over-current protection is illustrated in this study.

For improving the small signal stability various devices such as Power system stabilizer (PSS), Static Synchronous Compensator (STATCOM), Series dynamic braking resistor (SDBR) and different controllers can be used. High-Voltage Alternating Current (HVAC) and High-Voltage Direct Current (HVDC) can also be employed for the performance enhancement. And for tuning of controllers different optimization techniques such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) can be used [8, 11, 15, 17].

V. CONCLUSION

In this paper, review on various models of WECS, modelling of DFIG, and methods for the enhancement of stability has been presented. The DFIG based WECS system has costs is more than the fixed-speed induction generators without power converters. In this review presented, it is observed that the study of the energy system interconnected with renewable energy sources such as wind power can be performed by taking suitable assumptions to emphasis upon the effect to be studied. The performance of the system can be enhanced through proper tuning of controllers using several optimization techniques and also by using the devices such as HVDC, HVAC, SDBR, FACT devices like STATCOM etc.

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