Small-Disturbance Voltage Stability of Distribution Systems With Induction Generators

ALON KUPERMAN*, RAUL RABINOVICI**, IEEE Senior Member
* Department of Electrical and Electronic Engineering
Sami-Shamoon College of Engineering
** Department of Electrical and Computer Engineering
Ben-Gurion University of the Negev
Beer-Sheva
ISRAEL

Abstract: - The output power and mechanical torque of a wind turbine driven induction generator, connected to a distributed system, change with the rotation speed. Furthermore, in the region corresponding to speeds above the one resulting in maximum output power, the wind turbine output power and torque decrease in a drastic manner when the rotation speed increases. Hence, the induction generator speed stabilizes even when the power system is heavily loaded and the generator terminal voltage is much lower than the nominal value. Simulation results are presented to prove the correctness of the mentioned assumptions.

Key-Words: Distribution Generation, Wind Turbine, Speed Stability

1 Introduction

Paper [1] presents a simulation study regarding voltage stability of distribution systems with induction generators (IG). Behavior of power system, presented in Fig. 1, is examined under different loading conditions. It has been shown, that IG terminal voltage, as well as voltage at buses 1-5 would decrease if system load increased. In addition, it has been concluded that the IG speed would increase in an unlimited and monotonic manner when the system loading factor increased above some critical value. This conclusion was based on presumption of constant mechanical torque applied to the IG, i.e. the prime mover dynamics was neglected. However, this presumption is not valid when the prime mover is a wind turbine.

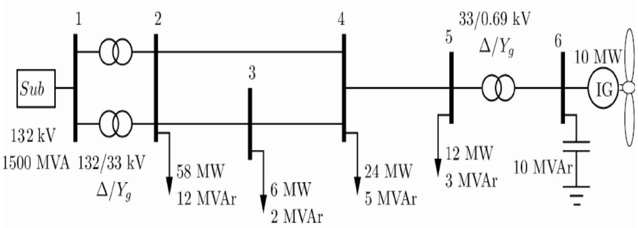

Fig. 1: Single line diagram of the system [1]

2 Approach Presentation

It is well known that wind turbine output power depends on both wind and rotation speeds [2]. Fig. 2 presents a typical relation between wind turbine output power and rotation speed for different wind speeds [3]. It is clear from observing Fig. 2, that when the rotation speed increases above the value resulting in maximum output power at particular wind speed, the turbine output power would drastically reduce. This is also true for turbine

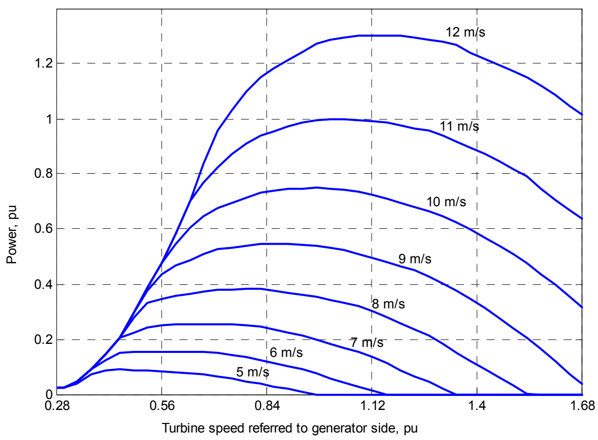

Fig. 2: Wind turbine power versus its rotation speed for different wind speeds

output torque. Therefore the assumption of constant mechanical torque should be re-examined for the discussed paper. Since the torque, applied to the IG by wind turbine, decreases with the increase of the rotational speed on the descending part of the IG mechanical torque characteristic, the IG speed stability could be achieved in this region.

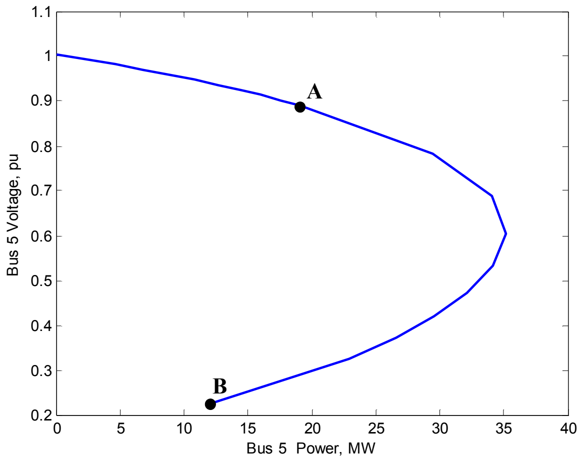

Fig. 3: PV curve of bus 5. Point A corresponds to a loading factor equal to 1, while point B corresponds to a loading factor equal to 10

3 Simulation Results

System of Fig.1 was simulated with the wind turbine, whose characteristic is given in Fig. 2, taken into account. The wind speed was chosen to be 7m/s, resulting in 10MW output power at rated speed. The simulations were carried out using SimPower Blockset ® of Simulink® [4]. Loading factor was varied from 0 to 10, and the simulations were run for 100 seconds in order to reach steady state values for all loading factors.

PV curve of bus 5 is shown in Fig. 3, where point A corresponds to loading factor of 1, and point B corresponds to loading factor of 10. The IG speed reached a stable value for all the above mentioned loading factors, as shown in Fig. 4. It is clear, that with the increase of the loading factor above some value (about 9 according to Fig. 4) the rate of change in steady state value of speed increases, but a stable speed is still reached for any loading factor. It is shown in Figs. 5 and 6 for loading factors of 1 and 10, respectively, through plotting electromagnetic torque of the IG together with the turbine mechanical torque. There exists an equilibrium point where both torqueses are equal and, hence, the speed reaches its stable value due to the fact, that the turbine output torque does not remain constant with the rotational speed increase.

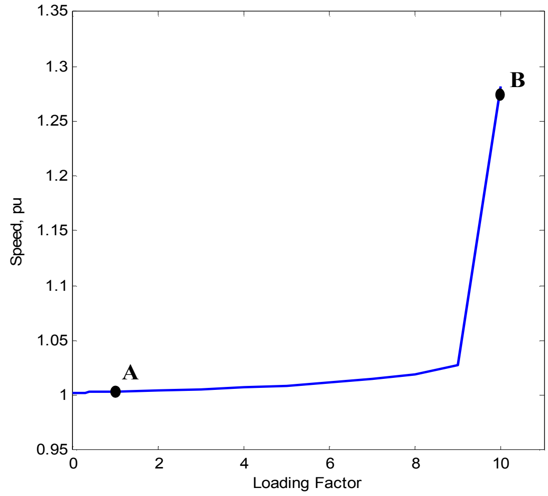

Fig. 4: Stable rotor speed versus loading factor curve. Point A corresponds to a loading factor equal to 1, while point B corresponds to a loading factor equal to 10

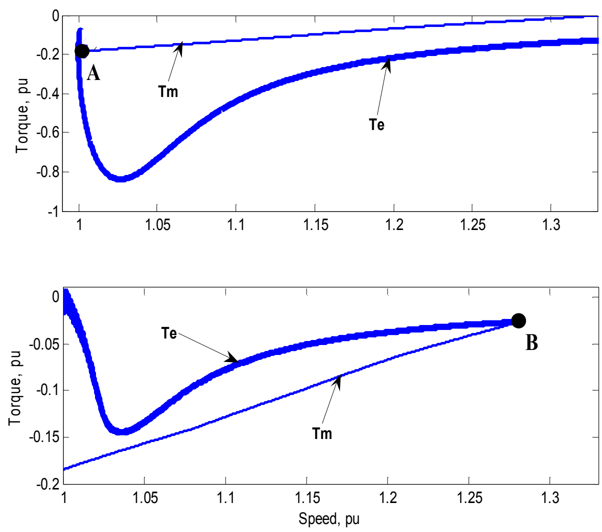

Fig. 5: Mechanical characteristics of the IG, while the system loading factor is 1 (point A in Figs. 3 and 4) and respectively 10 (point B in Figs. 3 and 4), together with the mechanical characteristic of the wind turbine, while the wind speed is 7 m/sec and the wind turbine dynamics is also taken into account.

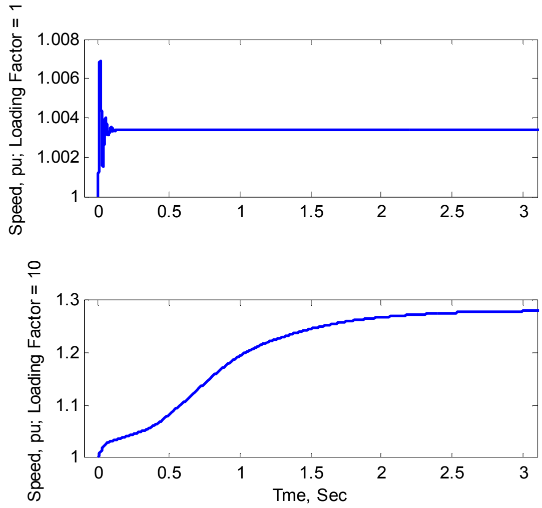

Fig. 6: Change of the IG rotation speed versus time for the same conditions as in Fig. 5.

4 Conclusion

When distributed systems with wind turbine driven IGs are studied, it seems, that the correct assumption is that the IG prime mover output power and mechanical torque change with the rotation speed. Furthermore, in the region corresponding to speeds above the one resulting in maximum output power, the wind turbine output power and torque decrease in a rather drastic manner when the rotation speed increases. Hence, the IG speed will stabilize even when the power system is heavily loaded and the IG terminal voltage is lower than the nominal value.

References:

[1] W. Freitas, L. C. P. Da Silva, A. Morelato, "Small-Disturbance Stability of Distribution Systems With Iiduction Generators," *IEEE Trans. Power Syst*., vol. 20, no. 3, pp. 1653-1654, August 2005.

[2] A. Kuperman, R. Rabinovici and G.Weiss, "A shunt connected inverter based variable speed wind turbine generation," *Int. Jour. of ELECTROMOTION,* vol. 13, no. 1, pp. 67-72, 2006.

[3] R. Gagnon, B. Saulnier, G. Sybille, P. Giroux; "Modeling of a Generic High-Penetration No-Storage Wind-Diesel System Using Matlab/Power System Blockset," Global Windpower Conference, Paris, France, April 2002.

[4] *SimPowerSystems User's Guide*, TransÉnergie Technologies Inc., 2006.