Preprints of the 19th World Congress
The International Federation of Automatic Control
Cape Town, South Africa. August 24-29, 2014

Impact of Increasing Wind Power Generation on the North-South Inter-Area Oscillation Mode in the European ENTSO-E System

Salaheddin AlAli *, Torsten Haase, Ibrahim Nassar***, Harald Weber***

**Institute of Electrical Power Engineering, University of Rostock*
***Dong Energy, Hamburg*
**** Department of Electrical Engineering, Al-Azhar University, Egypt*
Germany (Tel.: 0049-3814987125; e-mail: Salaheddin.alali@uni-rostock.de)

Abstract: After the enlargement of the European ENTSO-E power system towards Turkey at the end of 2010, the East-West Inter-Area Oscillation mode in the enlarged the European ENTSO-E power system has been identified in the frequency range of 0.15 Hz (T_P = 7s) accompanied by insufficient damping. By the end of 2012, more than 107 GW of wind generation capacity had been installed across Europe, representing about 25% of the peak demand of ENTSO-E power system. In this paper, the impact of large scale wind power generation in the European ENTSO-E system on the North-South Inter-Area Oscillation mode using a detailed dynamic model of the European ENTSO-E system is investigated by gradually replacing the power generated by the synchronous generators in the system either Full Size Converter or Doubly Fed Induction Generator (DFIG) wind turbines. Because the whole system is extremely nonlinear, the analysis method in state space is senseless; therefore the damping behavior of Inter-Area-Oscillations of the whole system was analyzed in detail using the analysis method in time domain. The model was created using DIgSILENT software.

Keywords: Inter-Area-Oscillations, Wind power, ENTSO-E power system.

1. INTRODUCTION

The European Network of Transmission System Operators for Electricity (ENTSO-E) is extended already today from Turkey to the Iberian Peninsula in East-West direction. The Maghreb countries (Morocco, Algeria and Tunisia) are connected with the European grid by an undersea cable between Morocco and Spain. Since the beginning of interconnecting national transmission systems in Western Europe in early seventies Inter-Area-Oscillations occur often in the system. In the current outline of the ENTSO-E power system poorly damped oscillation modes exist in North-South and East-West direction [1-2]. These Inter-Area-Oscillations are occurred by rapid changes in the power system, e.g. switching operations or outages of power plant. After the enlargement of the European ENTSO-E power system towards Turkey at the end of 2010, the East-West-Inter-Area Oscillation mode in the enlarged the European ENTSO-E power system has been identified in the frequency range of 0.15 Hz (T_P = 7s) accompanied by insufficient damping [3]. Within the framework of this paper, the oscillation behaviour of the ENTSO-E power system in North-South direction including the large scale wind power generation is analysed to identify the North-South Inter-Area-Oscillation mode.

By the end of 2012, more than 107 GW of wind generation capacity had been installed across Europe, representing about 25% of the peak demand of ENTSO-E power system. During 2012, wind energy installations were led by Germany (21%), the UK (16%), Italy (11%), Romania (8%) and Poland (8%). In terms of total installed capacity, Germany leads again (30% of total wind power capacity), followed by Spain (22%), the UK (8%), Italy (8%) and France (7%) [4].

2. INTER-AREA OSCILLATIONS IN THE ENTSO-E POWER SYSTEM IN NORTH-SOUTH DIRECTION

Recordings of a Wide Area Measuring System (WAMS) have shown significant changes of the dynamic system behaviour. The current status of the implementation of WAMS is given in Fig. 1. More than fifty devices for recording power flows, voltages, currents and frequency at the individual locations are installed in 400 kV and 220 kV order to show all recordings using the same time reference. A lot of recordings of Inter-Area Oscillations were collected from WAMS, which are in the majority of cases excited by emergency shut-downs of the power plant or failures in the 220 kV or 400 kV voltages level of the transmission network.

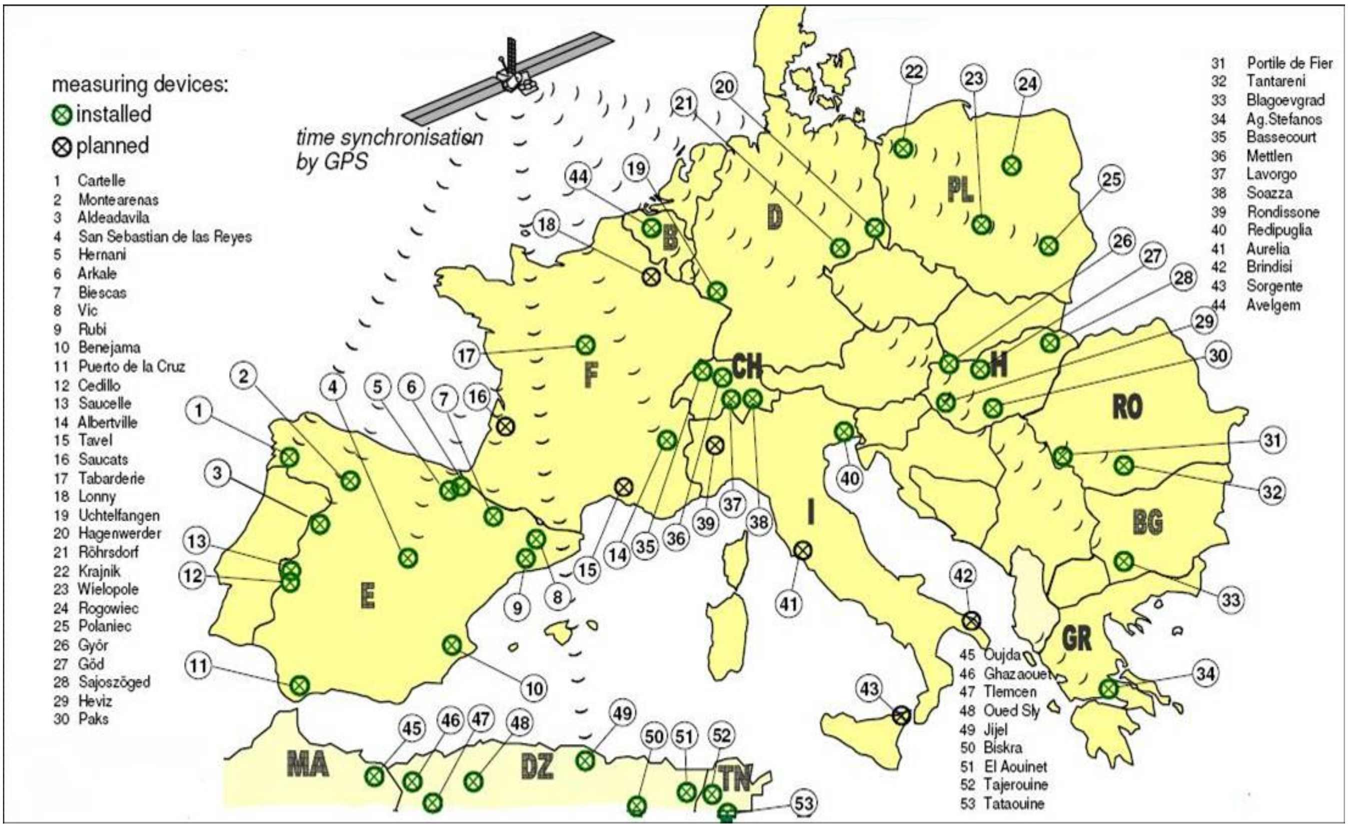


Fig. 1. Wide Area Measuring System (WAMS) [1].

Fig. 2 shows a North-South Inter-Area Oscillation caused on 01.04.2007. In this case the damping is very poor, because the amplitude of power and frequency oscillations increases significantly during the first ten oscillation periods. The frequency of the observed Inter-Area Oscillation is approximately 0.27 Hz (T_P= 3.63s).

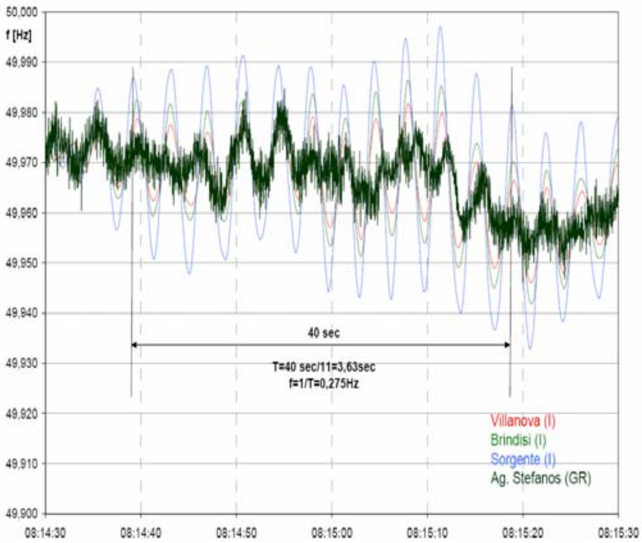


Fig. 2. The poor damping North-South Inter-Area Oscillation on 01.04.2007 (Italy against Greece) [1].

Fig. 3 shows unstable North-South Inter-Area Oscillation caused on 29.05.2007 due to a double busbar failure in 380 kV substation Wilster in Germany. Therefore the all 380 kV lines in substation Wilster were disconnected. After 28 seconds the remaining two 220-kV-lines between north of Hamburg and Danish network were tripped which lead to loss the import power from Denmark about 1.5 GW. The frequency of the observed Inter-Area Oscillation between the range from 0.22 to 0.26 Hz. The maximum value of oscillation amplitude reached to 15, 40 and 200 mHz in Spain, Italy and Denmark respectively.

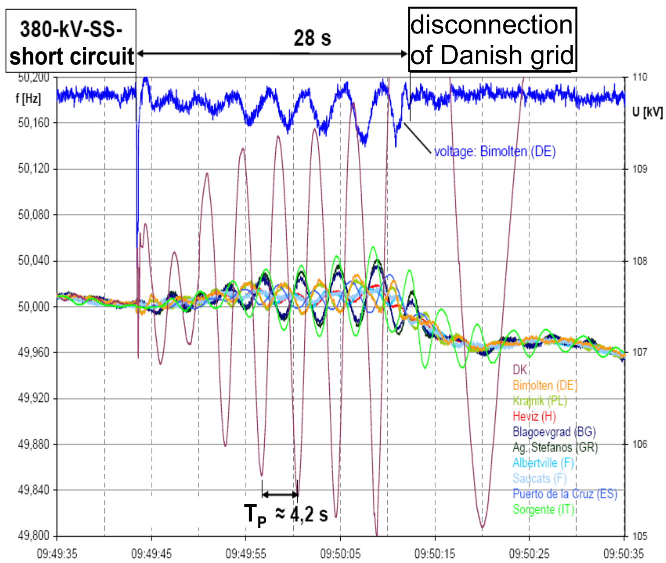


Fig. 3. Unstable North-South Inter-Area Oscillation on 29.05.2007 (Denmark against Italy) [1].

3. DYNAMIC MODEL OF THE ENTSO-E POWER SYSTEM

To analysis the dynamic behaviour of the ENTSO-E power system in North-South direction including the large scale wind power generation, a non-linear dynamic model of the current ENTSO-E power system is represented using DIgSILENT software for power system simulation.

The model is dedicated to the steady state analysis and represents accurately all the power system components involved in physical phenomena of Inter-Area Oscillation. Almost the complete 220/400 kV transmission grid of ENTSO-E is represented. The dynamic model contains:

9000 transmission lines

3100 transformers 400kV/220 kV

700 generators

4000 loads

400 wind parks

Typical load-flow situations obtained from real-time operation were considered. In order to limit the model size, all the units of one generation site are aggregated in one machine, which is valid as far as small-signal stability studies are concerned. The dynamic data of the generator characteristics, excitation controllers, power system stabilisers, turbine systems and governors, are mostly described by detailed models according to with the IEEE standard, [5-6].

The wind generators are assumed to 50% of the Doubly Fed Induction Generator (DFIG) and 50% of the Full Size Converter type.

3.1 Model Validation

Fig. 5 shows the comparison between the measurements and the simulation results due to 1.2 GW generation loss in Spain. The simulation results show, that the described model represents the real system behaviour with good accuracy regarding the analysis of Inter-Area Oscillations. The dynamic characteristics of frequencies at different locations are well according to the recordings, especially the oscillation frequency, amplitude and damping of the physical quantities. From the time behaviour point of view the dynamic model is a reliable basis for further investigations.

4. ANALYSIS OF THE DYNAMIC BEHAVIOUR OF THE ENTSO-E POWER SYSTEM IN NORTH-SOUTH DIRECTION

The centerpiece of this study is to identify the North-South Inter-Area Oscillation mode as the share of wind power increases. To simulate the influence of a large-scale wind power production, two different scenarios were created by time series of the European Wind Integration Study (EWIS) [7].

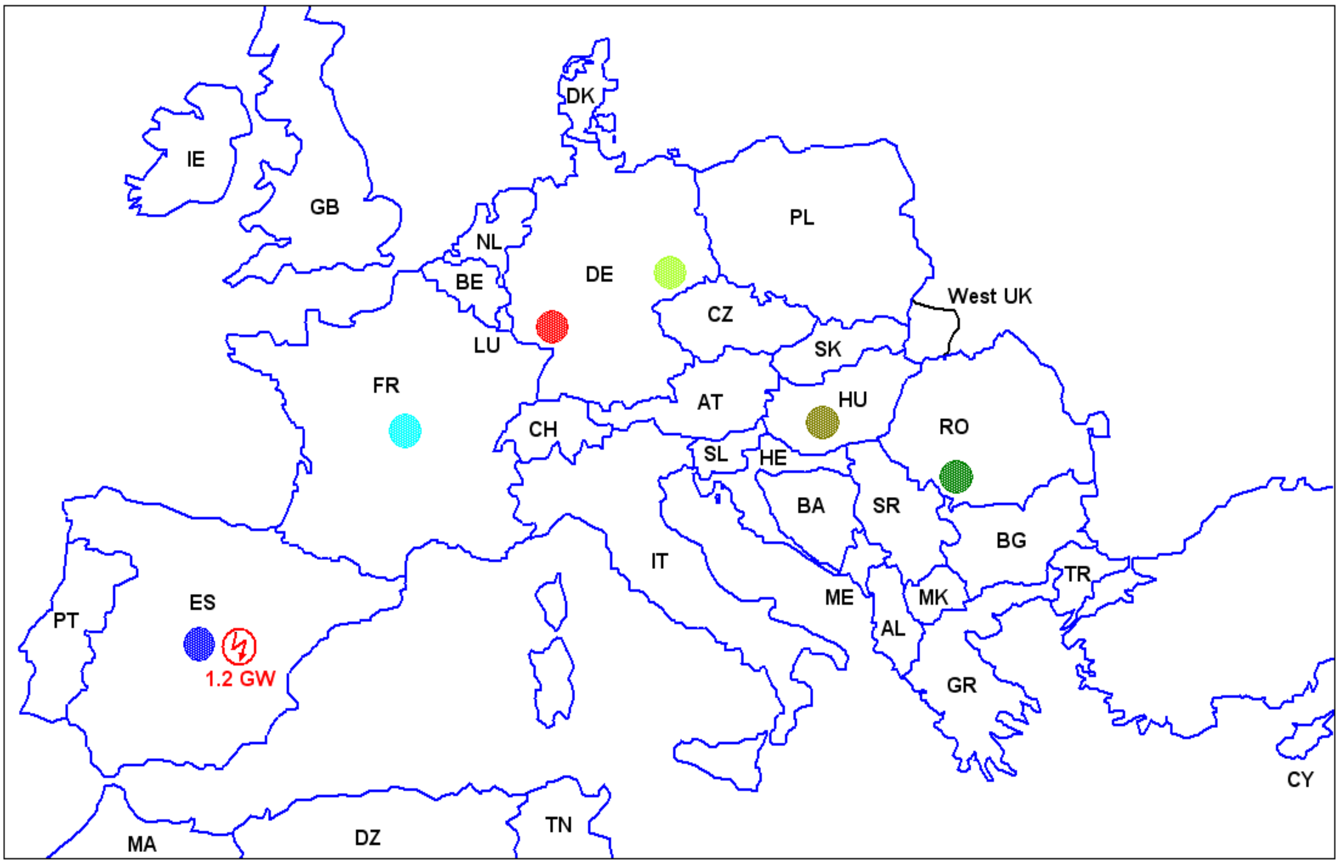
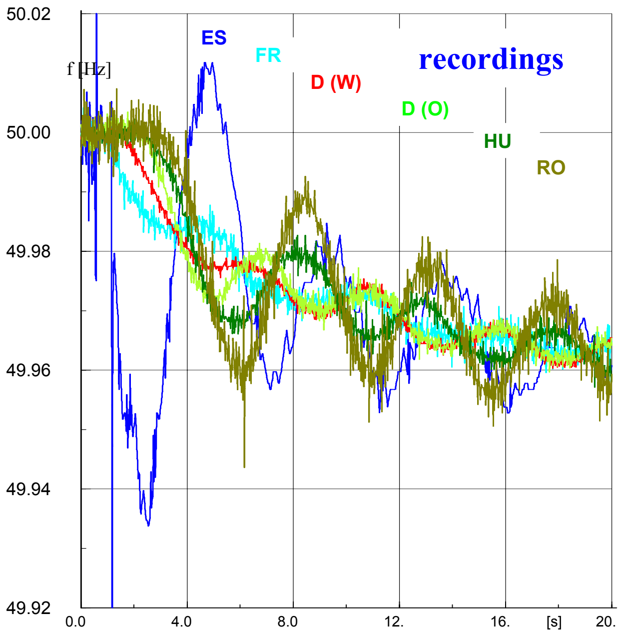


Fig. 4. Location of measuring devices (09.02.2006)



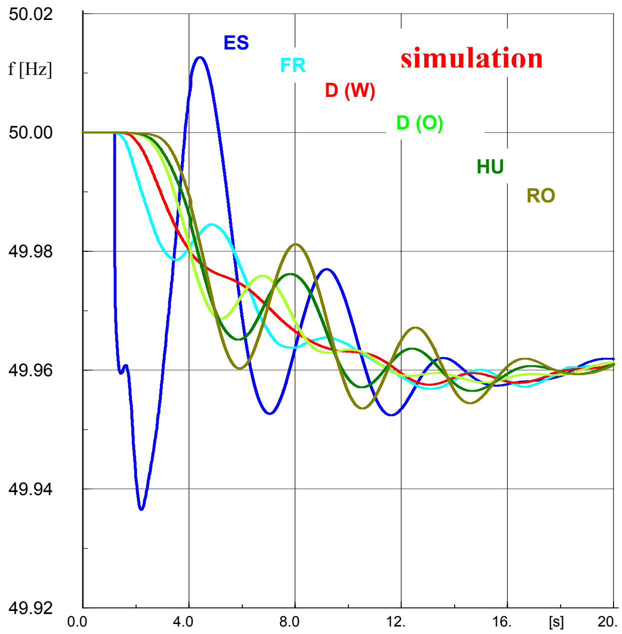


Fig. 5. Comparison between the measurements and the simulations after 1.2 GW power plant outage in Spain [3].

4.1 First scenario of March 2015 (South scenario)

In this scenario, the load of ENTSO-E power system is 400 GW, the wind power production is increased to 14% (57.5 GW). Fig. 6 shows the contribution of the wind power production for the European countries. The share of the northern European countries (FR, BE, NL, DE, DK and PL) is approximately 19.5 GW and the share of the southern European countries (PT, ES, IT and GR) is approximately 38 GW. It can be seen that the Iberian Peninsula has the largest contribution of the wind power production with a value of approximately 26.5 GW.

4.2 Second scenario of December 2015 (North scenario)

In this scenario, the wind power production is increasing to 20% (78.5 GW). Fig. 7 shows the contribution of the wind power production for the European countries. The share of southern European countries (PT, ES, IT and GR) is approximately 18 GW and the share f the northern European countries (FR, BE, NL, DE, DK and PL) is approximately 60.5 GW. It can be seen that Germany has the largest contribution of wind power production with a value of approximately 34 GW.

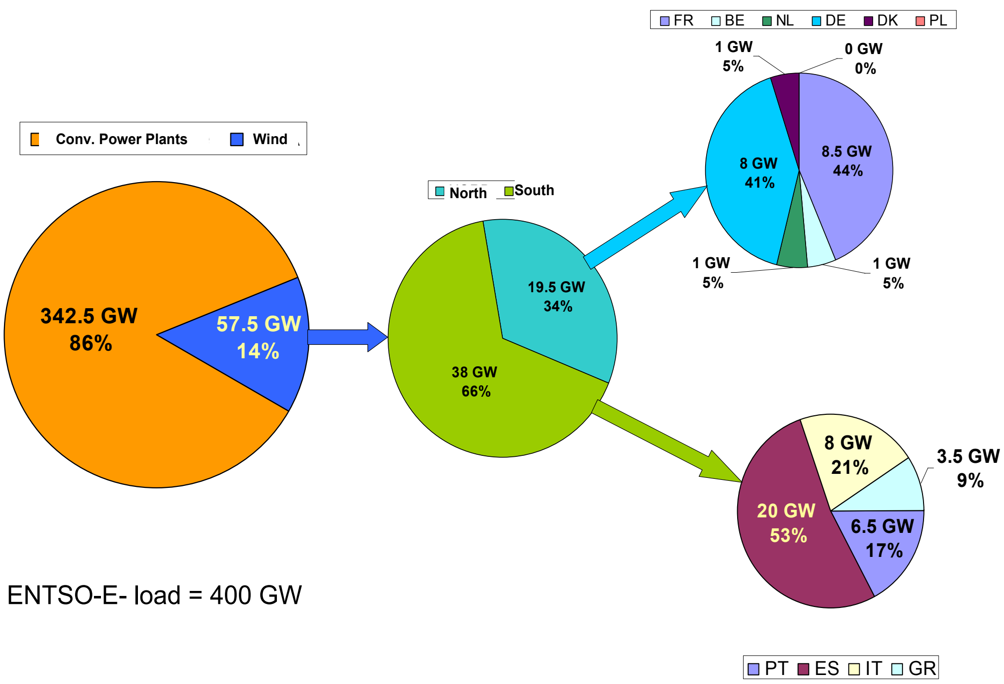


Fig. 6. First scenario of March 2015 (South scenario)

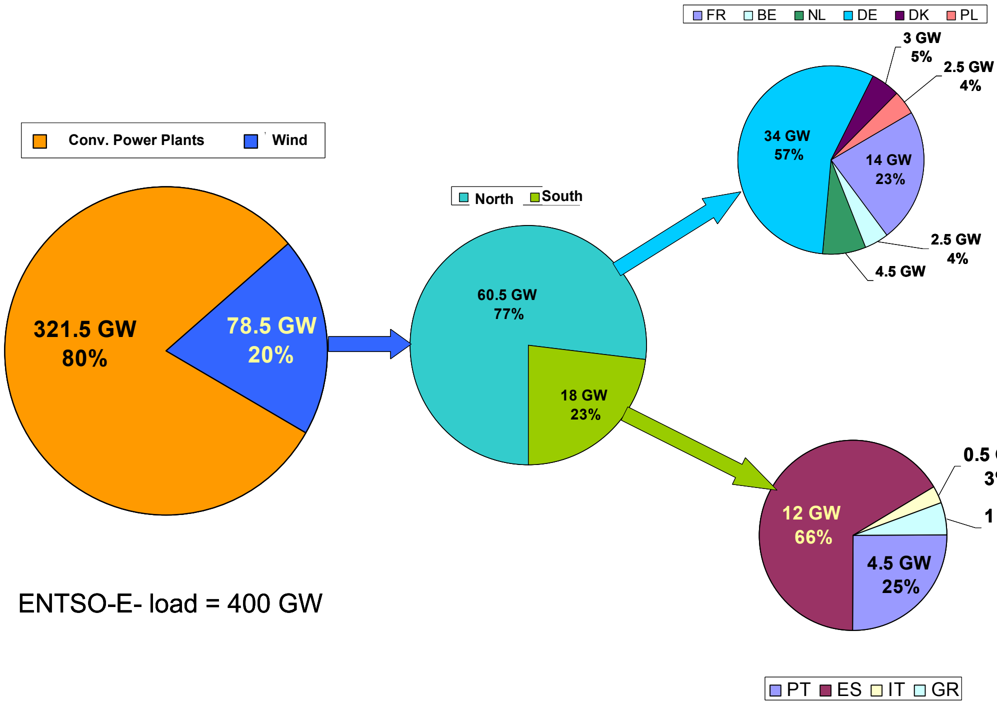


Fig. 7. Second scenario of December 2015 (North scenario)

4.4 Simulation results

Fig. 8 shows the simulation of the Inter-Area Oscillation frequency for one node in the Germany-Denmark border for the first scenario (red line) and second scenario (blue line) triggered by a 1.2 GW outage of power plant in the North of Germany. The contribution of the wind power production of ENTSO-E power system increases to 14% and 20% for the first and second scenarios respectively.

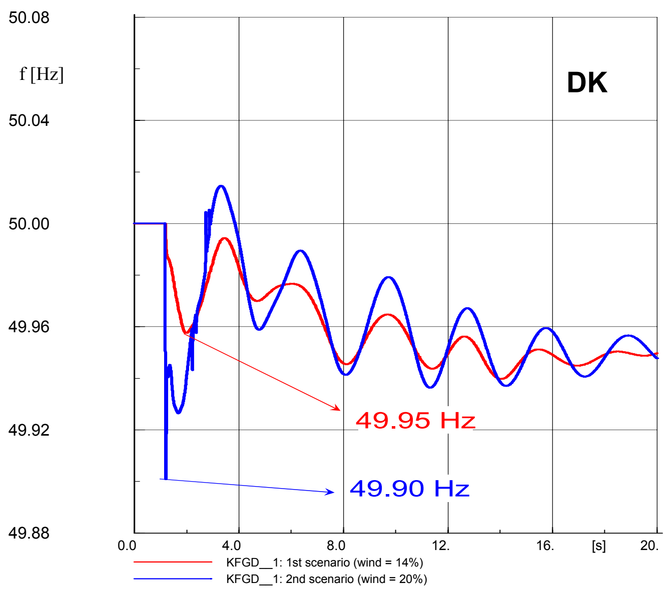


Fig. 8. Inter-Area Oscillation (Denmark against ENTSO-E) after 1.2 GW power plant outage in the North of Germany, for scenarios 1 and 2

As results, the frequency deviation for the first scenario (South scenario) reached to -50 mHz while for the second scenario (North scenario) more deeper to -100 mHz with more oscillation occurs compared to the first scenario due to the big contribution of the wind power production from the northern European countries (FR, BE, NL, DE, DK and PL). Therefore, it has to be lined out that the inertia system is reduced, if more wind power generations are connected to the system when at the same time the number of conventional power plant generators with masses are displaced by these intermittent generators as shown in the Fig. 9 while the total nominal power value of the whole system remains constant [8].

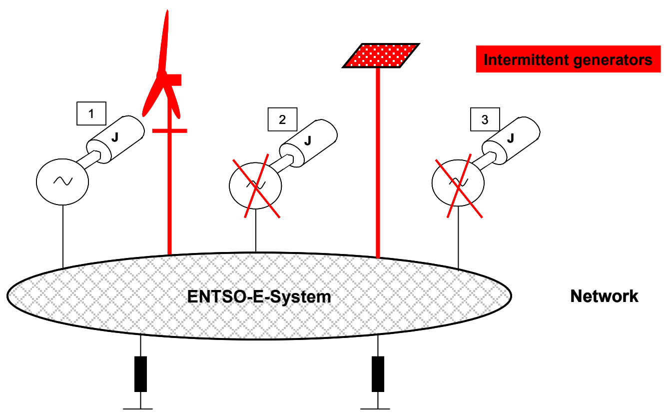


Fig. 9. European System

Fig. 10 shows the simulated Inter-Area Oscillation frequency for one node in Italy for the first scenario (red line) and second scenario (blue line) triggered by a 1.2 GW outage of power plant in Italy. As results, the frequency deviation for the first scenario (South scenario) reached to -100 mHz with more oscillation occurs compared to the second scenario (North scenario) and reached to -60 mHz due to the big contribution of the wind power production in Italy.

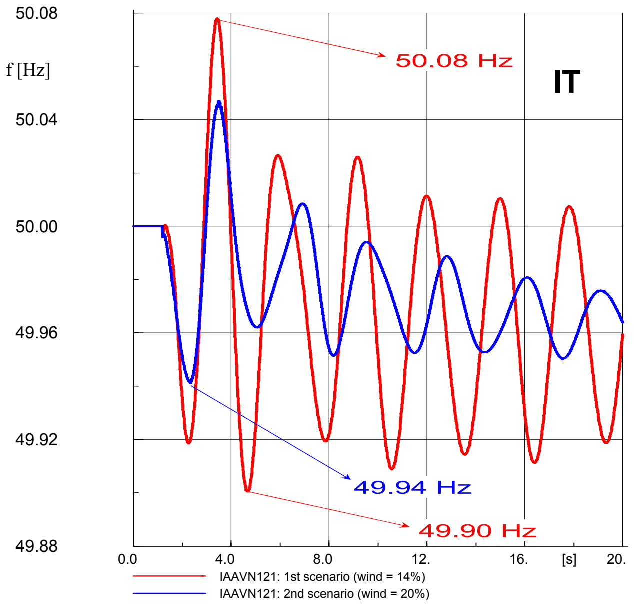


Fig. 10. Inter-Area Oscillation (Italy against ENTSO-E) after 1.2 GW power plant outage in Italy, for scenarios 1 and 2

The maximum value of oscillation amplitude in Italy reached to 105 and 180 mHz for the first and second scenarios respectively. Also it can be seen that the damping is very poor in the first scenario, because the amplitude of frequency oscillation does not decrease significantly during the first five oscillation periods. In first scenario, the frequency of the North-South Inter-Area Oscillation is calculated to 0.35 Hz (T_P= 2.9s) and the damping behaviour of the Inter-Area Oscillation can lead to the load shedding or may even cause a black-out.

4. CONCLUSIONS

The aim of this work studied the impact of the large scale wind power generation in the European ENTSO-E system on the North-South Inter-Area Oscillation mode.

The calculations of this study were based on a non-linear simulation model which is represented using DIgSILENT software for the power system simulation.

The ENTSO-E dynamic model validated by the measurement collected from the recording of WAMS. The model represented the real behaviour and therefore the model is a reliable basis for further investigations.

Two different scenarios were created by time series of the European Wind Integration Study (EWIS).

The inertia of the whole system is reduced due to the increasing of wind power generation due to the loss of the inertia system. In the future the existed North-South Inter-Area Oscillation frequency will be increase. Therefore the damping devices of the system have to be retuned in order to improve the oscillation damping behavior of the system. It has to be noted that sub networks need to install additional damping measures for the stability safety of the ENTSO-E system. Finally, the paper results show that the wind power generation has a negative effect on the damping behaviour of the ENTSO-E system.

ACKNOWLEDGMENTS

The authors would like to sincerely express their thank to 50Hertz Transmission GmbH for supporting the research project "Effects of Increasing Wind Power Generation and the Load on the damping behavior of the network and the damping measures to improve it.

REFERENCES

[1] Breulmann, H., Winter, W. and et al., (2000). Analysis and Damping of Inter-Area Oscillations in the UCTE/CENTREL Power System. CIGRÉ 2000, Paris.
[2] Kurth, K. and Welfonder, E., (2005). Oscillation Behaviour of the Enlarged European Power System under De-regulated Energy Market Conditions. Control Engineering Practice 13, pp.1525-1536.
[3] Al-Ali, S., Nassar, I., and Weber, H., (2011). Interconnection of the European ENTSO-E-CE System with the Turkish System: Investigation of the Expected Inter-Area-Oscillations Behaviour. 17th Power Systems Computation Conference, Stockholm, Sweden.
[4] GWEC., (2012). Global Wind Report Annual market update.
[5] IEEE Committee Report., *Computer representation of excitation systems.* IEEE Trans. PAS-87, No. 6, pp.1460-1464.
[6] IEEE Committee Report., *Dynamic models for steam and hydro turbines in power system studies.* IEEE Trans. PAS-92, No. 6, pp.1904-1915.
[7] Winter, W., (2010). *The European Wind Integration Study (EWIS),* EWIS Final Report.
[8] Nassar, I. and Weber, H., (2013). Influence of Increasing Intermittent Renewable Energy Sources on the Power System. Nachhaltige Energieversorgung und Integration von Speichern Symposium, Hamburg, Germany.