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STEADY STATE VOLTAGE STABILITY STUDY IN THE CONTEXT OF THE INTEGRATION OF A DFIG-BASED WIND FARM INTO THE ELECTRICITY GRID

BY

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Abstract. The paper presents a comparative study between the effects on voltage stability of the integration of a wind farm into an electricity grid using as Point of Common Coupling (PCC) the medium or high voltage substation busbars. The P-V curves are built by using the PowerFactory DigSilent 15.2.2 and the continuation power flow (CPF) method. Four cases were considered in the paper with the same level of wind power penetration at different buses that have different voltage levels. The results show that voltage stability is influenced by the penetration of wind farms, while voltage critical values at different buses are largely determined by the wind farm position in the grid and the rated voltage at the PCC.

Key words: voltage stability; continuation power flow; wind power generation.

1. Introduction

In present, due to the need of reducing greenhouse gas emissions, the renewable energy became one of the most important and studied subject. In order to ensure a sustainable economic and social development and to improve quality of life, the conventional ways of producing energy should be replaced

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gradually with renewable energy sources. One of the most widespread renewable energy sources is wind energy. The reason why wind energy is used more and more for producing electrical energy is the low impact on the environment, the fast development of the technology with less cost than other competitive technologies and its wide availability. Besides those positive aspects, this way of producing energy has also some negative effects on the voltage stability of electrical grids, especially in case of high penetration levels. Therefore, in order to ensure an acceptable level of supply continuity a thorough analysis of wind power penetration effects on voltage stability must be taken into consideration.

Thus, different studies in the literature treated specific issues related to wind power penetration in existent electricity grids. Paper (Boonchiam *et al.*, 2009) presents a study which aims to improve the penetration limit of wind energy by using FACTS devices, for two models of wind generators, using as benchmark the IEEE 14-bus test system. This study shows that from the point of view of voltage stability a Static Synchronous Compensator (STATCOM) will have better results than a Static VAr Compensator (SVC) in both analysed cases, namely when the wind farm contains fixed speed induction generators (FSIG) and when wind farm contains Doubly Fed Induction Generators (DFIG). The authors of paper (Kunwar and Krause, 2014) present the voltage stability influences of a DFIG wind farm on a modified 16–bus test system. They conclude that with the wind farm integration the loading limit will increase and voltages at all buses will show a rising trend that is higher in the proximity of the wind farm. Paper (Aly and Abdel-Akher, 2011) presents the voltage stability influence of the increasing wind power penetration, by building the P-V curves with the CPF method for a 37-bus radial test system. This study shows that both active power losses and voltage stability of the radial system are improved with wind energy integration and that they can be improved further more with the integration of some shunt capacitor banks. In (Choung and Anh, 2014) the aim is to improve the voltage stability in the Ninh Thuan grid for two cases of renewable energy integration, namely for two wind farms with different types of wind turbines (FSIG and DFIG). In addition, the authors compared various solutions to improve the voltage stability limit, like using VAr compensation, grid reconfiguration and automatic On-Load Tap Changer transformers (OLTC). The authors found that the DFIG has a better capability for voltage stabilization than FSIGs wind farm due to their ability of producing reactive power. Also by comparing the results obtained after using the voltage stability improvement methods, they conclude that in both cases the best way of improving voltage stability limit is reconfiguring the grid. The study from paper (Bhumkittipich and Jan-Nguru, 2013) analyses the voltage stability variation for the radial power system of the Sikhio’s power stations before and after installing the Lamtakong wind turbines. In this case, the authors show that the Lamtakong wind farm is capable to produce enough power to stabilize the system and improve the voltage stability.

This paper presents the impact of the integration of a DFIG wind farm on the voltage stability, by using the CPF method to build the P-V curves in different cases. Also this paper presents a comparative study between voltage stability effects of the DFIG wind farm integration in the standard IEEE 14 bus system and in a modified IEEE 14 bus system.

2. The Principle of the CPF Method

The ability of a power system to sustain steady voltages at all its buses is called voltage stability. This capacity can be evaluated by building the P-V curves at specific system buses. CPF method can be efficiently used to trace the trajectory of P-V curves for a complex power system. The CPF method purpose is to find a set of active power – voltage pairs results from a base-case up to the critical point for a given system load increase scenario. The CPF method is creating the P-V solution curve by implementing a predictor-corrector scheme as shown in Fig. 1. To do this, it starts from a known solution and then creates a tangent predictor that will be corrected with the Newton – Raphson method.

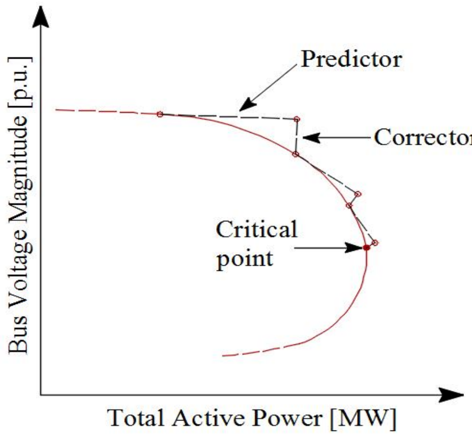


Fig. 1 – CPF: predictor-corrector scheme used to build the P-V curves.

For the simulation of different loading conditions a loading parameter λ is considered, which in the base case is $\lambda = 1$ and at the maximum loading level is $\lambda = \lambda_{crit}$. The power variation according to loading parameter is described by the following equations:

$$P_{Li}(\lambda) = P_{Li0}[1 + \lambda K_{Li}], \tag{1}$$

$$Q_{Li}(\lambda) = Q_{Li0}[1 + \lambda K_{Li}]. \tag{2}$$

where: P_{Li0}, Q_{Li0} is the active and reactive power at the base load at bus i; K_{Li} – multiplier to designate the rate of load change at bus i as loading conditions change. In this paper K_{Li} is considered the same for all buses, namely $K_{Li} = 1$.

3. Case Studies

The voltage stability analysis conducted in this paper aims to find out the optimal solution of wind energy integration into a power grid, using for benchmarking the IEEE 14-bus test system, presented in Fig. 2. The total initial loading of the system is 259 MW. Starting from this loading conditions and using an initial step of 0.5% (this step can vary between 0.01% and 2% of the total system load) and a maximum of 400 iterations, the P-V curves were built for all system buses.

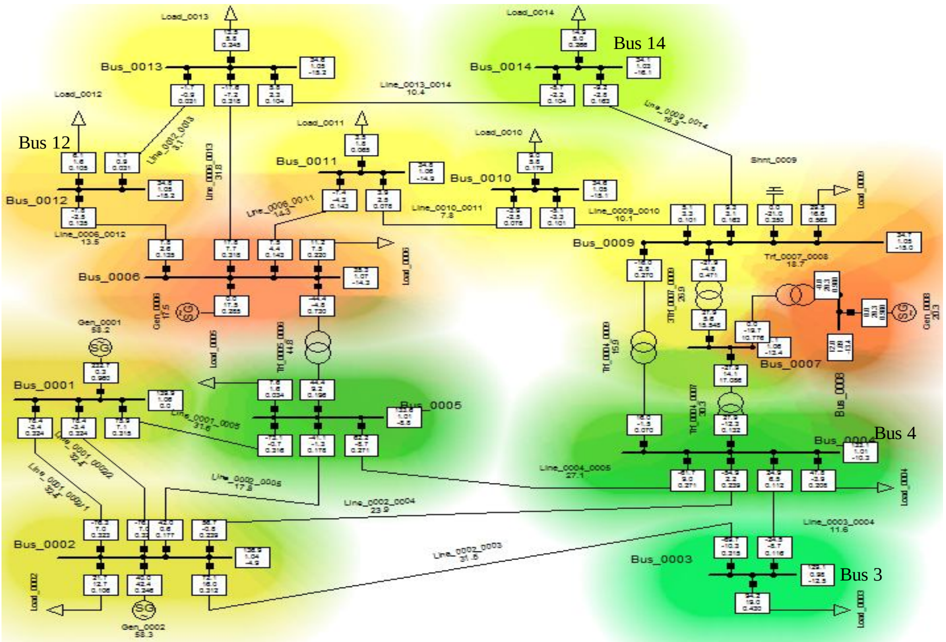


Fig. 2 – IEEE 14-bus test system.

The analysis has considered five case studies, as described below. The base case has considered the standard IEEE 14-bus test system with no wind energy integrated. In all other cases, the standard IEEE 14-bus test system was modified by adding a 20 MW DFIG-based wind farm at different buses, as presented in Table 1. The DFIG-based wind farm consists of four 4 MW DFIG generators and is modeled with a constant reactive power load controller and a capacitive power factor of 0.95.

Table 1
Specific Placement of the 20 MW DFIG-based Wind Farm for the Five Case Studies.

Case study	I	II	III	IV	V
Bus location of DFIG wind farm	n/a	3	4	12	14

In case II and III the wind farm was connected to the system at a high voltage bus, namely bus 3 and bus 2. On the other hand, in cases IV and V the PCC were chosen at medium voltage buses, namely bus 12 and bus 14. The static voltage stability studies used the PowerFactory DigSilent software to carry out the CPF method for the five cases. For all cases the P-V curves were built for the buses at which the DFIG-based wind farm was placed, namely: buses 3, 4, 12 and 14.

As a result, Table 2 presents numerical values of voltage levels at critical loading P_{crit} for the base case and for the four specific cases. These data refer also to the cases when the synchronous compensator (SC) from bus 8 was or was not considered. From Table 2 it can be observed that in the case of wind farm integration in an existing electricity grid the value of the critical active power load P_{crit} is higher when the wind farm is placed at a medium voltage bus. Also it can be observed that it improves the system voltage stability when is placed in a high voltage bus, namely at bus 4. That's because this bus is close to the SC from bus 8. In the absence of the SC from bus 8, in all cases, the voltage stability will decrease. The numerical values of P_{crit} in absence of the SC from bus 8 show that even in the best case from the four specific ones the results will still be lower than in the initial base case. On the other hand it can be observed that if we consider a base case without the SC from bus 8 the voltage stability limit is improving in case V, while in case IV is getting close to the one from the considered base case.

Table 2
Numerical Values of Voltage Levels at Critical Loading P_{crit} for the Five Cases in the Presence or Absence of the Synchronous Compensator (SC) from Bus 8

Case study	I	II	III	IV	V
V[p.u.] in Bus 3 with the SC	0.589	0.670	0.587	0.591	0.589
V[p.u.] in Bus 4 with the SC	0.772	0.824	0.771	0.779	0.779
V[p.u] in Bus 12 with the SC	1.026	1.029	1.025	1.033	1.025
V[p.u.] in Bus 14 with the SC	0.898	0.918	0.897	0.896	0.904
V[p.u.] in Bus 3 without the SC	–	0,669	0,592	0,589	0,586
V[p.u.] in Bus 4 without the SC	–	0,792	0,732	0,740	0,739
V[p.u] in Bus 12 without the SC	–	1,021	1,016	1,024	1,016
V[p.u.] in Bus 14 without the SC	–	0,829	0,798	0,794	0,807
P crt [MW] with the SC	560	546	565	571	572
P crt [MW] without the SC	527	501	517	527	530
Bus location of DFIG wind farm	–	3	4	12	14

The P-V curves were built for two assumptions, namely the four studied cases in the presence and in the absence of the SC from bus 8. Also, the P-V curve for the base case in the presence of SC from bus 8 was represented in all figures. Figs. 3 to 10 present the P-V curves for the four buses of the test system (buses 3, 4, 12 and 14). In those figures the base case was represented by

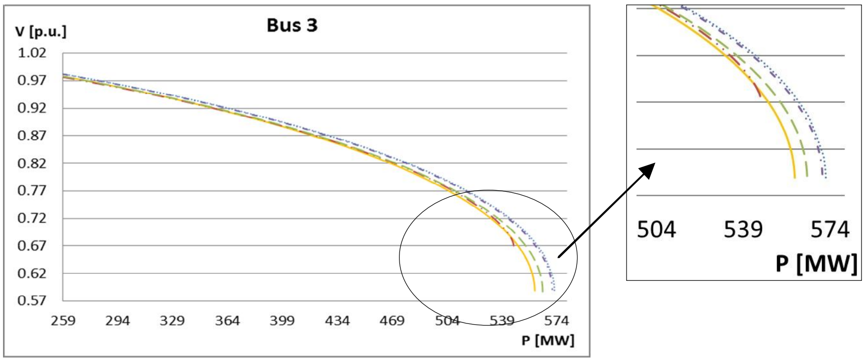


Fig. 3 – Bus 3 P-V curves in the presence of SC for all studied cases.

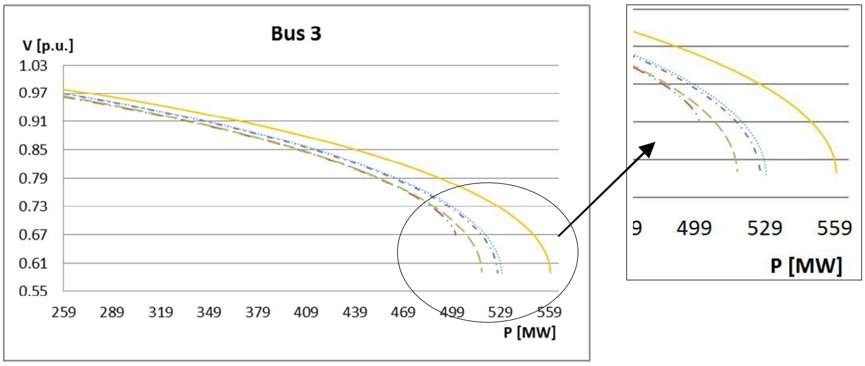


Fig. 4 – Bus 3 P-V curves in the absence of SC for all studied cases.

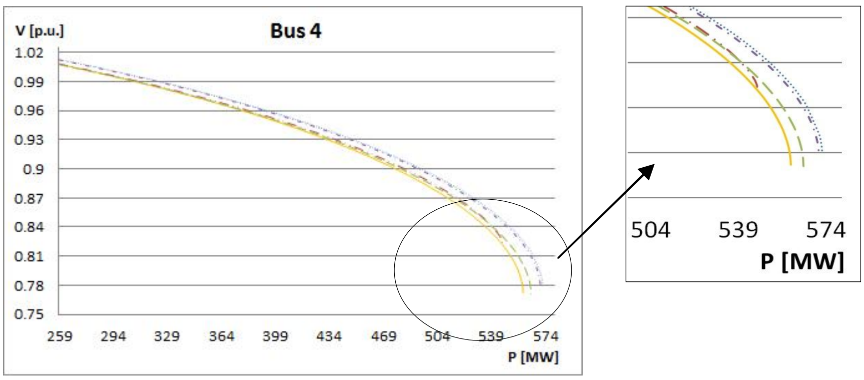


Fig. 5 – Bus 4 P-V curves in the presence of SC for all studied cases.

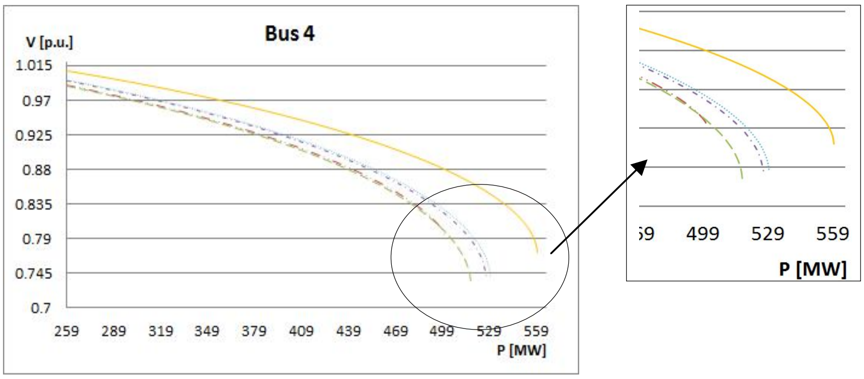
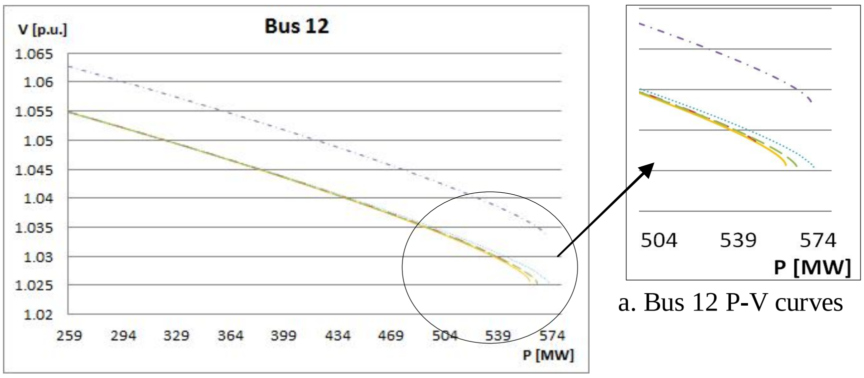


Fig. 6 – Bus 4 P-V curves in the absence of SC for all studied cases.



a. Bus 12 P-V curves

Fig. 7 – Bus 12 P-V curves in the presence of SC for all studied cases.

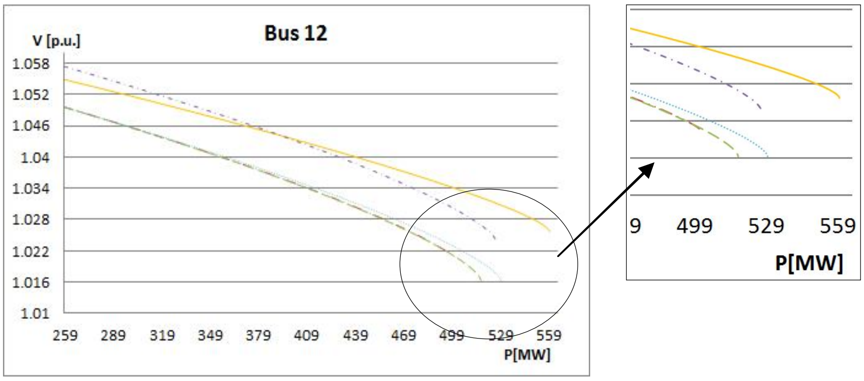


Fig. 8 – Bus 12 P-V curves in the absence of SC for all studied cases.

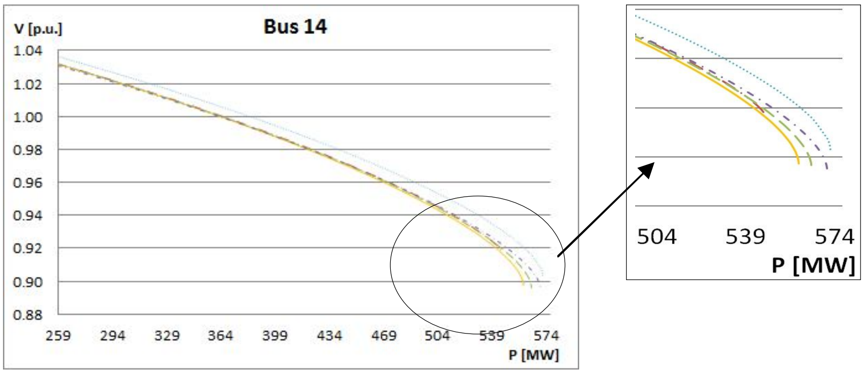


Fig. 9 – Bus 14 P-V curves in the presence of SC for all studied cases.

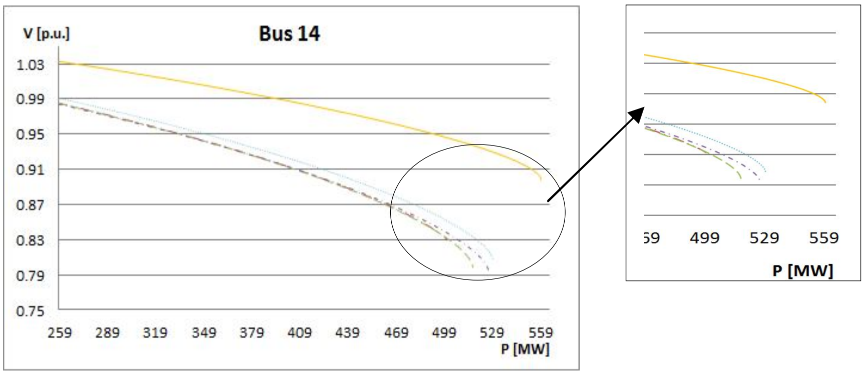


Fig. 10 – Bus 14 P-V curves in the absence of SC for all studied cases.

a continuous line, case II by a dash double dotted line, case III by a long dash line, case IV by a dash dotted line and case V by a round dotted line. From these figures it can be observed that the test system has better voltage stability in cases IV and V, which demonstrates that the system will have better voltage stability when the PCC of the wind farm is located closer to the system load area. Also from those figures it can be observed that in all studied cases, no matter where the PCC of the wind farm is located, the wind farm can't compensate the absence of the SC from bus 8 and the voltage stability limit is lower than the voltage stability limit from the base case.

4. Conclusions

This paper presents the results of an analysis that aims to evaluate the effects of wind farm integration in existing electricity grids over the voltage stability characteristics of the grid.

The case studies were conducted using the well-known IEEE 14-bus test system and different hypotheses considering the location of the wind farm and the presence or absence of the SC from bus 8.

The results show that voltage stability is influenced by the penetration of wind farms, while voltage critical values at different buses are largely determined by the wind farm position in the grid and the rated voltage at the PCC.

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REFERENCES

Aly M.M., Abdel-Akher M., *Voltage Stability Assessment for Radial Distribution Power System with Wind Power Penetration.* IET Conf. on Renewable Power Generation (RPG 2011), Edinburgh, 1-6, January, (2011).

Bhumkittipich K., Jan-Ngurn C., *Study of Voltage Stability for 22 kV Power System connected with Lamtakhong Wind Power Plant, Thailand.* 10th Eco-Energy and Mater. Sci. a. Engng. (EMSES), Energy Procedia, **34**, 951-963 (2013).

Boonchiam P.N., Sode-Yome A., Mithulananthan N., Aodsup K., *Voltage Stability in Power Network when Connected Wind Farm Generators*. Internat. Conf. on Power Electron. A. Drive Syst., PEDS 2009, December, Taipei, 655-660 (2009).

Chuong T.T., Anh T.V., *Study of the Voltage Stability of Distribution Network Connected Induction Machines*. Internat. Conf. on Power Syst., Energy, Environ., 63-68 (2014).

Kunwar A., Krause O., *Steady-State and Transient Voltage Stability Analysis of a Weak Distribution System with a Remote Doubly Fed Induction Generator-Based Wind Farm*. Energy Sci. a. Engng., **2**, *4*, 188–195, October (2014).

STUDIUL STABILITĂȚII STATICE A TENSIUNII ÎN CONTEXTUL INTEGRĂRII UNUI PARC EOLIAN CU TURBINE DE TIP DFIG ÎN REȚELELE ELECTRICE

(Rezumat)

Se prezintă un studiu comparativ între efectele integrării unui parc eolian asupra stabilității tensiunii atunci când este utilizat ca punct comun de conectare un nod de medie tensiune sau un nod de înaltă tensiune. Curbele de tip P-U sunt construite utilizând programul PowerFactory DigSilent 15.2.2 şi metoda CPF. În lucrare s-au considerat 4 cazuri cu acelaşi nivel de integrare a energiei eoliene în diferite noduri ale rețelei ce au nivele diferite de tensiune. Rezultatele arată că stabilitatea tensiunii este influențată de integrarea parcului eolian, în timp ce limita stabilității este determinată în special de poziția parcului eolian în rețea precum şi de nivelul de tensiune din punctul comun de conectare.