2010 IEEE International Conference on Power and Energy (PECon2010)., Nov 29 - Dec 1, 2010, Kuala Lumpur, Malaysia

Influence of Distributed Generations and Renewable Energy Resources Power Plant on Power System Transient Stability

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***Abstract*— This paper analyzing influence of distributed generation (DG) on transient stability of power system network operating parallel with large renewable energy resources (RES) power plant. The study is performed in hypothetical power system network envision in the future which contains a large number of DG. Network behavior when subjected to disturbance is compared with different level of DG penetration. The results are compared with the performance of the network without DG and RES power plant as a reference case. It can be concluded that addition of DG and RES power plant makes power system network more transiently stable. This integration enhances the power system network capability in handling more larger disturbances.**

***Keywords* — Transient Stability; Distributed Generation; Renewable Energy Resources; Fault Ride Through**

I. INTRODUCTION

The need for unconventional generation units for supplying electricity is clearly due to various reasons such as responding to current climate change; depleting sources of fossil fuel; and to overcome the threat on security, reliability, and quality of supplies due to ageing infrastructures. It is anticipated that future generation of electricity will be shared between central power plants, small scale distributed generation (DG) units and large renewable energy sources (RES) power plant. In this electricity network as illustrated in Fig. 1, DG and large RES power plant will replace a proportion of electricity presently generated by conventional power plants [1-2]. DG technologies mostly anticipated in future network is microturbine generation system (MTGS), fuel cell generation system (FCGS) and photovoltaic generation system (PVGS).

The sharing of generation among conventional power plant, large RES power plant and DG is in fact already realized in many European countries. In Germany for example, by the end of 2007, 22.2 GW of wind turbines and 3.8 GWp of Photovoltaic systems had been installed. Combining with other energy sources including hydropower and biomass plant a total of 34 GW RES has been installed [3]. This magnitude of penetration is considered significant comparing to the Germany load demand of 40-80 GW. This DG and RES can constitute more than 50% of the total power generation when the weather condition is optimum.

With this large number penetration, some conventional power plant is dismantled and the supplied power is replaced by DG and RES which are mostly coupled to grid through power electronic converter (PEC). Different characteristic posses by these nonconventional generation creates a lot of concern on power system network stability which led to transient stabilities studies [4-5,13]. In [4-5] the stability of a power system network with the penetration of DG is analyzed. In [13] the influence of windfarm on transient stability is investigated in. It is demonstrated these nontradional generation units improves the stability of power system if they are properly sized, located and controlled.

In [4-5] however DG units are disconnected if the voltage at the point of connection goes bellow 80 % [4] or 85% [5]. This disconnection however creating another disturbance to the network after already went through a critical situation. If DG penetration is large as expected in future power system which is termed smart grid, there is substantial loss of active power supply inside the network and this strategy is feared will brings the power system network to instability. In [13] the influence of different control strategy in wind farm and the influence on power system stability is compared. In this studies even voltage at the point of connection reaching zero, fault ride through is necessary if the disturbance is less than 150 ms. With appropriate control, addition of wind farm to power system is shown enhances power system transient stability.

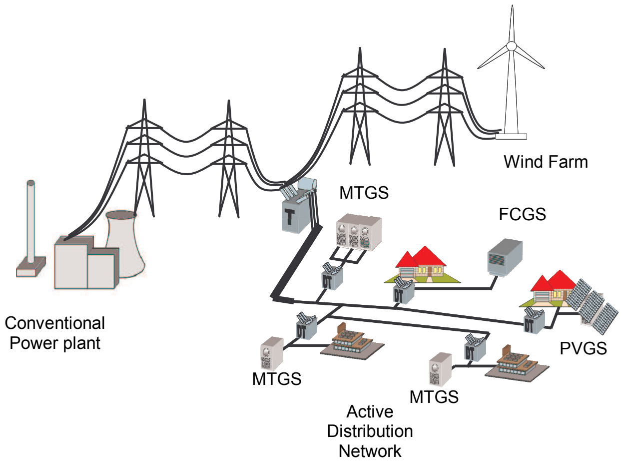

Figure 1. Future power system network.

All these studies however investigate the influence of nonconventional generations separately where only DG is considered in [4-5] and only large windfarm considered in [13]. There is so far lack of technical publication assessing the stability of the network considering both DG connected to LV and large windfarm connected to HV.

In this paper, transient stability of the power system with the large penetration of DG connected to LV levels operating parallel with large RES connected to HV bus is studied. Grid code which demands fault ride through and at the same time providing a reactive support is considered. Transient stability is analyzed with different levels of DG penetration.

II. CHARACTERISTIC OF PEC BASED DG

DG coupled to electrical grid through power electronics converter possesses different characteristics compare to the conventional generator connected directly to the grid. The power system network that we know today is evolved based on the synchronous generator characteristic. In summary, conventional power system operation and control is influenced greatly by the characteristic of synchronous generator as follow [14]:

- Magnitude of short circuit current is high due to low source impedance and no current limiting devices or control is equipped.
- Current rating is subjected to the withstand capability of the winding insulation to the rise of temperature. Short circuit current up to 10 times of the nominal current can be tolerated for a few cycles due to relatively large thermal time-constant of the winding and surrounding steel.
- Real power exchange is proportional to the applied torque to the rotor shaft. Power output can be made proportional to the frequency by applying closed loop governor setting.

The corresponding characteristics of the power electronic converter are:

- Short circuit current can be controlled and limited with the current control loops.
- Current rating is largely determined by thermal withstand capability of semiconductor devices. Large over currents will cause device failure due to very short thermal time-constant of the semiconductor devices.
- Power exchange can be controlled by providing power setpoint to the controller subjected to the converter rating.

Huge differences in characteristics makes clear a need to perform a thorough study on power system operation and control with the large penetration of power electronic based DG. The influence of this new generation technology on the traditional power system therefore must be assed to evaluate any necessary modification to be made to maintain the stability, security and reliability of power system.

III. GENERATOR FAULT TOLERANCE

In a large interconnected power system network, each generation unit must participate in maintaining the stability, security and reliability of the of power system which it is connected to. Each unit must have a capability to recover voltage and remain in synchronism with the power system after a disturbance. In a future grid in addition to this capability, each generation unit must also has a capability to ride through a fault. This fault ride through (FRT) requirement is depicted in Fig. 2 for synchronous generator connected to HV grid. As depicted in Fig. 2, the unit must remain connected to the grid even if the voltage at the point of connection reaching zero for up to 150 ms.

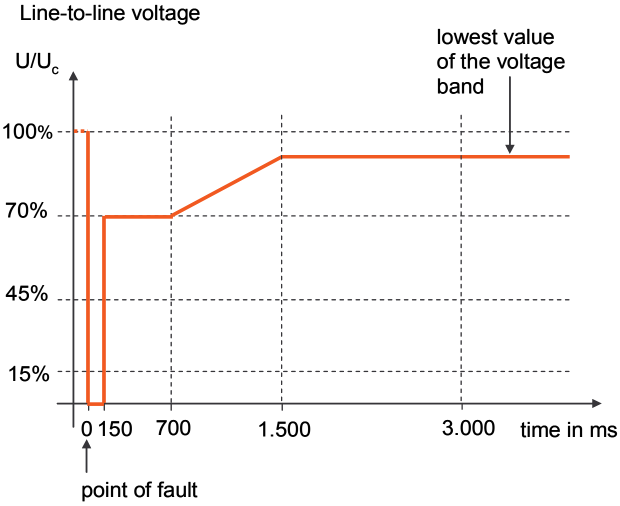

Figure 2. FRT requirement for SM connected to HV network [6]

For non-traditional generator which includes generation units interface to the grid through PEC, the requirements are different and are depicted in Fig. 3 when connected to HV network and Fig. 4 if it is connected to MV voltage level. But the similarity is in the FRT requirement for the first 150 ms after the occurrence of fault. Non traditional generators must also remain connected to the grid even when the voltage at the point of connection reaching zero value for up to 150 ms.

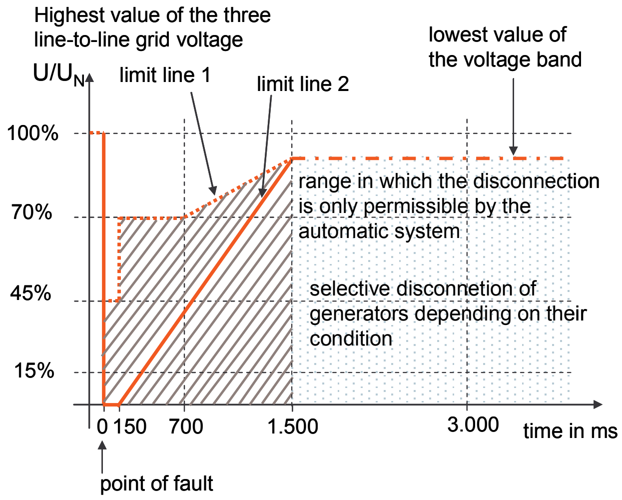

Figure 3. FRT requirements for PEC coupled generation unit connected to HV network [6].

For generators coupled to grid through PEC, additional requirements are imposed. During the FRT through, the generator is demanded to inject reactive current with the gain of at least two as depicted in Fig. 5. This reactive support supposed to be available within 20ms after fault was detected and be added to already injected reactive current during steady state operation. After the voltage already returned inside the deadband range, this reactive support must still be continually provided further for at least 500 ms. If the voltage however rises above 110% after the faults is cleared, an inductive reactive current in opposed to capacitive is demanded to reduce the grid voltage.

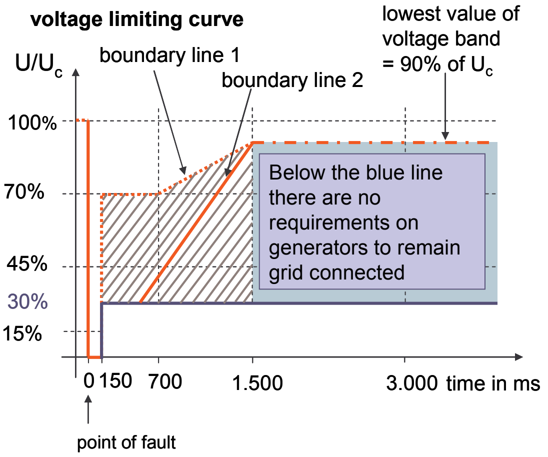

Figure 4. FRT requirement for PEC coupled generation unit connected to MV network [7].

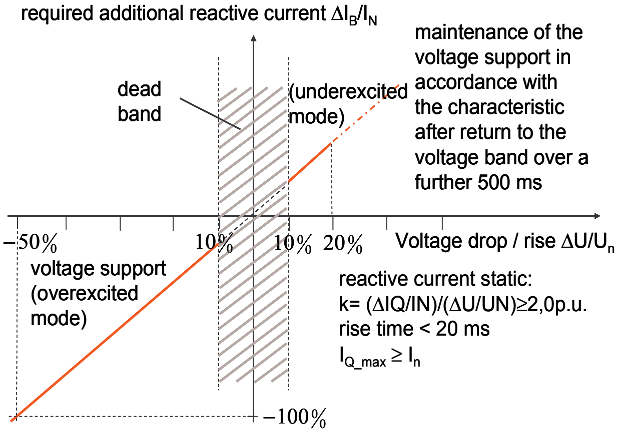

Figure 5. Demanded reactive support from PEC coupled generation unit

In Germany, DG with rated capacities from 100 kVA up to 10 MVA is directly connected to the MV network (10kV to 35 kV). These DG units include large PV plants, CHP units and single or several wind turbines. For these generators grid code for medium voltage level depicted in Fig. 4 [7] applies. For the generation unit connected to LV, FRT and reactive support is still not required but in this study, the requirements as depicted in Fig. 4 and Fig. 5 are assumed.

IV. POWER SYSTEM DESCRIPTION

Power system network considered is similar to the network used in [4]. This network as depicted in Fig. 7 comprises two HV level 380 kV and 110 kV. There are two conventional power plant with synchronous generators (SG) connected through step up transformer to 380 kV bus. SG_2 in the studies is treated as a slack generator. The area which is circled and colored in green is where the distribution network with DG is connected. Six typical distribution networks as shown in Fig. 7 are connected to the 110 kV busses in this area.

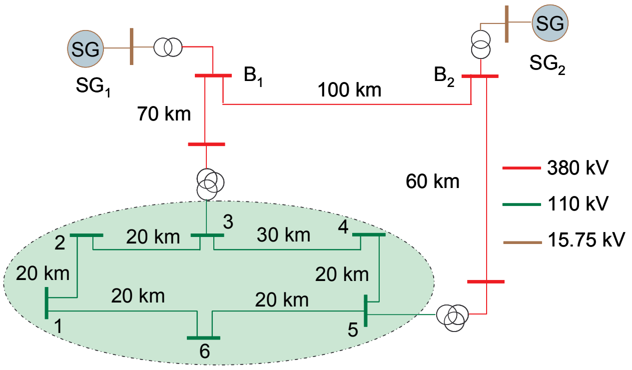

Figure 6. Test power system network

A. Distributed Generation

DG interfaces to the grid using PEC has no direct coupling between grid and DG sources. The characteristic of this kind of DG is greatly influence by its line side converter (LSC). It is therefore acceptable to represent MTGS dynamic model introduced in [8] to represent nontraditional DG coupled to the grid through PEC in performing power system studies. Each MTGS as shown in Fig. 8 is rated at 1.4 MVA and comprised of back to back voltage source converter with DC circuit. LSC is used to control reactive power and DC voltage while terminal voltage of permanent magnet synchronous machine (PMSM) is controlled through machine side converter (MSC).

MTGS is model to follow the requirements of the grid code depicted in Fig. 4 and Fig. 5. For allowing MTGS injecting high amount of reactive current during FRT, the maximum allowable total current output is temporary change to 1.5 p.u. of rated current. This DG technology is shown capable in meeting these new grid code requirements as demonstrate in [9].

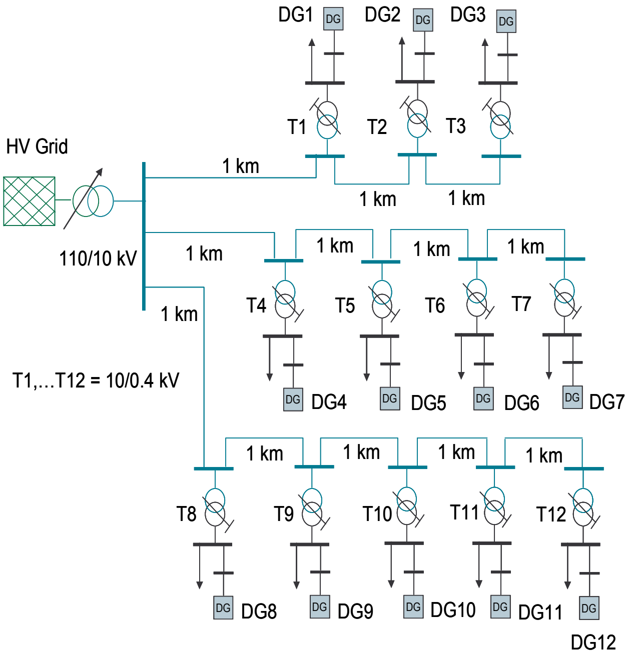

Figure 7. Distribution network with DG

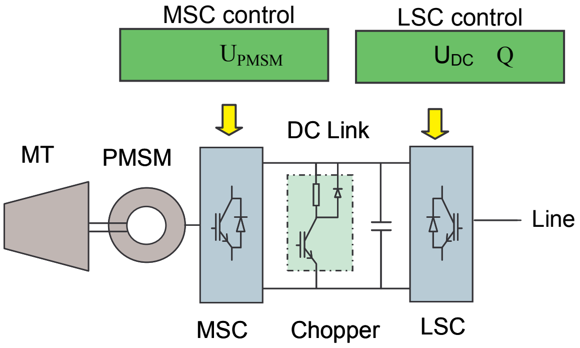

Figure 8. Layout of single shaft MTGS

B. *Wind Farm*

With installation of 22.2 GW by the end of 2007 [3] and comparing to German load demand of 40-80 GW, performing stability study without considering wind penetration is considered unrealistic. Wind turbines operated as a wind farm with rated capacities from 10 to 200 MW is fed directly into 110 kV level. In the studies carry out in this paper, 25 MW wind farm (refer Fig. 9) comprises of five 5 MW DFIG wind turbine [10] is considered. This wind farm is connected to bus 3 which is 110kV bus. DFIG is considered as nearly all modern large wind turbines are based on this technology. Compared to the wind turbine using PMSM interface to the grid through full size converter, this DFIG technology posses an advantage in usage of smaller and cheaper converter but still possesses reactive power controllability. The layout of DFIG wind turbine is shown in Fig. 10.

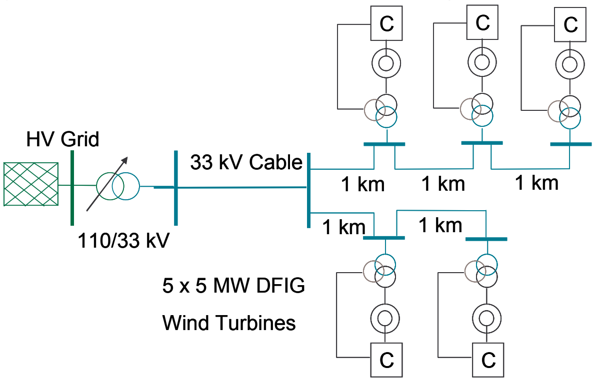

Figure 9. Layout of the wind farm

V. SIMULATION RESULTS

All modelings and dynamic simulations are carried out in simulation package Power System Dynamic software [11]. Synchronous generator is modeled as fifth order model with the rated voltage of 15.75 kV. Typical parameters of thermal units are used. For speed governors and excitation systems, standard IEEE regulators are used.

A. *Generator response to grid fault*

SG, DFIG wind turbine and MTGS due to different in technology responding differently when the voltage at their connection node reduce sharply due to fault in the grid. Fig. 11-13 respectively depicting the response of the SG, DFIG and MTGS when power system network in Fig. 6 is subjected to temporary self-clearance three phase fault at bus B_2 for 150 ms. This fault causes the voltage dip of 75 % from the nominal voltage throughout the network. During the fault and after the fault no component inside the network is disconnected.

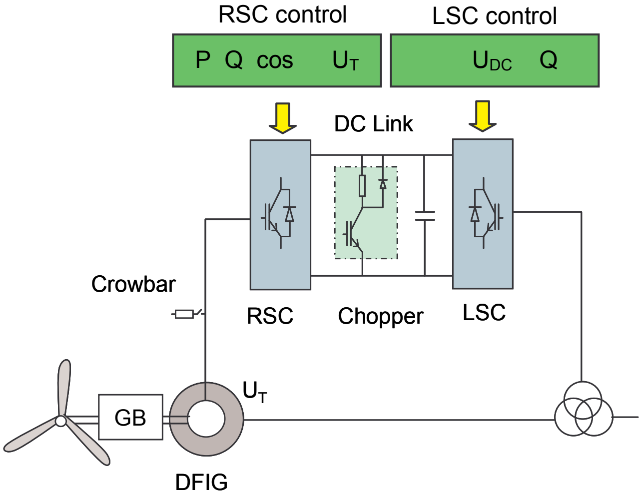

Figure 10. Layout of the DFIG wind turbine

All types of generators in responding to voltage dip at the point of connection inject lower active power because rated power cannot be transfer due to drop in voltage. Reactive power however during this time is temporarily increases. For SG reactive power changes during this low voltage even is only a small portion of its rating. For DFIG wind farm the reactive power changes is 15 MVar. For MTGS its reactive power output rises to nearly 1.5 MVar. This amount is considered significant comparing to its rating of 1.4 MVA. But it is already mention before during this critical time the allowable maximum current is change to 1.5 p.u of the rated value with the priority is given to the reactive component. Active current during this FRT is temporarily curtailed.

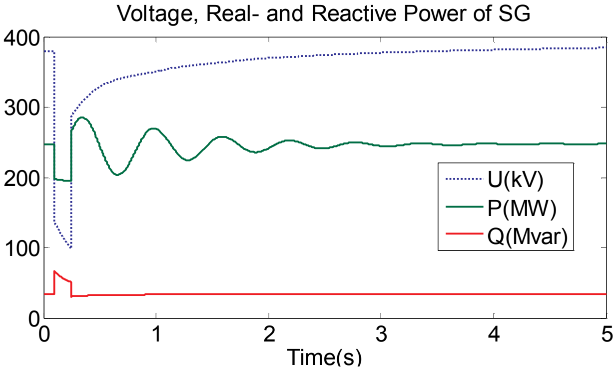

Figure 11. Response of SG to a grid fault

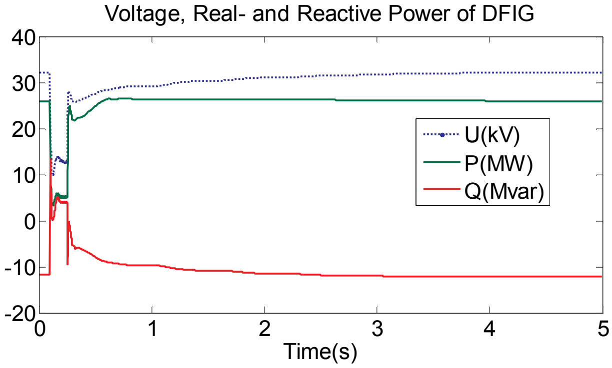

Figure 12. Response of DFIG wind farm to a grid fault

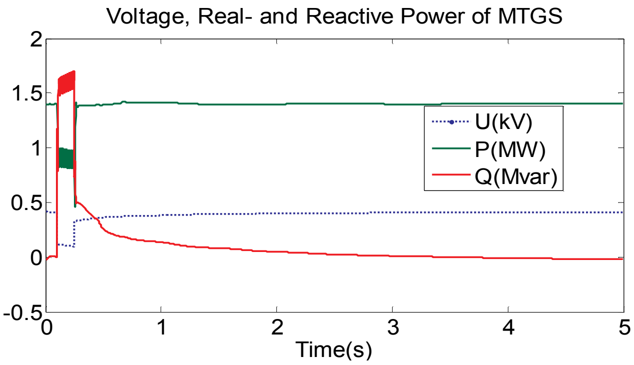

Figure 13. Response of MTGS to a grid faults.

B. Transient Stability

With different output characteristic illustrated in previous subsection, transient stability of the power system is a main concern. Transient stability is the ability of the synchronous generator in interconnected power system network to remain in synchronism after been subjected to a disturbance [12]. In broadest sense, it is capability of a power system to survive a variety of disturbances in the system and have the generation and load return to a balance condition. It is also referred to first swing stability. Initial operating condition of the system, as well as the type, severity of the location will affect this transient stability. Most widely used method in assessing transient stability is time domain simulation method which is adopted in this study. The excursion of power angle between synchronous generators is used to evaluate the stability.

C. Transient Stability with DG

To access the transient stability a few cases is investigated. In the first simulation setup, no wind farm is considered. The base case is the power system with conventional generator only (case 1). Case 2 considering maximum penetration by DG without many changes necessary on the existing infrastructures and control devices inside network. DG penetration in this case 2 is 40 %. In a future power system network under smart grid, distribution network is expected to be an active network where it is not only importing active power but also exporting active power when required. This requires penetration of larger than 40 % of DG. This amount of penetration making it possible to operated the whole distribution network as a cell or some portion of the network as a microgrid which are two concept of DG control under smart grid concept. This envisions operation is considered under case 3 and case 4 with 80 % and 110 % respectively. Summary of the cases simulated is tabulated in Table I.

Fig. 14 depicting the change of the power angle of SG1 in respect to SG2 following 150 ms self temporary fault which occurs at bus B2. As desired by new grid code requirements there are no parts of the networks are disconnected during the fault. From the observation of the first swing, addition of DG units reduces the magnitude of the maximum angle deviation. This reduction is seemed proportional with the penetration level and also consistent with the result presented in [4-5] but [4-5] only performed stability studies with the maximum DG penetration of 40 % only. With larger penetration simulated of which 80 % and 110 %, the maximum rotor angle deviation is furtherly reduced. This indicates that more extreme penetration of DG improves power system transient stability.

TABLE I.
SUMMARY OF THE SIMULATED CASES

Cases	Description
Case 1	DG Penetration is 0 %
Case 2	DG Penetration is 40 %
Case 3	DG Penetration is 80 %
Case 4	DG Penetration is 110 %

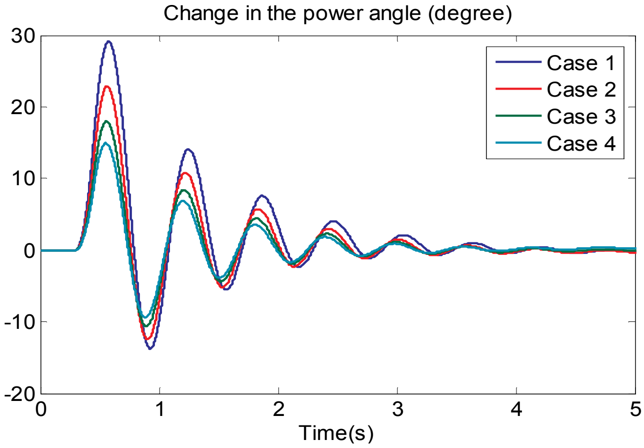

Figure 14. Change of power angle against DG penetration

D. Transient Stability with DG and RES

In the second simulation setup, 25 MW wind farm is added to the power system network. For the base case again the power system network only fed by conventional generator is simulated as case 1. Power system with wind farm but without DG is considered in case 2. In case 3 power system is fed by conventional synchronous generator and wind farm with 40 % penetration level of DG. Penetration of DG of 110 % is simulated in case 4. All simulated cases are summarized in Table II.

TABLE II.
SUMMARY OF THE SIMULATED CASES

Cases	Description
Case 1	No Wind farm and no DG
Case 2	25 MW Wind farm with 0 % DG
Case 3	25 MW Wind Farm with 40 % DG
Case 4	25 MW Wind Farm with 110 % DG

From the observation of the first swing in Fig. 15, addition of wind farm and DG units reduces the magnitude of the maximum angle deviation. This reduction in power angle is proportional with the penetration level of DG. This indicates that combination of DG and wind farm furtherly improves the power system transient stability.

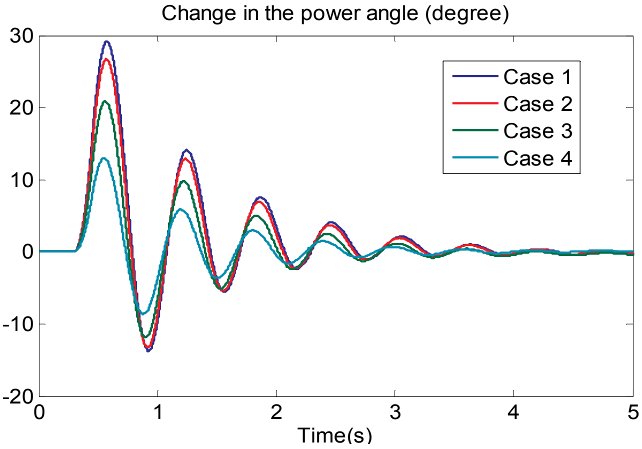

Figure 15. Change of power angle against DG penetration considering wind farm.

E. Comparing Transient Stability with and without wind farm

It is of interest to know to what extend the influence of wind farm on the power system network in handling disturbance. In Fig. 16 the deviation of power angle is compared for the same DG penetration level. Observation on the first swing clearly indicate power system network is more transiently stable with combination of wind farm and DG in opposed to only DG. Network is evident to have more capability in withstanding more larger disturbance.

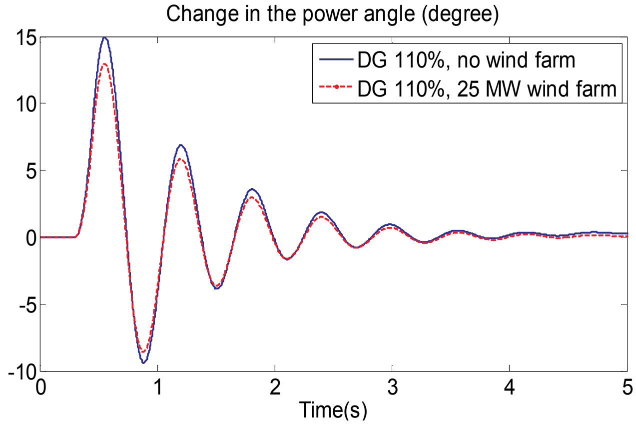

Figure 16. Change of power angle for the same DG penetration with and without wind farm.

VI. CONCLUSION

In this paper, stability of hypothetical power system network has been studied and analyzed through digital simulation. In the first simulation setup, only DG penetration is considered. The power system is found more transiently stable with increasing penetration of DG. In the second simulation setup, transient stability is assed with different level of DG penetration but this time with the consideration of wind farm connected to HV level. The mix of RES power plant and DG is found further improved power system transient stability. It can be concluded that sharing generation between conventional power plants with a large RES power plant and small scale DG units improves power system transient stability and enhances the network's capability in handling larger disturbances. Extended research works is at the same time is carried out to asses different type of power system stabilities such as small signal stability, frequency stability and voltage stability.

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