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Mitigation of Voltage Fluctuations in Power System Using STATCOM

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Abstract
Wind energy being a renewable source of energy is enjoying a rapid growth globally. However, wind energy being an uncontrollable source of energy coupled with the fact that it uses distributed induction generators for power conversion poses a challenge in integrating a large scale wind-farm into a weak power system. An actual weak power system with two large Wind-Farms (WFs) coupled to it is introduced as part of this study. A model of this integrated system along with a STATCOM for steady state and dynamic impact study is developed in the MATLAB/Simulink environment. The power quality issues are highlighted and a centralized STATCOM is proposed to solve the issue of the voltage fluctuations in particular in addition to addressing the other issues. Based on the results obtained from the simulation, the system voltage control issues are analyzed and the location of STATCOM is assessed. Finally, a STATCOM control strategy for suppression of voltage fluctuations is presented.
Index Terms— Static synchronous compensator (STATCOM), voltage fluctuation, voltage stability, wind farm (WF).

I. INTRODUCTION

RECENTLY, mainly due to the technology innovation and cost reduction, renewable wind energy is enjoying a rapid growth globally to become an important green electricity source to replace polluting and exhausting fossil fuel. The wind turbines with 2–3-MW capability have already been commercially available and a 5-MW wind turbine also will be available in a few years. The cost of wind energy has been reduced to 4.5 cents/kWh and is very competitive against conventional fuels, and will be further reduced to 3 cents/kWh for utility-scale wind energy onshore and 5 cents/kWh offshore by 2012.Wind being an uncontrollable resource and the nature of distributed wind generators into a power system poses challenges. Conventionally, Mechanical Switched Cap (MSC) banks and Transformer Tap Changers (TCs) are used for Stability and Power Quality issues. The issues such as power fluctuations, voltage fluctuations, and harmonics, cannot be solved satisfactorily by them because these devices are not fast enough. Therefore, a fast response Shunt VAR Compensator (STATCOM) is needed to address these issues more effectively. The static synchronous compensator (STATCOM) is considered for this application, because it provides many advantages, in particular the fast response time (1–2 cycles) and superior voltage support capability with its nature of voltage source. With the recent innovations in high-power semiconductor switch, converter topology, and digital control technology, faster STATCOM (quarter cycle) with low cost is emerging, to achieve a more cost-effective and reliable renewable wind energy. Firstly, an actual weak power system with two large WFs are introduced. Secondly, a model of the system, WF and STATCOM for steady state and dynamic impact study is developed in MATLAB/ Simulink model. The power quality issues are highlighted and a centralized STATCOM is proposed to solve them, particularly voltage fluctuations. Based on the results obtained from the simulation the system voltage control issues are analyzed and the location of STATCOM are assessed. Finally, a STATCOM control strategy for voltage fluctuation suppression is presented.

II. SYSTEM DESCRIPTION

Fig. 1 shows the diagram of the system investigated in this paper. The two WFs, WF1 and WF2, are connected to the existing 69-kV loop system at bus 3 and 5. The system is supplied by the two main substations, which are represented by three remote boundary equivalent sources at bus 1, 2, and 12. Among them, bus 1 is a strong bus with a short-circuit capacity of about 4000 MVA. The WF2 at bus 3 is a large WF with a total rating of 100 MVA. It is a type C WF [2] with variable-speed double fed induction generators (DFIGs) and partial back-to-back converters. The WF1 at bus 5 is located at the middle of the weak 69-kV sub transmission system, and the short- circuit capacity at the bus 5 is about 152 MVA

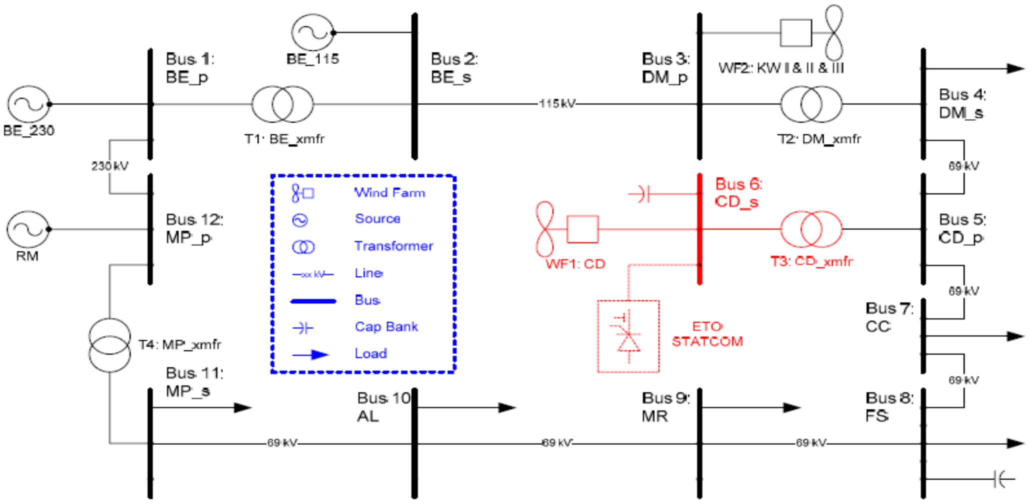


Fig. 1. One-line diagram of the studied system.

The WF1, with a total rating of 50 MVA, is a type A WF [2] using fix-speed squirrel-cage induction generators (SCIGs). The six loads tapped on the 69-kV weak loop system are mostly rural radial loads. The loop network is normally kept closed to improve the reliability of power supply. The integration of WF2 into the grid is facilitated by the power-converter-based interface as it provides VAR compensation capability and, hence, voltage control capability. On the other hand, theWF1 poses a challenge, as the SCIGs sink more VARs when they generate more real power, the generated wind power is rapidly fluctuating with uncontrollable wind speed and large surge current during frequent startups of wind turbines. Thus, when WF1 is located at the weakest part of the loop system, these characteristics ofWF1 not only increases the transmission and distribution losses, reduces the system voltage stability margin, and limits power generation, but also causes severe voltage fluctuations and irritates the customers in the system, particularly in the weak 69-kV loop, where a significant portion of the loads are induction motors, which is sensitive to voltage fluctuations. There is also voltage fluctuation even without any WF1 generation, which means that the voltage fluctuations of local system are not only caused by generated power fluctuation of WF1, but they are also contributed by WF2 and voltage fluctuations at the remote boundary buses. Therefore, a single STATCOM using emitter turn-off (ETO) thyristor [10] and cascaded-multilevel converter (CMC) [11] is proposed to suppress the voltage fluctuations of the weak loop system.

III. MODELING AND CONTROL

A. Twelve-Bus System Model

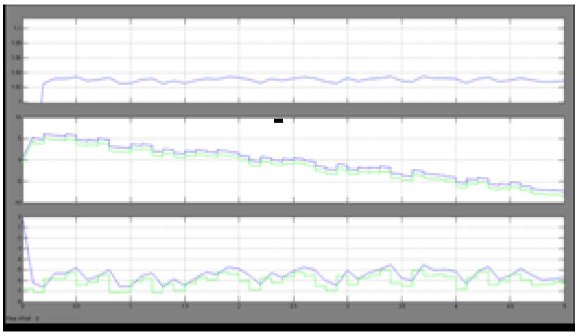
The system shown in Fig. 1 is modeled using MATLAB/ SIMULINK. Since only balanced operation is considered for this study, the positive-sequence dynamic model is developed. Some of the details include the following.

- Boundary equivalent source is modeled as ideal voltage sources with series equivalent impedances.
- Transmission lines are represented by their equivalent π model.
- Transformer is implemented using the PSCAD classical transformer modeling approach and including the leakage inductance and resistive loss.
- Loads are considered as constant power. Only one load profile is considered. Data for the monitored loads are obtained from the SCADA, and for the non monitored loads, they are assumed to be 30% of their supply transformer rating.

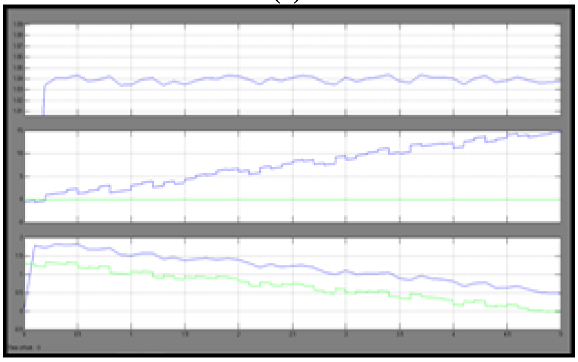
B. WF Model

Since the focus in this paper is on the system impact study of electrical power flow and voltage, the implemented model of the WFs does not include mechanic dynamics and the detailed electrical model of induction machine [6], [12], and it is an ideal voltage source with equivalent series and shunt impedance. For such a WF model, the following assumptions have to be made.

- All wind turbines are identical.
- Wind speed is uniform, so that all wind turbines share the same power generation.
- Each turbine runs at the same operating modes at all times, and the voltages, current, and power factor of each turbine are the same.
- The series equivalent impedances of underground cables that connect the SCIGs to the common bus 6 are negligible.
- All transformers connecting individual SCIGs are identical.



(a)



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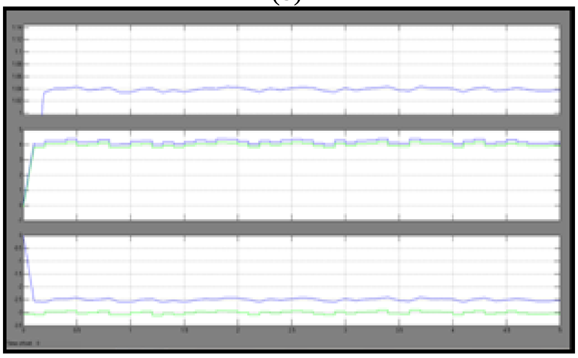

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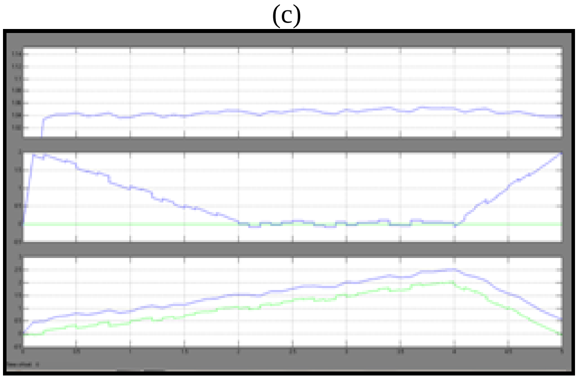
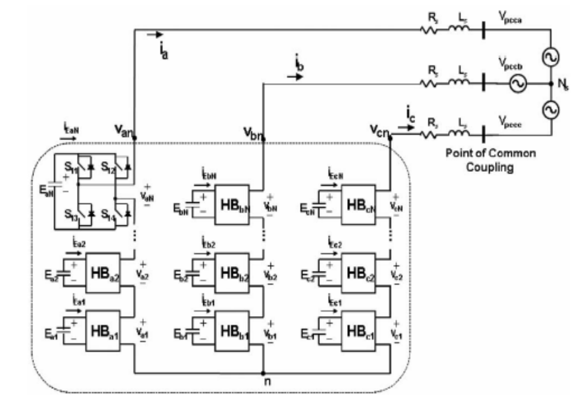
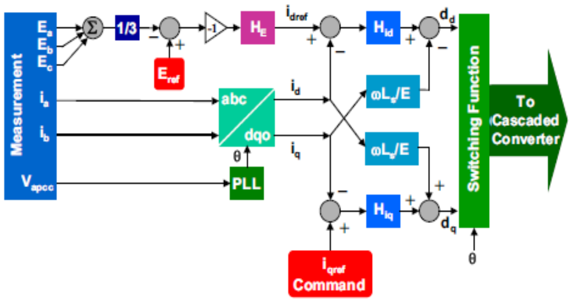


(d)

Fig. 2.Simulation Results.(a) Bus 2 voltage and Power Flow from bus 2 to 3. (b) Bus 3Voltage and Power Flow from WF2. (c) Bus 4Voltage and Power Flow from Bus 4 to 5. (d) Bus 6 voltage and WF1 Power Output at bus6.



(a)



(b)

Fig.3.Proposed STATCOM and its controller.(a) Generalized CMC-based Y-connected STATCOM schematic. (b) Internal control strategy of CMC-based STATCOM.

C. STATCOM Model and Control

The proposed STATCOM uses a CMC-based topology, as shown in Fig. 3(a). For this study, a harmonics-free dynamic model of the CMC-based STATCOM with its internal control, as shown in Fig. 5(b), is implemented on MATLAB/SIMULINK [9], [11], [13].

The simulated results, as shown in Fig. 4, illustrate how the STATCOM shown in Fig. 3(a) responds to step change commands for increasing and decreasing its reactive power output, where the units of dc voltage, reactive current, ac voltage, ac output current, and reactive power output are kV, kA, p.u., p.u., and Mvar, respectively. As the figure illustrates, the reactive current step change response has a bandwidth as fast as a quarter cycle, and ±10 Mvar is generated by the STATCOM, and the average dc capacitor voltage of about 1.5 kV is dynamically controlled and does not change due to the VAR command change. Therefore, the STATCOM model is validated.

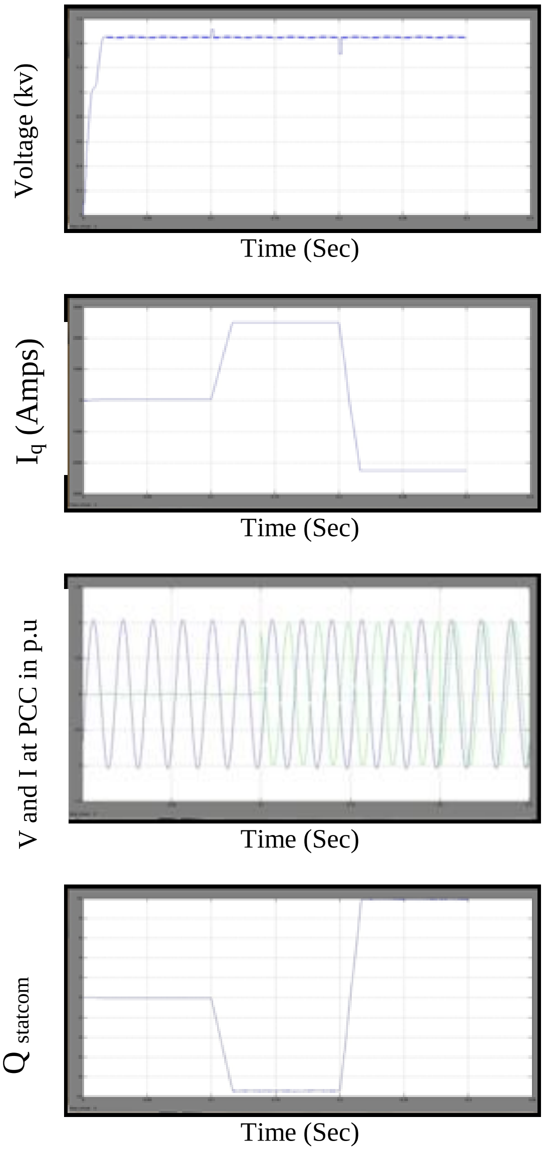


Fig. 4.Simulation Results of the CMC-based STATCOM model.

IV. SIMULATION AND ANALYSIS

Actually, from technology point of view, the most effective location to install STATCOM to suppress the voltage fluctuation related to WF1 is just directly at the WF1's point of common point (PCC), which is at 69-kV bus 5.A 10-MVA STATCOM is a reasonable size to suppress voltage fluctuations at bus 5 covering the most severe ±5% case, and a STATCOM with the size of 5 MVA is enough to suppress voltage fluctuation for typical ±1.5% cases.

Although bus 5 seems an effective location for STATCOM, if STATCOM can be installed inside the substation at bus 6, as shown in Fig. 1, from the practical cost-effectiveness point of view, the additional space for STATCOM need not be planned and the civil works can be significantly reduced so that the cost can be significantly lowered.

Fig. 5 gives the simulation results using STATCOM with its control strategy for voltage fluctuation suppression. In addition, since the STATCOM suppresses the voltage fluctuation, it is apparent that, compared to the case without STATCOM, the switching times of MSCs and TCs of both main transformers and load transformers to address the voltage fluctuation issue in the system shall be significantly reduced. Therefore, the maintenance and replacement cost of MSC, TC, and wind turbines can be lowered, and the power quality issues related to the switching of MSCs and TCs can also be lessened.

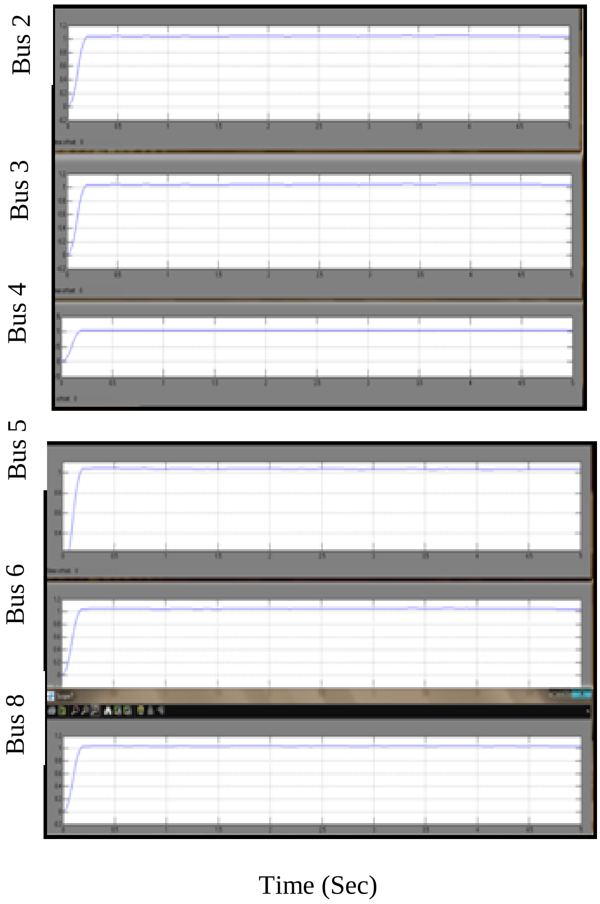


Fig.5.SimulationResults of Bus Voltages with STATCOM

V. CONCLUSION

For the system study, the models for the system, WF and STATCOM are developed. The low-cost MSCs and TCs boost the steady-state voltage locally but are ineffective to suppress the voltage fluctuations (seconds to minutes) due to their nature of slow dynamic response. STATCOM, which is a small percentage of WF rating, can not only effectively suppress the voltage fluctuations of the WF and the whole 69-kV loop system, but also inherently reduce the operation times of MSCs and TCs in the system so that the maintenance and replacement cost of MSCs, TCs, and wind turbines can be reduced. The power quality issues related to the switching of MSCs and TCs can also be lessened. The results also show the location of STATCOM selected at 35-kV bus 5 can be a good tradeoff from cost-effectiveness point of view. Installation of STATCOM on the integration of a large WF into the weak loop power system is effective and mitigated the faster voltage fluctuations with well-designed fast control bandwidth. Therefore, it is concluded that the installation of a 10-Mvar STATCOM system is effective for integrating the specific WF into the weak loop power system.

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