Optimal location of STATCOM for reducing voltage fluctuations

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Abstract:

This paper deals with the optimal location of static synchronous compensator (STATCOM) for reducing voltage fluctuation at different buses. A 12 bus system with an actual weak power system with two near by large wind farms (WF) is introduced used as an example to illustrate the technique. The STATCOM is one of the most promising FACTS devices for solve power quality issues . In this paper the optimal location of a STATCOM is investigated based on the MATLAB/SIMULINK. The results obtained shown that optimal placement of the STATCOM varies with the change the location of the STATCOM at different buses. And the fault level characteristics at different locations also observed. Finally, a STATCOM control strategy for voltage fluctuation suppression is presented and dynamic simulations verify the performance of proposed STATCOM and its control strategy.

Keywords: **optimal location, static synchronous compensator (STATCOM),wind farm(WF), Voltage fluctuations.**

I. INTRODUCTION

Power systems components mainly consist of generators, transmission lines, transformers, switches, active or passive compensators and loads. Power system networks are complex systems that are nonlinear, non-stationary, and prone to disturbances and faults. Reinforcement of a power system can be accomplished by improving the voltage profile, increasing the transmission capacity and others. Nevertheless, some of these solutions may require considerable investment that could be difficult to recover. Flexible AC Transmission System (FACTS) devices are an alternate solution to address some of those problem[1] .Simple heuristic approaches are traditionally applied for determining the location of FACTS devices in a small power system. However, more scientific methods are required for placing and sizing FACTS devices in a larger power system network. FACTS sizing and allocation constitutes a milestone problem in power systems.

However, with wind being a geographically and climatically uncontrollable resource and the nature of distributed wind induction generators, the stability and power quality issues of integrating large wind farm (WF) in grid may become pronounced, particularly into a weak power system. Conventionally, the low-cost mechanical switched cap (MSC) banks and transformer tap changers (TCs) are used to address these issues related to stability and power quality. However, although these devices help improve the power factor of WF and steady-state voltage regulation, the power quality issues, such as power fluctuations, voltage fluctuations, and harmonics, cannot be solved satisfactorily by them because these devices are not fast enough[3] . Moreover, the frequent switching of MSC and TC to deal with power quality issues may even cause resonance and transient overvoltage, add additional stress on wind turbine gearbox and shaft, make themselves and turbines wear out quickly and, hence, increase the maintenance and replacement cost[4] . Therefore, a fast shunt VAR compensator is needed to address these issues more effectively, as has been pointed out in many literatures [2],[4]-[7].

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 , which is promising to help integrate wind energy into the grid to achieve a more cost-effective and reliable renewable wind energy. In this paper, the effectiveness of a STATCOM in facilitating the integration of a large WF into a weak power system is presented. Firstly, an actual weak power system with two nearby large WFs is introduced. A STATCOM is proposed for dynamic voltage control, particularly to suppress the short-term (seconds to minutes) voltage fluctuations. Secondly, a model of the system, WF and STATCOM for steady state and dynamic impact study is developed in the MATLAB simulation environment.. Finally, a STATCOM control strategy for voltage fluctuation suppression is presented, and the dynamic simulations are used to verify the Performance of the proposed STATCOM and its control strategy.

The main goal of this paper is to show the application of STATCOM for the optimal allocation of a Static Compensator (STATCOM), shunt FACTS device, in a power system A 12 bus system used as an example to illustrate the methodology.

Section II presents the concepts of system description. The modelling and control of the power system used in this study is presented in section III. In section IV the CMC based STATCOM described. Section V presents the Optimal location of statcom and simulation results are presented. In section VI Conclusions are given.

II.
III.

IV. SYSTEM DESCRIPTION

Fig. 1 shows the diagram of the system investigated in this paper. The two WFs, WF1 and WF2, are connected at bus 3 and 6. The system is supplied by the two main substations, which are represented by three remote boundary equivalent sources at bus 1, 2, and 12. The WF2 located at bus3 with variable-speed double fed induction generators (DFIGs). The WF1 at located at bus6 using fix-speed squirrel-cage induction generators (SCIGs). 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 start ups of wind turbines. Thus, when WF1 is located at the weakest part of the loop system, these characteristics of WF1 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.

To reduce the voltage fluctuations and improve power factor, small size MSCs (hundreds kilo var) are installed at each individual SCIG terminal and large size MSCs (1–2 Mvar) are installed at bus 6.All the main transformers T1–T4 and many customer transformers have several taps, and two additional MSCs (2.75Mvar each) are installed at bus 8. However, because of slow response time, these devices do not satisfactorily address the dynamic issues of WF1, and even exacerbate them.

WF1 produces 1–2 Mvar(capacitive) because of the shunt capacitance of the underground cables connecting individual wind turbines to the common bus6. 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 cascaded-multilevel converter (CMC) is proposed to suppress the voltage fluctuations of the weak loop system. The STATCOM is located based on different buses in the system and observing the location where voltage fluctuation reduce more.

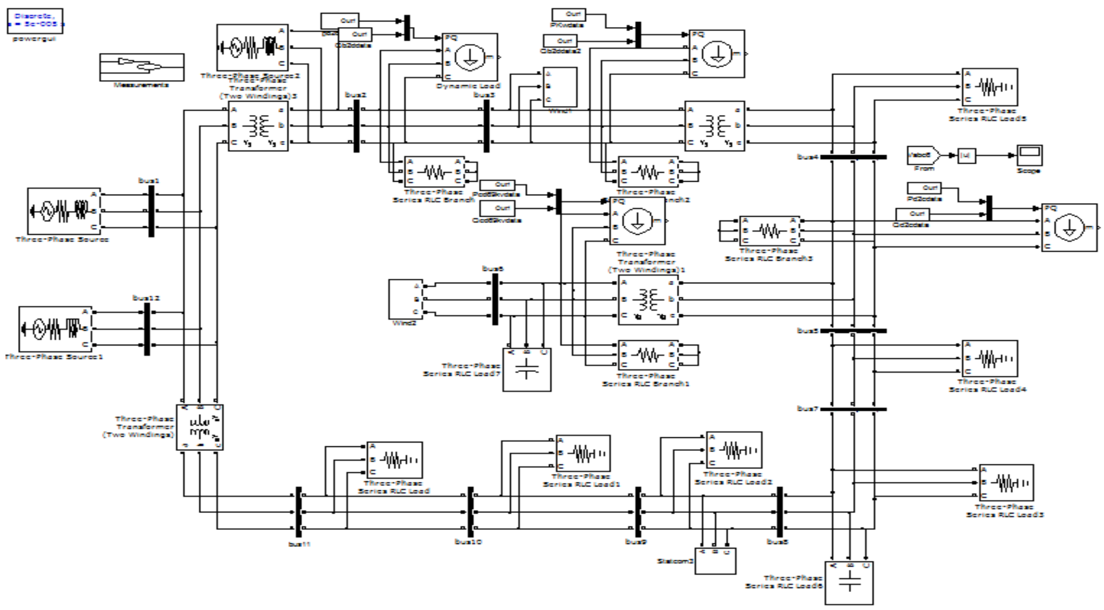


Fig1.proposed simulink model diagram

V. MODELING AND CONTROL

In this section, the modeling, MATLAB implementation and validation of the studied 12-bus power system, WF, and STATCOM are presented.

In this paper the main circuit consists of two WF. One advantage of Simulink over circuit simulators is the ease in modeling the transients of electrical machines and drives and to include drive controls in the simulation. According to his model, the modeling equations in flux linkage form are as follows:

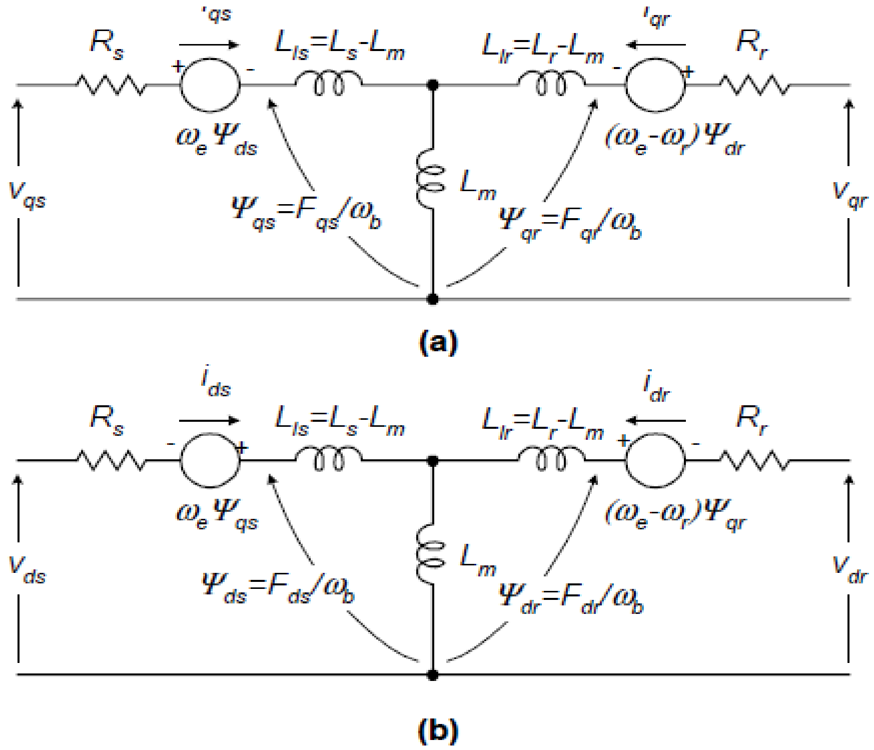


Fig. 2. Dynamic or d-q equivalent circuit of an induction machine

$$\frac{dFqs}{dt} = \omega b\left[Vqs - \frac{\omega e}{\omega b}Fds + \frac{Rs}{xls}(Fmq + Fqs)\right] \quad (1)$$

$$\frac{dFds}{dt} = \omega b\left[Vds + \frac{\omega e}{\omega b}Fqs + \frac{Rs}{xls}(Fmd + Fds)\right] \quad (2)$$

$$\frac{dFqr}{dt} = \omega b\left[Vqr - \frac{(\omega e - \omega r)}{\omega b}Fdr + \frac{Rr}{xlr}(Fmq - Fqr)\right] \quad (3)$$

$$\frac{dFdr}{dt} = \omega b\left[Vdr + \frac{(\omega e - \omega b)}{\omega b}Fqr + \frac{Rr}{xlr}(Fmd - Fdr)\right] \quad (4)$$

$$Fmq = \dot{X}ml\left[\frac{Fqs}{xls} + \frac{Fqr}{xlr}\right] \quad (5)$$

$$Fmd = \dot{X}ml\left[\frac{Fds}{xls} + \frac{Fdr}{xlr}\right] \quad (6)$$

$$iqs = \frac{1}{xls}(Fqs - Fmq) \quad (7)$$

$$ids = \frac{1}{xls}(Fds - Fmd) \quad (8)$$

$$iqr = \frac{1}{xlr}(Fqr - Fmq) \quad (9)$$

$$idr = \frac{1}{xlr}(Fdr - Fmd) \quad (10)$$

$$Te = \frac{3}{2}\left(\frac{p}{2}\right)\frac{1}{\omega b}(Fdsiqs - Fqsids) \quad (11)$$

$$Te - Tl = J\left(\frac{2}{p}\right)\frac{d\omega r}{dt} \quad (12)$$

Where

d: direct axis,
q:quadrature axis
s:stator variable, r:rotor variable,
Fij is the flux linkage (i=q or d and j=s or r),
Vqs, Vds : q and d-axis stator voltages,
Vqr, Vdr : q and d-axis

rotor voltages, Fmq, Fmd : q and d axis magnetizing flux linkages, Rr : rotor resistance,
Rs : stator resistance, Xls : stator leakage reactance (ωeLls), Xlr : rotor leakage reactance (ωeLlr), Xml*: $\left[\frac{1}{\frac{1}{xm}+\frac{1}{xls}+\frac{1}{xlr}}\right]$,
iqs, ids : q and d-axis stator curents,
iqr, idr : q and d-axis rotor currents,
P : number of poles,
J : moment of inertia, Te : electrical output torque, TL (or Tl) : load torque, ωe : stator angular electrical frequency, ωb : motor angular electrical base frequency, and ωr : rotor angular electrical speed.

For a squirrel cage induction machine as in the case of this paper, Vqr and Vdr in (3) and (4) are set to zero.

An induction machine model can be represented with five differential equations as seen above. To solve these equations, they have to be rearranged in the state-space form, ẋ=Ax+b where x=[Fqs Fds Fqr ωr]^T is the state vector. Note that Fij= ψij.ωb, where Fij is the flux linkage (i=q or d and j=s or r) and ψij is the flux.

In this case, state –space form can be achieved by inserting (5) and (6) in (1-4) and collecting the similar terms together so that each derivatives is a function of only other state variables and model inputs. Then, the modeling equations (1-4 and 12) of a squirrel cage induction motor in state-space become

$$\frac{dFqs}{dt} = \omega b\left[Vqs - \frac{\omega e}{\omega b}Fds + \frac{Rs}{xls}\left(\frac{xml}{xlr}Fqr + \left(\frac{xml}{xls} - 1\right)Fqs\right)\right] \qquad (13)$$

$$\frac{dFds}{dt} = \omega b\left[Vds - \frac{\omega e}{\omega b}Fqs + \frac{Rs}{xls}\left(\frac{xml}{xlr}Fdr + \left(\frac{xml}{xls} - 1\right)Fds\right)\right] \qquad (14)$$

$$\frac{dFqs}{dt} = \omega b\left[-\frac{(\omega e - \omega r)}{\omega b}Fdr + \frac{Rr}{xlr}\left(\frac{xml}{xls}Fqs + xmlxlr - 1Fqr\right.\right. \qquad (15)$$

$$\frac{dFqs}{dt} = \omega b\left[\frac{(\omega e - \omega r)}{\omega b}Fdr + \frac{Rr}{xlr}\left(\frac{xml}{xls}Fds + \left(\frac{xml}{xlr} - 1Fdr\right.\right.\right. \qquad (16)$$

$$\frac{d\omega r}{dt} = \left(\frac{p}{2J}\right)(Te - Tl) \qquad (17)$$

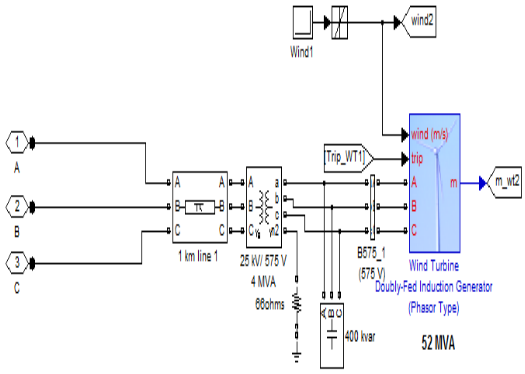


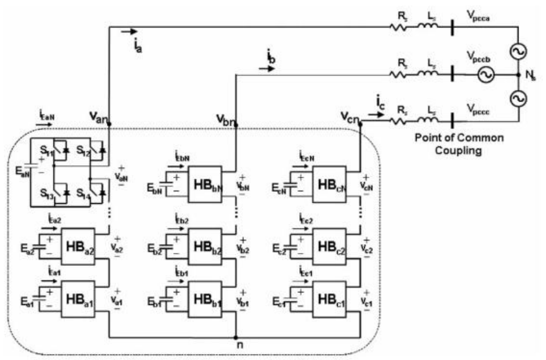
Fig.3. implementation of wind farm using MATLAB

The fig3 indicates the modeling of wind farm with doubly fed induction genaratator, a capacitor is connected because to improve power factor.

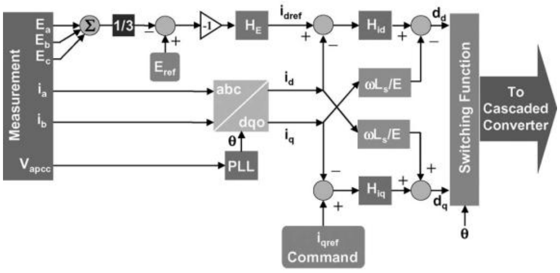
VI. Cascaded-Multilevel Converter-Based STATCOM

Multilevel converters are used in high power applications. These converters synthesize voltage waveform of superior harmonic spectrum and attain higher voltages with a limited maximum device rating. Several topologies with various control strategies are available in literature .These topologies are mainly classified into three types. 1) Diode clamp inverter 2) Capacitor clamp inverter 3) Cascaded inverter. In cascaded inverters, H-bridge topology is most widely used because of its modular circuit layout. In recent years cascaded two level inverter topology has become popular due to its simple power circuit configuration. The multilevel converters especially cascaded H-bridge topology are used for STATCOM application .In these converters it is difficult to control individual dc link voltages. Various control strategies are available in literature to minimize the dc voltage unbalance between converters .

The proposed STATCOM uses a CMC-based topology, as shown in Fig. 4(a). For this study, a harmonics-free dynamic model of the CMC-based STATCOM with its internal control, as shown in Fig. 4(b), is implemented on MATLAB Fig. 4(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.



(a)



(b)

Fig. 4. Proposed STATCOM and its controller. a)Generalized CMC-based Y-connected STATCOM schematic. (b) Internal control strategy of CMC-based STATCOM.

To improve the performance and effectiveness of the control for the CMC-based STATCOM system, the following five contributions are proposed in this dissertation:

1. optimized design for the CMC-based STATCOM power stage and its passive components,
2. modeling of the CMC for reactive power compensation,
3. decoupling power control method,
4. DC-link balancing technique, and
5. improvement in the CMCs.

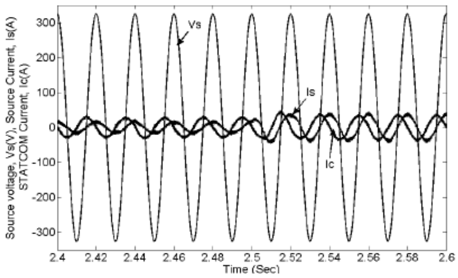


Fig.6. Source voltage, source current and STATCOM current

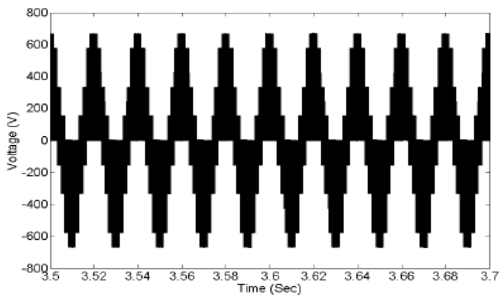
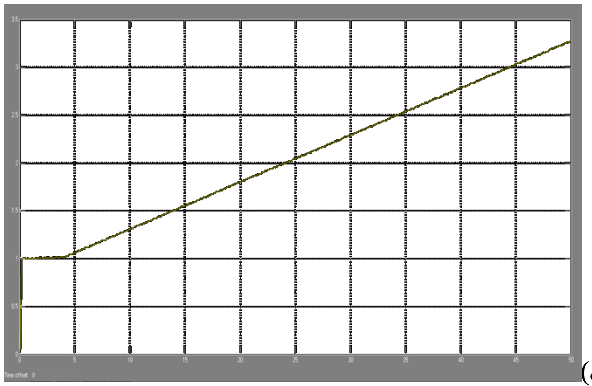


Fig.5. Cascaded converter output voltage

VII. Optimal location of STATCOM and simulation results

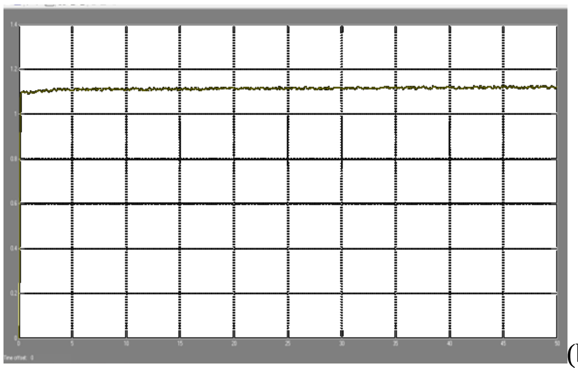
In addition, since the STATCOM suppresses the voltage fluctuation, it is apparent that, compared to the case without STATCOM, the switching times of MSCs and TCs of both main transformers and load transformers to address the voltage fluctuation issue in the system shall be significantly reduced. Therefore, 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.

In fig the wave forms shows voltage fluctuations without and with STATCOM .In presence of STATCOM at bus8 the voltage fluctuation are completely reducing at bus5,6,8 the remaining buses are near the source so the voltage fluctuations are slightly receduced. bus 2 and 3 is almost unchanged even with STATCOM, which is obvious because they are closely connected to a very strong bus 1 with the low impedance of T1and the short 115 kV-transmission line.



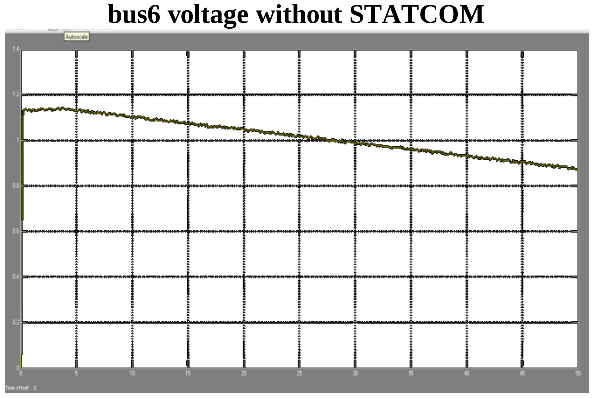
(a)

bus 5 voltage without STATCOM

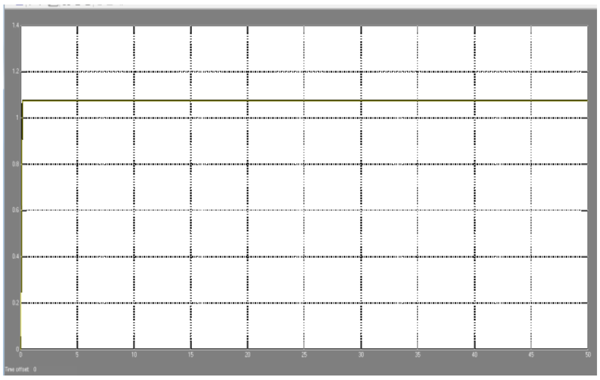


(b)

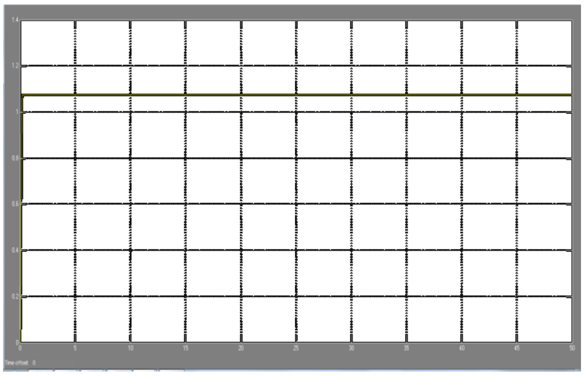
bus6 voltage without STATCOM



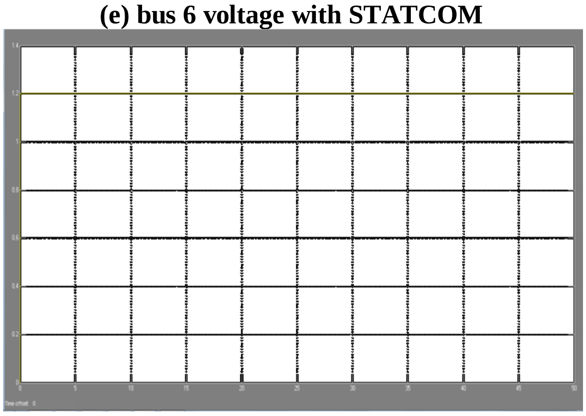
(c) bus 8 voltage without STATCOM



(d) bus 5 voltage with STATCOM



(e) bus 6 voltage with STATCOM



(f) **bus 8 voltage with STATCOM**

Fig.7. voltage fluctuations with and without STATCOM

If the STATCOM is connected at another bus the voltage fluctuations are reducing in that bus and remaining buses voltage fluctuations reducing depends on the distance of the STATCOM location. So from the above output waveforms we can observing in the STATCOM is connected at bus 8 the fluctuations are reducing at more number of buses. so bus 8 is the optimal location of the proposed system.

VIII. Conclusion

The optimal location of STATCOM is identifying by using matlab. This paper describes the methodology to conduct an impact study of a STATCOM on the integration of a large WF into a weak loop power system. The specific issues and solutions of the studied WF system are illustrated. For the system study, the models for the system, WF and STATCOM are developed , and wind turbines can be reduced, and the power quality issues related to the switching of MSCs and TCs can also be lessened. For this specific application of suppressing the voltage fluctuations, the dynamic simulation results for a continuous operation period also verify the effectiveness of the proposed STATCOM and its control strategy, which can adaptively deal with voltage fluctuation, independent from system steady-state voltage regulation by operations of MSCs and TCs, and even mitigate the faster voltage fluctuations and flicker emission, possibly from WFs 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.The fault at different location also with or without STATCOM is observed.

IX. References

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