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Advanced Control of FACTS Devices for Improving Power Quality Regarding to Wind Farms

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Abstract

In recent years, there has been a worldwide development in the utilization of wind farms. Because of enlarging wind generation, growing non-liner loads and competitive electricity markets the operation mechanism of power systems are facing some problems like voltage regulation, damping of power oscillation, etc. in shunt FACTS devices STATCOM and SVC have been identified as a good device and perfect compensators to solve these troubles. So control strategies for STATCOM are sequentially changing. The proposed paper is shown that the use of advanced control methods, such as the standard robust control method, in the control system of FACTS could improve their performance.

Keywords: FACTS; Power quality; Robust control; STATCOM; SVC; Wind generation.

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1. Introduction

Wind energy is a fast-growing interdisciplinary field that encloses many different departments of engineering and science. According to the American Wind Energy Association, the used capacity of wind grew at an median rate of 29% per year over the years 2002-2007 [3]. At the end of 2007, the installed capacity in the United States was closely 17,000 megawatts (MW) and the worldwide installed capacity was over 94,000 MW [3], [4].

Fig. 1 shows a conventional wind generator that has an induction generator directly connected to the grid. These types of generator are simple, robust and cheap. In order to link the turbine to the utility grid a soft-starter (consisting of anti-parallel thyristors) is employed in order to obey the currents under rated when the turbine is being connected to the utility grid. Phase-compensating capacitors are utilized to reimburse for the no-load consumption of the generator, or in some cases also for full-load working [5].

In the past, the total installed wind power capacity was a small fragment of the power system and ongoing connection of the wind farm to the grid was not a important worry. With raising portion from the wind power sources, it has become important for stable connection of the wind farm to the system to make capable uninterrupted power supply to the load even in small disturbances. Under these conditions,

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the new power system has had to oppose some big acting problems, such as transient stability, power flow control, voltage regulation and damping of power oscillations, etc.

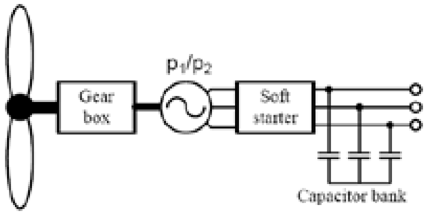

Fig 1. Fixed speed induction generator.

Standard devices used to supply the needed reactive recompense are mechanically switched capacitor banks. Flexible AC transmission system (FACTS) devices can be use. They are capable to provide quick active and reactive power compensations to power systems, and hence can be used to provide voltage support and enhance power oscillation damping. properly located FACTS devices enable additionally efficient employment of existing transmission lines. amid the FACTS family, the shunt FACTS devices such as the static synchronous compensator (STATCOM) has been greatly used to provide flat and fast steady state and transient voltage control at points in the network[1].

2. Robust Controller Design

Robust control theory handles control system design for dynamic systems with uncertainties in their models. Two basic issues are stressed: robust stability and robust performance. A system is said to be robust to a given set of system uncertainties (or operating situations) if it provides solidity and adequate performance for whole system models in this set. In robust control theory, uncertainties can be in multiplicative or additive forms [7].

Considering multiplicative uncertainty marked by Δ_m, if the factual and the nominal transfer functions of the plant are respectively denoted G(s) and G0(s), we have:

$$G(s) = (1 + \Delta_m(s))G_0(s) \quad (1)$$

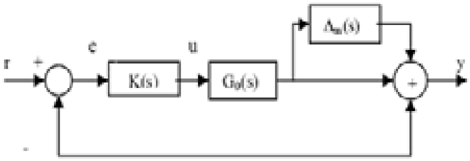

Fig 2. Uncertainty model and the controller

From Fig. 4, we explain the following transfer functions:

$$T = \frac{y}{r} = \frac{KG_0}{1 + KG_0} \text{ and } S = \frac{e}{r} = \frac{I}{I + KG_0} \quad (2)$$

T is the closed loop transfer function between the output of the system (y) and the input signal (r), while S is the transfer function between the error (e) and the input signals. The firmness of the closed loop system with the uncertainties, i.e. the robust stability will be assured by the existence of a weighting function W2 such that situation (3) is gratified [2].

$$\|W_2(s).T(s)\|_\infty < 1 \qquad (3)$$

$\|\cdot\|_\infty$ marks the H_∞ norm which is equal to the highest value over the full frequency range. The steady state performance (the decreasing of the error signal) will be gratified in a frequency range of interest if the amplitude of the transfer function S is small in that frequency limit. This could be obtained by the existence of a weighting function W_1 such that the following situation is satisfied:

$$\|W_1(s).S(s)\|_\infty < 1 \qquad (4)$$

W_2 could be selected in such a way that the following situation is gratified.

$$\|W_2(s)\|_\infty > \|\Delta_{max}(s)\|_\infty \qquad (5)$$

Where Δ_{max} is the highest uncertainty respecting the set of system uncertainties considered. Considering condition (4), if we want the amplitude of S to be small in a frequency range, W_1 could be so modeled that it has a high amplitude in that frequency range.

3. The Test System

The network simulated for this application, extracted from [6] is presented in Fig 3. A big wind farm (rated power max 200 MW) is connected to the main transmission system via a long existing 132 kV radial with limited transfer capability. Induction machines are used as generating units in the wind conversion system and as said before, reactive power compensation should be supplied. For additional details about the model, see Appendix A.

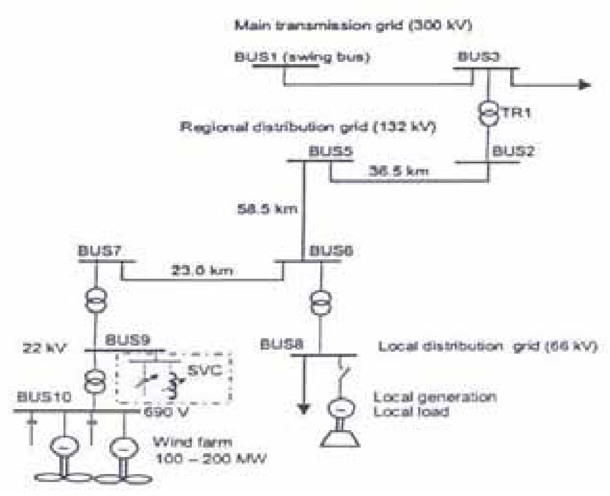

Fig 3. Test system

4. Simulation Result

We will study capacitor banks denoted as the typical case and FACTS devices (STATCOM and SVC) as compensation devices. We use first FACTS devices with PI controller then apply robust control theory for control STATCOM. The FACTS devices will be rated at 100 MVA and their efficacy, compared to capacitor banks sized for full compensation. A 150 ms short-circuit to ground is accomplished in the branch between nodes 5 and 6. The voltage at the connection node of the compensation devices has been inscribed.

Case A: In this case wind induction generator connected to a grid with capacitor banks is modeled. The result shows voltage at bus 9 as shown in Fig 4.

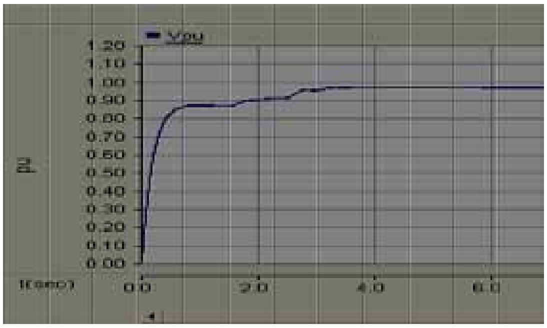

Fig 4. Voltage at BUS 9 (capacitor banks)

Case B: In this case wind induction generator connected to a grid with SVC and STATCOM is modeled. Figs. 5 and 6 indicate the simulation results for the voltage of the bus 9 with SVC and STATCOM respectively.

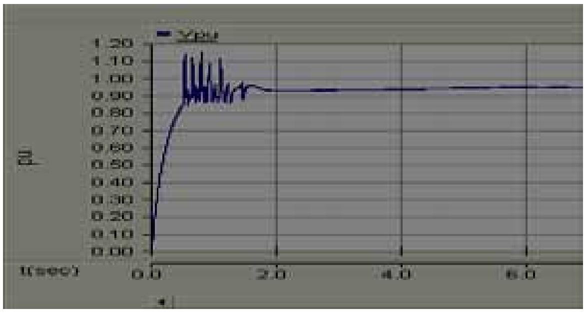

Fig 5. Voltage at BUS 9 (SVC)

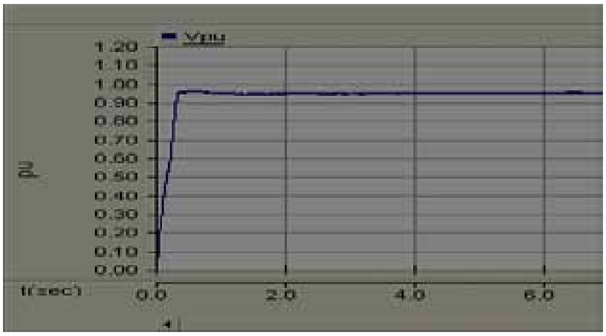

Fig 6. Voltage at BUS 9 (STATCOM)

From above figures we see that when FACTS devices are used (especially STATCOM), the voltage fall during the fault is lower relative to the case where capacitors are used and the system recuperates quickly from the disturbance.

STATCOM is best response with PI regulator. This regulator will now be replaced by a robust controller designed using the H∞ robust control method.

To assign the model uncertainties, three operating conditions corresponding to three different wind farm output powers have been studied. The weighting functions allowing the pleasure of the control specifications have been selected as:

$$W_{1\_STATCOM}(s) = \frac{0.1s + 0.02}{s + 2} \tag{6}$$

$$W_{2\_STATCOM}(s) = \frac{0.5s + 10.7}{1.2s + 0.0002} \tag{7}$$

Using the Matlab software package and the Robust control toolbox [8], the STATCOM controllers have been designed. For easy execution, they have been decreased to second order controllers using standard reduction techniques. They are given respectively by the following formulas:

$$k_{STATCOM}(s) = \frac{150896(s + 29.75)}{(s + 1)(s + 306)} \tag{8}$$

Fig 7 shows the simulation results for the voltage with robust controller.

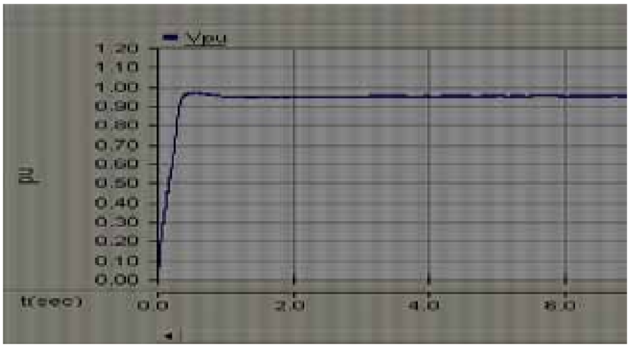

Fig 7. Voltage at BUS 9 (STATCOM with h-infinity)

With compare Fig. 7 and Fig. 8 we can see the magnitude of voltage oscillations has been reduced.

5. Conclusion

This paper was inscribed to some specific troubles that happen in power systems when renewable energy production, specially wind energy conversion, is comprised. It has been exhibited that the use of FACTS devices, like in traditional power systems could also play an important role. They have been successfully used to handle high fault current level. The supremacy of STATCOM compared to SVC has also been demonstrated. Moreover, the implementation of robust control theory presents the probability of the improvement of power system stability and control of FACTS devices.

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Appendix A.

A detailed description of input data to the simulation model is given in this Appendix.

Table 1. INDUCTION GENERATOR DATA

V_n	0.69 KV
R_s	0.00619 pu
I_s	0.1359552 pu
I_r	0.112143 pu
M	3.904762 pu
R_m	0.088095 pu
R_r	0.02 pu

Table 2. TRANSFOMER DATA

	BUS2 BUS3	BUS8 BUS6	BUS10 BUS9	BUS9 BUS7
S [MVA]	250	70	160	160
U_{n1}[KV]	132	66	0. 69	22
U_{n2}[KV]	300	132	22	132
Reactance (pu)	0.1462	0.24787	0.055	0.1

Table 3. TRANSMISSION LINES DATA

	BUS7 BUS6	BUS6 BUS5	BUS5 BUS2
Length [km]	23	58.5	36.5
Resistance [Ω/km]	0.098	0.098	0.098
Reactance [Ω/km]	0.398	0.398	0.398
Suseptance [S/km]	2.89e-6	2.89e-6	2.89e-6

Line between nodes BUS1 and BUS3 (300 kV), R=0.0047 pu, XL=0.05884 pu, BC=0.086543 pu, System base 100 MVA.