Contribution of Static Synchronous Compensators for Enhancing Wind Power Performance

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Abstract

This paper examines the impact of a Static Synchronous Compensator on improvement of wind generation performance. A power system model including wind power is investigated. The structure of the model is selected based on the experiences from a real grid with wind generation. The models for mechanical and electrical part of the wind generator and the connected network are developed. Based on these models, the influence of the wind power on power system voltage quality and voltage regulation is studied.

Keywords: ***Wind power, power quality, SSC, flicker, voltage stability.***

1. INTRODUCTION

Renewable energies and rational use of energy are the fundamental concepts of a responsible energy policy for the future. Due to their sustainable character, renewable energy technologies are capable of preserving resources and of ensuring security and diversity of energy supply. Renewable energy technologies for electricity production can make major contribution to the electricity production. In recent years, appreciable progress has been made in the development of renewable energy and related technologies. However, in the present energy market situation, because of the size of the investment needed, the contribution of the renewable to the total production will only change if the present problems faced in the development of wind energy could be solved. Some important aspects of this issue are: technical improvement in wind-turbine generators, cost improvement, environmental improvement and power system performance improvement.

This paper focuses mostly on improvement of the behaviour of a power system with distributed generation like wind power. When examining a network including wind generation, we are normally faced with the following phenomena:

- Voltage regulation and voltage stability
- Flicker

This paper first develops a power system model including wind power. The structure of the model is selected based on the experiences from a real grid with wind generation. Based on this model, the influence of the wind power on power system voltage quality and voltage regulation is studied. The basic theoretical studies show how voltage flicker is influenced by the network structure and how the voltage stability can be a major problem in the network. Recognising the major problems in the studied network is an important background to investigate the solutions which will result in a reliable and secure operation of the grid with wind power.

In recent years, rapid development in power electronics and control techniques has presented a new power electronic shunt compensation equipment with turn-off switching capability. The device is called a *Static Synchronous Compensator (SSC).* This device has a robust output and rapid response which can offer excellent contribution to the enhancement of power systems performance. This report has examined the model and the control algorithm for this device. The report presents some interesting results describing the impact of an SSC for enhancing the voltage stability and minimising the flicker in a power system with wind generation. This paper is organised as follows:

- Section 2 examines the influence of wind power generation on the grid voltage.
- Section 3 studies the possibility of introduction of a *Static Synchronous Compensator* for improving voltage quality and enhancing voltage stability.

2. Effect of Wind Power Generation on the Grid Voltage

In this section we analyse the voltage variations produced when a source of variable power is connected to a weak network. We assume a simplified model representing the source of power (wind turbine) and the grid impedance. The aim is to find an expression which gives the voltage at the generator terminal as a function of the power generated and the impedance of the grid (Fig 2-1):

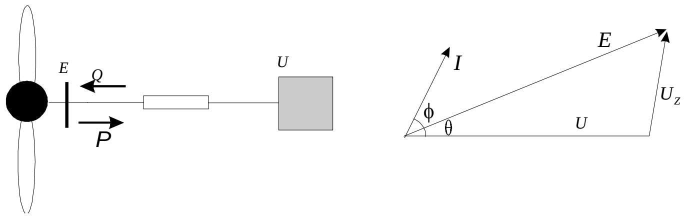


Fig. 2-1: *Generator - grid model and phasor diagram representation*

From phasor diagram:

$$U_Z^2 = U^2 + E^2 - 2EU\cos\theta = I^2(R^2 + X^2)$$

Considering $I^2E^2 = P^2 + Q^2$, we have:

$$\frac{P^2 + Q^2}{E^2}(R^2 + X^2) = U^2 + E^2 - 2EU\cos\theta$$

From the phasor diagram:

$$E = U\cos\theta + RI\cos\varphi - XI\sin\varphi$$

After some manipulation:

$$E^4 - \left[2(PR - XQ) + U^2\right]E^2 + (P^2 + Q^2)(R^2 + X^2) = 0$$

Solving Equation above, the voltage E can be expressed as

$$E = \sqrt{c_1 + \sqrt{c_1^2 - c_2}} \quad \text{where } c_1 = \frac{U^2}{2} + (RP - XQ) \text{ and } c_2 = (P^2 + Q^2)(R^2 + X^2)$$

If we set Z equal to 0.05 p.u., and a constant voltage U= 1 p.u., the short circuit ratio is 1 / Z = 20 for P=1 p.u. The power factor has been chosen equal to 0.97. Fig 2-2 shows the relation between E and the output power with the ratio X/R as a parameter for two different short circuit ratio SCR=20 and SCR=5. The figures below show how the voltage varies with respect to the active power flow and the network characteristics.

Fig 2-2. *Voltage E as a function of active power, for different ratios X/R,*

3. Power and voltage disturbances produced by wind power generation.

The stochastic behaviour of the wind gives rise to an irregular profile of the power generated from wind turbines and therefore constitute a potential source of deficient power quality and disturbances in the grid if the generators are connected to a weak system. Usually the highest wind potential exists in rural and coastal areas where the grids are weaker. For this reason, the amount of large scale wind power connection is limited by the grid characteristics. Two main phenomena are considered:

Voltage variations result from wind gusts and slow changes in wind speed. The changes in power from variations of wind speed can be in the order of 60 % in 3 minutes, depending on the location and the wind direction. The standards set a limit of amplitude of variation in function of how often these variations occur. The IEC 868 Standard allows a maximum value of 3% of voltage variation if they occur in 1 minute period or lower incidence frequency.

Flicker refers to the oscillations occurring at frequencies between 1 and 2 Hz. This phenomena is associated to the tower shadow effect together with the wind gradient in wind turbines operation. For a single turbine, the amplitude of the power fluctuations can have a typical magnitude of $\pm 10\%$ deviation from the average, but the mechanical resonance frequency of the tower can make these fluctuations as high as $\pm 20\%$. For a wind power park with several turbines, the average power fluctuation is less than for a single turbine.

3.1. Use of SSC for Improving System Performance

When constant speed directly connected turbines are used, the power control is not possible, and consequently the voltage will be subjected to factors that disturb the power absorbed by the wind turbine. Voltage control by reactive power can avoid the necessity of using variable speed converters to eliminate voltage fluctuations. This can be a very effective way to improve the voltage quality when the grid X/R ratio is high enough . If the X/R ratio is low, then reactive power compensation becomes less effective.

The studied model represents an equivalent of the Gotland system in the area where large scale wind power production is located. Today, the short circuit ratio is less than 4 times lower than the recommended value. The model is an example of weak network where most of the generators are asynchronous with constant speed turbines directly connected to the grid. The aim of study is to analyse the problems and examine how the voltage quality can be improved without strengthening the grid.

Power System Model

The model represents a 30 MW offshore wind power station consisting 30 turbines with fixed speed asynchronous generators directly connected to the grid. The turbines are stall regulated type, with a rating of 1 MW each. The park is divided into three equivalent groups of generators connected via 10 kV submarine cables to the land. Fig 3-1 shows the equivalent model of the system. The data is given in the Appendix.

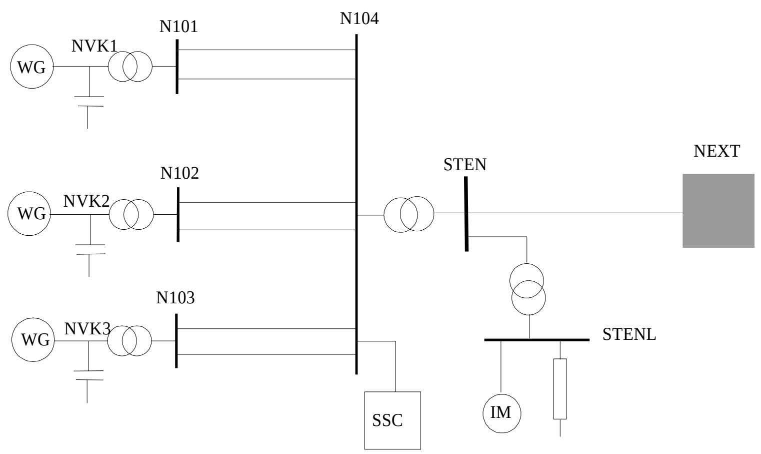


Fig. 3-1: *Model of the system used for the simulation*

The SSC is assumed to be connected at node N104, and will control the voltage at node STEN. In order to simulate the different types of oscillations of power generated by the wind turbines, each of the three groups of generators are modelled as sinusoidal power sources with two different frequencies and amplitudes of oscillations.

We consider first the fluctuations due to the tower shadow effect. We assume that each single machine generates power with variations of $\pm 10\%$ the average output power. The phase between the rotational speeds of the three different groups is 10^{o}, and the frequency of the fluctuations is assumed equal to 1.5 Hz. The second type of oscillations results from changes in wind speed. For this example, we will assume that power variations due to changes of wind speeds are 20% in the order of 10 to 20 seconds for every group. According to this, the amplitude of the power variations are $\pm 10\%$ of the average, for each group. The phase displacements of the sinusoidal of the three different groups are taken: 0, -90 and 120 degrees. The frequency of the fluctuations for each group 0.1, 0.07 and 0.05 Hz. With these assumptions, the output power for each group consisting ten turbines will be expressed as :

$$P_i(t) = P_0 \cdot (1 + a_1 \cdot \sin(\omega_{1,i} t + \phi_{1,i}) + a_2 \sin(w_{2,i} t + \varphi_{2,i}))$$

where ω_1 and ω_2 are the frequency of fast and slow oscillations.

3.3. SSC Model

Fig. 3.3 shows the model of an SSC. The voltage source converter (VSC) produces a voltage (*Ussc*) which is controllable in magnitude and phase. The voltage magnitude is controlled to regulate the voltage at the connection of SSC. The angle of voltage is controlled to regulated the voltage across the DC capacitor.

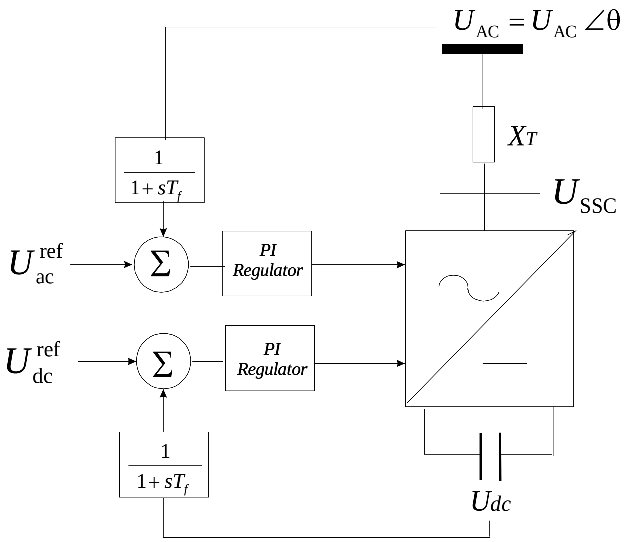


Fig. 3-3: *Model of SSC*

For this study the following parameters have been selected:

Rating of VSC: 10 MVA

Rating of DC voltage: 20 kV

$X_T = 0.15$ p.u.

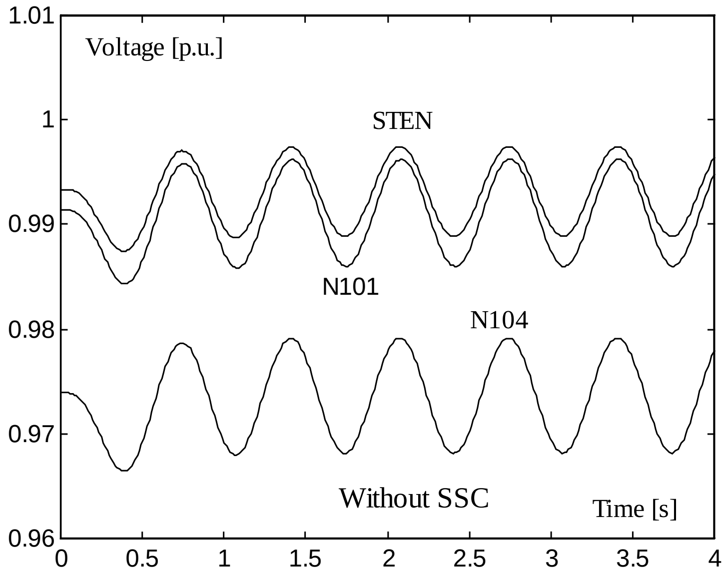
$C = 250\,\mu F$

3.4. Fast fluctuations (flicker)

Table 3.4 compares the values of the voltage fluctuations without and with the SSC. With SSC, the fluctuations are eliminated at node STEN, and reduced to very low values at the rest of the nodes. The fluctuations have been considerably damped compared with the initial system, even if some of the nodes still have some flicker. It is noted that it is not possible to eliminate completely the fluctuations of voltage at every node by reactive power injection or absorption. Figures 3.4-1 and 3.4-2 show the voltage variations for the different cases

	N104	*STEN*
Without SSC	1.1%	0.9%
With SSC	0.1%	0%

Table 3.4: *Voltage fluctuation for the different*



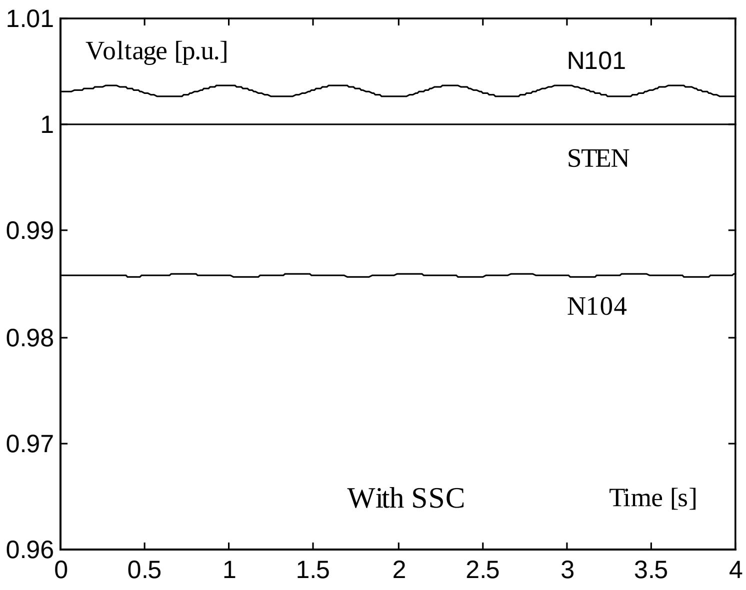


Fig 3.4: *Voltage flicker at nodes N101, N104 and STEN 1) SSC not connected 2) SSC connected*

3.5. Low frequency variations

Fig. 3.5 shows the voltage variation for low frequency. Table 3-5 compares the values of the maximum voltage variation in three minutes time interval at different nodes.

	N104	*STEN*
Without SSC	5.24%	4.5%
With SSC	0.8%	0%

Table 3-5: *Voltage variation for the different nodes*

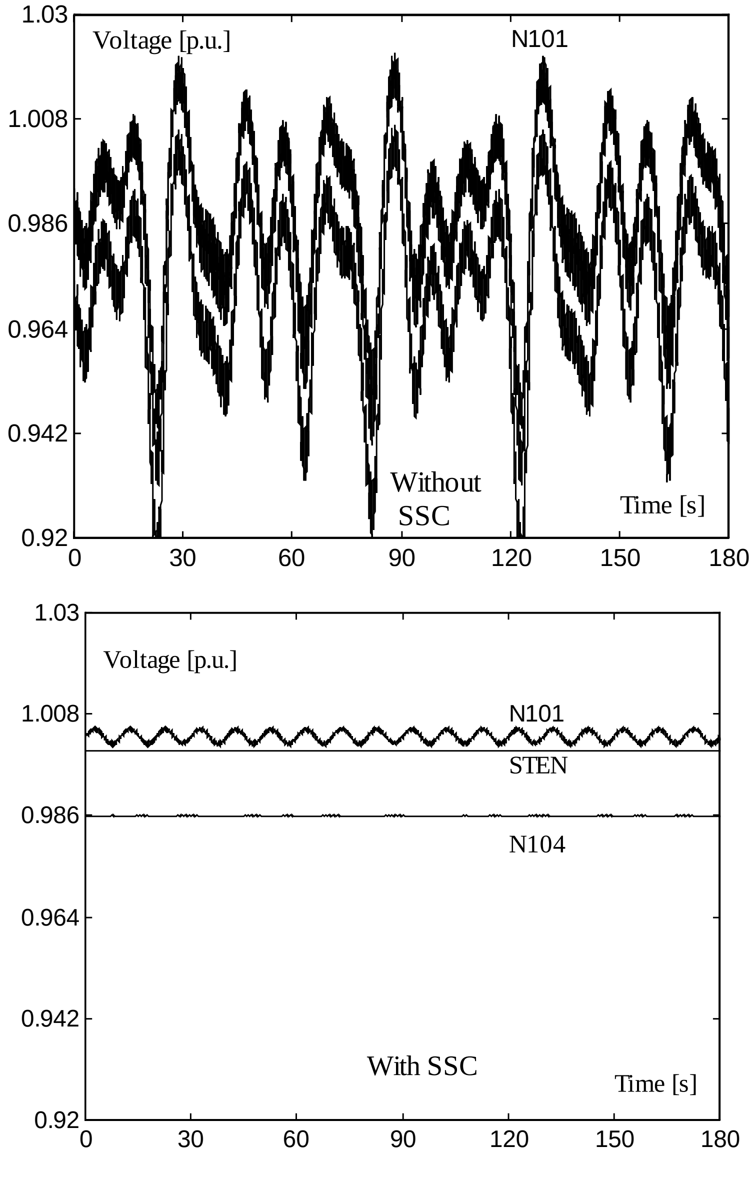


Fig 3-5: *Voltage variation at nodes N101, N104 and STEN 1) SSC not connected 2) SSC connected*

3.6. Fault Simulation

In this section we will study how the weak characteristics of the grid affect the system stability. A three phase to ground short circuit with 100 ms duration at the 10 kV side of the node STEN is simulated. Fig 3.6-1 shows that the system will recover by itself after the fault is cleared. However, the duration to achieve the steady state is too long and the undervoltage or overspeed protection of both generators and motors might become activated. In this case, the stability of the system is improved when the SSC with 10 MVA rated capacity is introduced. Figure 3.6-2 shows that the recovering time has been reduced considerably. The support from the SSC results into a faster reaction of the system after the fault is cleared. In this case, the protections for both motor and generators do not act since the undervoltage has a duration of less than one second.

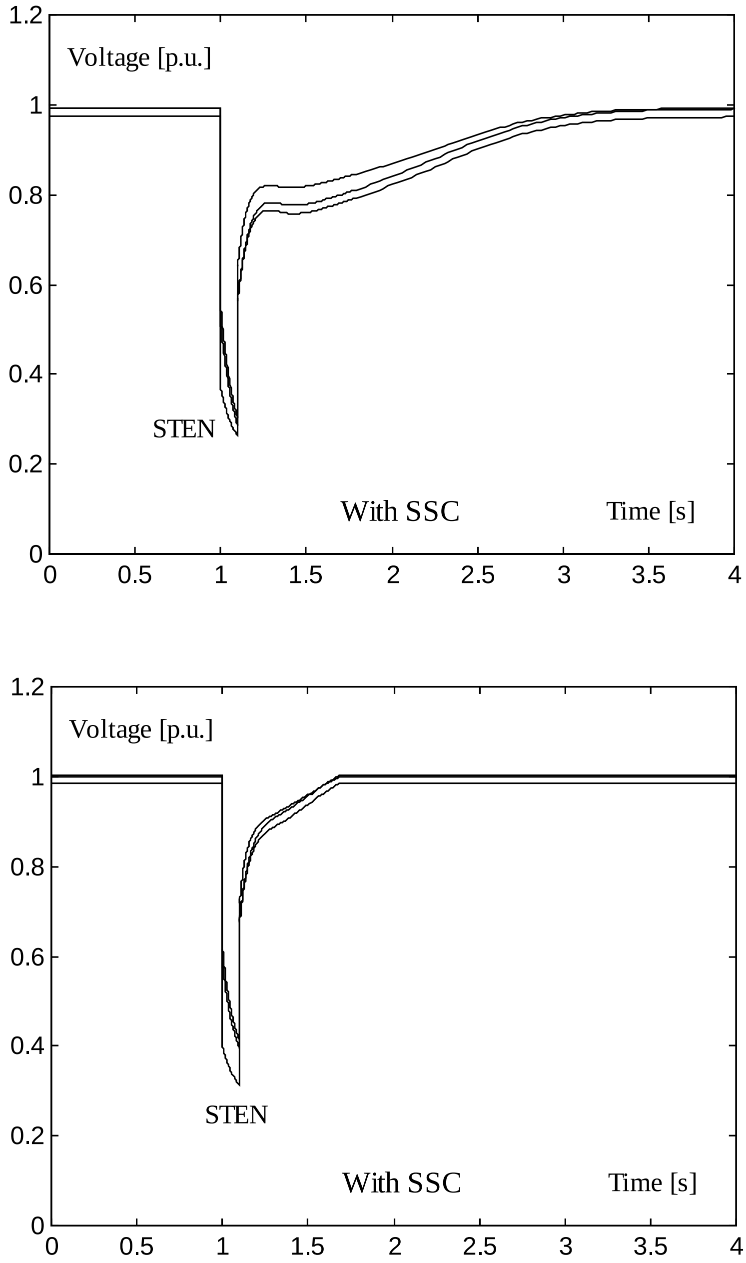


Fig 3.6: *Voltages at different points of the grid after a fault 10 kV bus bar at 1) SSC not connected 2) SSC connected*

CONCLUSIONS

Using distributed generation might lead to voltage quality problems. The distribution networks are more resistive and the voltage is more dependent on active power flow. Some of these problems could be handled if the net operator and the producer cooperate to work out a regulating policy for each specific case. Power fluctuations result from different mechanical phenomena. Wind gusts, start and shutdown operations are potential sources of voltage disturbances. Flicker control and voltage stabilisation are important issues in a power system with wind generation. The findings of this work can be summarised as follows:

- With fixed speed wind turbines operation in a weak grid, power fluctuations result into voltage fluctuations. The magnitude of voltage fluctuations are related to the grid characteristics. Flicker depends on the system short circuit ratio, the ratio between the line reactance and resistance, the load distribution and the nature of the load.
- If the ratio X/R is high enough, reactive power compensation is effective. However, because of load factors and variable grid characteristics from point to point, it is not expected to eliminate completely the flicker produced by wind turbines.
- Using fixed capacitor banks is not always a sufficiently good solution for the voltage quality. One has to consider the flicker problems and eventually also harmonics. Providing an Static Synchronous Compensator (SSC) with sufficient energy storage capacity can reduce the fluctuation of active power. Using this approach, the flicker distribution can become minimum throughout the network by the simultaneous control of reactive and active power through the SSC.
- To evaluate the SSC benefits, one must consider the whole economic benefit of the system, i.e., the value for a better utilization of the network and saving in infra-structure costs.

BIBLIOGRAPHY

[1] Grid interaction and Power Quality of Wind Turbine Generator Systems. Åke Larsson. Technical Report No. 265 L. 1997. Chalmers University of Technology, Göteborg.

[2]Wind Energy Conversion Systems. L.L. Freris. 1990

[3] Factors that affect the Connection of Asynchronous Generators to Utility Distribution Networks. M Gonzalez, L. Rouco, (IIT) , F. J. Perez Thoden. (ENDESA).

[4] Wind Energy Systems. R. David. Richardson. Proceedings of the IEEE. Vol 81. No 3. March 93. Pag 382

[5] Electrical Transients of Wind Turbines in a Small Power Grid. C.S. Demoulias, P. Dokopoulos. IEEE Transactions on Energy Conversion, Vol. 11, No. 3. Sept. 96. Page 636.

[6] Small Wind Turbine Effects on Distribution System Operation. D. Curtice. Systems Control Inc. Page 379.

APPENDIX

The main data used in the model are the following:

Generators : Rated power 1 MW / Asynchronous, fixed speed.
Load: 30 kV: 5 MW domestic load 5 MW Induction motors

Cables: R=0.225 ohm/km, X=0.07 ohm/km , Length: N101-N104=4 Km , N102-N104=3 Km, N103-N104=2 km

Grid: Node NEXT: Infinite bus

Node STEN SCC: 122 MVA X/R ratio = 2.6 V= 33 kV

Node N104 : SCC =101 MVA X/R ratio = 3 V= 11 kV

Node N101 : SCC =44 MVA X/R ratio = 0.78 V= 11 kV