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Study And Analysis Of Fixed Speed Induction Generator Based Wind Farm Grid Fault Control Using Static Compensator

[1]Nazia Zameer, [2]Mohd Shahid
[1]M.Tech(Power System) Scholar, Department of EEE, AFSET, M.D.University(Rohtak), Haryana,India
[2]Associate Professor, Department of EEE, Al-Falah University, Haryana, India

Abstract

WIND energy is playing a key role on the way toward a sustainable energy future. The voltage stability of fixed-speed induction generator (FSIG) based wind turbines can be improved by using a Static Compensator. In this thesis paper basically we are analysing voltage in grid. Unbalanced grid voltage dips causes heavy generator torque oscillations that reduce the lifetime of the drive train. In this thesis, investigations on an FSIG-based wind farm in combination with a Static Compensator under unbalanced grid voltage fault are carried out by means of theory, simulations, and measurements. A Static Compensator control structure with the capability to coordinate the control between the positive and the negative sequence of the grid voltage is proposed. The results conclude the effect of the voltage dip compensation by a Static Compensator on the operation of the FSIG-based wind farm. With first priority, the Static Compensator ensures the maximum fault-ride-through enhancement of the wind farm by compensating the positive-sequence voltage. The remaining Static Compensator current capability of the Static compensator is controlled to compensate the negative-sequence voltage, in order to reduce the torque oscillations.

Keywords: - STATCOM, FSIG, Wind Turbine.

I– INTRODUCTION

Wind power industry is developing rapidly, more and more wind farms are being converted into power systems. Year to year, there will be more significant growth in wind energy. Although the great development in the technology of electrical generation from wind energy, there is only single way of generating electricity from wind energy is to use wind turbines that convert the energy contained in flowing air into electric power. Fixed speed wind turbines utilize squirrel cage induction generator directly connected to the grid to produce the electricity [1]. These induction generators which are usually connected at weak end of a grid or at distribution networks draw huge amount of reactive currents during disturbances such as faults. Consequently under these conditions the terminal voltage and the electrical output power are significantly reduced, whereas the mechanical torque may be still applied to the wind turbine and the rotor speed increases. After fault clearance the generator needs reactive power for voltage recovery, however this reactive power to be supplied by network which in turn causes a voltage drop, so the machine terminal voltage cannot be recovered any more. If the voltage could be recovered and the generator speed is not too high, torque could be restored and the wind turbine may restore its normal operation. Otherwise the generator would continue to accelerate and the rotor speed and reactive power consumption will increases, so the terminal voltage decreases further. If the rotor speed exceeds a certain critical value the generator set becomes unstable, thus must be tripped out by over speed protection devices. As for cases in which a large amount of power is supplied by generators, theses generators should stay connected to the grid. Therefore, the stability becomes an important problem and has recently attracted considerable attention. Various methods of stability improvement have been presented by researchers. The pitch control system is used to control the power output of the wind turbine and also for stabilization of the wind turbine at grid faults. When a fault occurs in the external power system, the blade-angle control orders the mechanical system to reduce the wind turbine mechanical power to improve stability. For fixed-speed rotor short-circuited induction generators, it is not possible to control the input mechanical power, and therefore the effective approach would be the use of reactive power compensators such as Static Synchronous Compensator STATCOM or Static Var Compensator to help the voltage recovery. Squirrel cage induction generators can become easily unstable under low voltage conditions, as low terminal voltage lead to: larger rotor slip, larger reactive power consumption, further lowering of terminal voltage, and this may lead to disconnecting the turbine. Initial low voltage conditions may be originated by conditions different than faults. So that the wind turbines can be equipped with a controllable source of reactive power to deliver the reactive power required to accelerate the voltage restoration. Since the induction generators do not perform voltage regulation and absorb reactive power from the utility grid, they are often the source of voltage fluctuations [2]. The ability of a wind power plant to stay connected during disturbance is important to avoid the time of reconnection process, which need from 4 to 5 min and also to avoid cascading disturbance due to lack of generation.

Furthermore it is economically convenient to handle the fault, without disconnecting the wind turbine from the grid. It is necessary to examine the responses of FSIG wind farm during the faults and possible impacts on the system stability. In this thesis, the impacts of fault and its duration time on 275kW wind farm interconnected grid are studied by monitoring the active power, reactive power, and bus voltage of the wind farm. Also, the contribution of static compensator to support the wind farm during different fault locations and durations are studied.

II– INDUCTION GENERATOR

An induction generator or asynchronous generator is a type of AC electrical generator that uses the principles of induction motors to produce power. Induction generators operate by mechanically turning their rotor in generator mode, giving negative slip [3]. In most cases, a regular AC asynchronous motor is used as a generator, without any internal modifications.

PRINCIPLE OF OPERATION

Induction generators and motors produce electrical power when their rotor is rotated faster than the synchronous frequency. For a typical four-pole motor (two pairs of poles on stator) operating on a 50 Hz electrical grid, synchronous speed is 1800 rotations per minute. Similar four-pole motor operating on a 50 Hz grid will have synchronous speed equal to 1600 rpm [6]. In normal motor operation, stator flux rotation is faster than the rotor rotation. This is initiating stator flux to induce rotor currents, which create rotor flux with magnetic polarity opposite to stator. In this way, rotor is dragged along behind stator flux, by value equal to slip. In generator operation, a prime mover (turbine, engine) drives the rotor above the synchronous speed. Stator flux still induces currents in the rotor, but since the opposing rotor flux is now cutting the stator coils, active current is produced in stator coils, and motor is now operating as a generator, and sending power back to the electrical grid [4].

In induction generators the magnetizing flux is established by a capacitor bank connected to the machine in case of stand-alone system and in case of grid connection it draws magnetizing current from the grid.

For a grid connected system, frequency and voltage of the machine will be dictated by the electric grid, since it is very tiny compared to the overall system.

For stand-alone systems, frequency and voltage are complex function of machine parameters, capacitance used for excitation, and load value and type.

GRID CONNECTED INDUCTION GENERATOR

Grid connected induction generators develop their excitation from the Utility grid. The generated power is fed to the supply system when the IG is run above synchronous speed. Machines with cage type rotor feed only through the stator and generally operate at low negative slip. But wound rotor machines can feed power through the stator as well as rotor to the bus over a wide range known as Doubly Fed Induction Machines [5].

FIXED SPEED GRID CONNECTED WIND TURBINE GENERATOR

The structure and performance of fixed-speed wind turbines as shown in Fig. 1 depends on the features of mechanical sub-circuits, e.g., pitch control time constants etc.

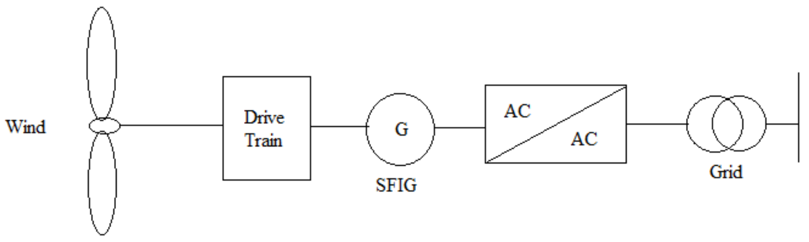

Fig.1 Fixed speed wind turbine with directly grid connected squirrel-cage induction generator

The reaction time of these mechanical circuits may lie in the range of tens of ms. As a result, each time a burst of wind hits the turbine, a rapid variation of electrical output power can be observed. These variations in electric power generated not only require a firm power grid to enable stable operation, but also require a well-built mechanical design to absorb high mechanical stress, which leads to expensive mechanical structure, especially at high power rating.

VARIABLE SPEED WIND TURBINE GENERATOR

A way to make more convenient turbines is variable speed turbines. Variable speed turbines have become the most dominating type of the yearly installed wind turbines as they can store some of the power fluctuations due to turbulence by increasing the rotor speed, pitching the rotor blades, these turbines can control the power output at any given wind speed [4].

Fig. 2 shows a variable speed turbine connected to a Squirrel-Cage Induction Generator SCIG. Although these direct-online systems have been built up to 1.5 MW, but presence of power inverter causes lots of disadvantages such as:

a) This power converter, which has to be rated at 1 p.u. of total system power, is expensive.

b) Converter efficiency plays an important role in total system efficiency over the entire operating range.

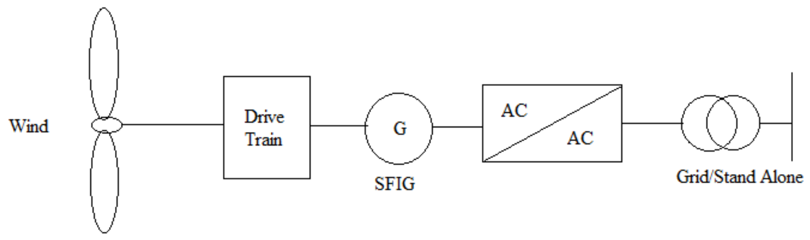

Fig. 2 Variable speed wind turbine with squirrel-cage induction generator

Another way is using Doubly Fed Induction Generator DFIG, as shown in Fig. 3 It consists of a stator connected directly to grid and a rotor – via slip rings – is connected to grid through four-quadrant ac-to-ac converter based on insulated gate bipolar transistors (IGBTs)

This system offers the following advantages:

1. Reduced inverter cost, because inverter rating is typically 30% of total system power.

2. Improved system efficiency.

3. Power-factor control can be implemented at lower cost.

4. It has a complete control of active and reactive power.

FIXED-SPEED WIND TURBINES

A fixed-speed wind turbine with a squirrel cage induction generator is the simplest electrical topology in a wind turbine concept. The schematic structure of the turbine is illustrated in Fig. 3.

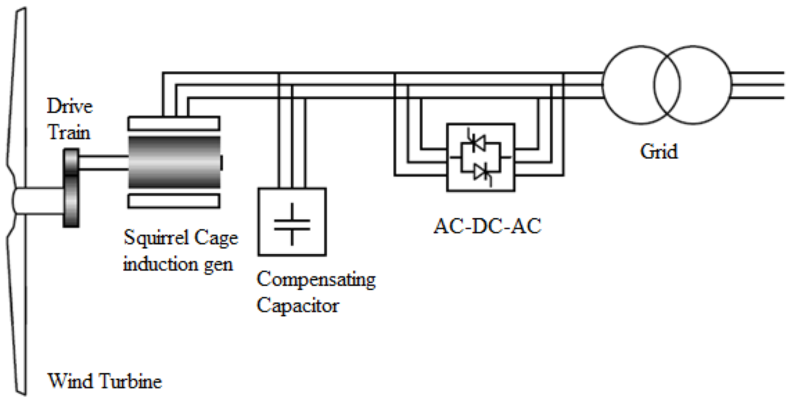

Fig. 3 System structure of fixed-speed wind turbine with direct connected squirrel cage induction generator

The turbine blades convert the kinetic energy of wind into rotational mechanical energy. The squirrel cage induction generator transforms the mechanical energy into electrical energy and delivers the energy directly to the grid. Note that the rotational speed of the generator is relatively high in the order of 1000-1500 rpm for a 50 Hz system frequency. Such rotational speed is too high for the turbine rotor speed with respect to turbine efficiency and mechanical stress. Thus, the generator speed must be stepped down using a multiple-stage gearbox with an appropriate gear ratio.

III- REACTIVE POWER CAPABILITY OF A WIND POWER PLANT

In recent years, severe requirements have been placed on the transmission network, and these requirements will continue to increase because of the increasing number of non-conventional generator plants. Several factors such as increased demands on transmission and the need to provide open access to generating companies and customers have reduced the security of the system and the quality of supply. The cost of transmission lines and losses, as well as difficulties encountered in building new transmission lines, would often limit the available transmission capacity.

These problems have necessitated a change in the traditional concepts and practices of power systems. There are emerging technologies available, which can help system operators to deal with above problems [7].

Flexible AC Transmission System (FACTS) is one aspect of the power electronics revolution that happened in all areas of electric energy. These controllers provide a better adaptation to varying operational conditions and improve the usage of existing installations. FACTS controller is defined as a power electronic-based system that provide control of one or more AC transmission system parameters (series impedance, shunt impedance, current, voltage, phase angle).

The FACTS controllers are mainly used for the following applications:

☐ Power flow control,
☐ Increase of transmission capacity,
☐ Voltage control,
☐ Reactive power compensation,
☐ Stability improvement,
☐ Power quality improvement,
☐ Power conditioning,
☐ Flicker mitigation,
☐ Interconnection of renewable and distributed generation and storages.

Using the advantages offered by the power electronic devices the FACTS controller provides a smoother operation and an increased lifetime of the system(less maintenance), compared to the conventional devices which are mechanical switched [7].

In general, FACTS controllers can be divided into four categories:

☐ Series Controllers
☐ Shunt Controllers
☐ Combined series-series Controllers
☐ Combined series-shunt Controllers

IV- STATCOM

STATCOM typically consists of an inverter, a DC capacitor and a coupling transformer, see Figure 4.

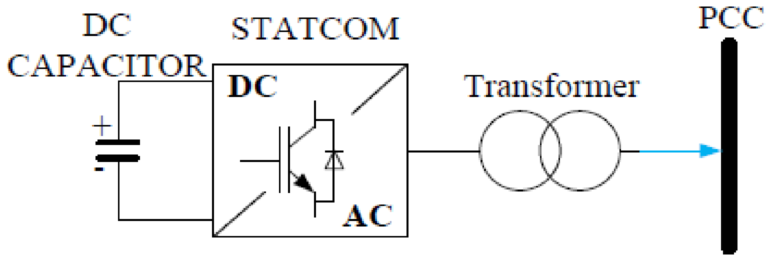

Fig. 4 Schematic representation of a STATCOM [25]

Assuming that no active power is exchanged between STATCOM and the grid (lossless operation) the voltage of the controller is in phase with the grid voltage. If the compensator voltage magnitude is smaller than the voltage at the connection node current will flow from the grid to STATCOM. In this case the reactive power will be consumed. If the situation is opposite the reactive power will be delivered to the grid. Schematic representation of this principle is presented using phasor diagrams in Figure 5 [8].

A STATCOM injecting reactive current is supporting the grid voltage. Comparably when STATCOM is absorbing reactive current it is decreasing the grid voltage. In the first case controller behaves as an overexcited generator or capacitor and in the second case STATCOM behaves as an under excited generator or inductor [8].

The STATCOM is essentially an alternating voltage source with the corresponding *V-I* and *V-Q* characteristics shown in Figure 5.

These show that the STATCOM can be operated over its full output current range even at very low system voltage levels. In other words, the maximum capacitive or inductive output current of the STATCOM can be maintained independently of the ac system voltage, and the maximum VAr generation or absorption changes linearly with the ac system voltage [7].

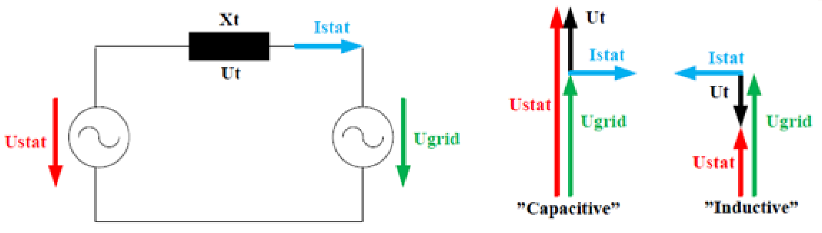

Fig.5 Equivalent circuit representation of a STATCOM [9]

V- SIMULINK MODEL AND RESULT

In this thesis a system is analysed at steady state condition and fault state condition. Fault is generated grid side and voltage and active power and reactive power are monitored at overall system. The behavior of the wind power plant is monitored during fault events and after fault clearance. A wind farm designed without using STATCOM and another with STATCOM and finally both models are compared to check the difference created due to STATCOM. The studied wind farm operates at the fixed wind speed of 14.9 m/s, so the wind turbines operate at nominal values. During fault period, it can be assumed that the wind speed does not change. To study the effect of fault, the simulation is performed when the fault occurs in 3 phases with respect to ground at a fixed time interval. In this paper, the fault duration times are varied between 500ms and 550 ms. The system is studied four times: one without fault second without STATCOM connection, third with grid connection and the other with STATCOM connection. Simulation model and results are shown below.

FIXED SPEED INDUCTION GENERATOR WIND TURBINE MODEL

In basic model of FSIG, a wind turbine is operated on a fixed wind speed of 19.4m/s and torque generated by turbine is applied to the squirrel cage induction generator now generator provide three phase output on the terminal.

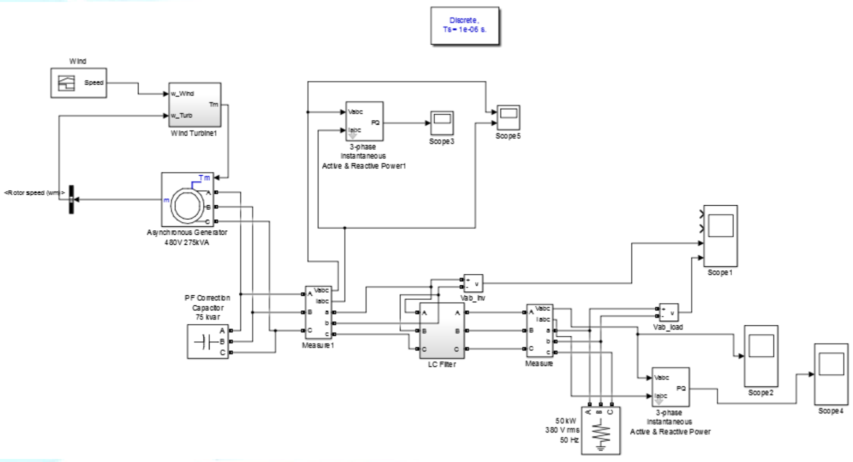

Fig. 6 Simulink Model of wind turbine using induction generator

Terminal is connected to a bus and a 75kvar capacitor bank for power factor correction. Again power is passed through a 3kvar filter having inductor value 2mH and a power factor correcting capacitor of 3kvar. An RLC load of 50kW power rating is connected at output terminal. Generated output voltage at load side is shown in fig. 7.

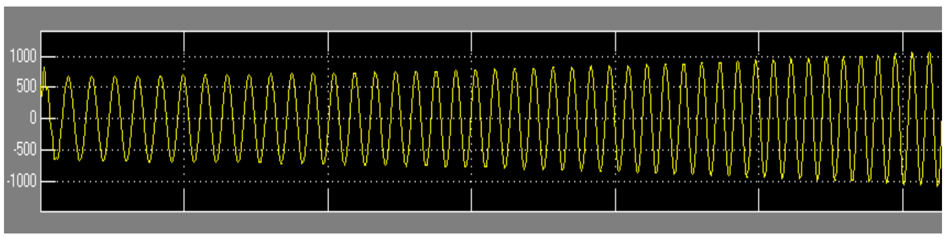

Fig. 7 output voltage from generator

Model Parameters

S. No.	Parameters	Values
1	Wind speed	19.4 m/s
3	Induction motor	275kva, 480v, 50Hz
4	PF correction Capacitor	75kvar
5	Transformer	50kva,25kv/600v
6	LC filter	3kvar
7	Load	50kw

FIXED SPEED INDUCTION GENERATOR WIND TURBINE MODEL WITH GRID CONNECTION WITH FAULT MODEL

In figure 8 wind turbine induction generator is connected to grid load. Grid phase to phase voltage is 315kv and Y grounded is used. A filter of 80Mvar is connected to grid for correcting power factor. Then grid signal is forwarded to a Y grounded primary winding and delta connection of secondary winding power transformer with 600MVA nominal power and 315kv/210kv. A fault is generated from 0.5 second to 0.55 second.

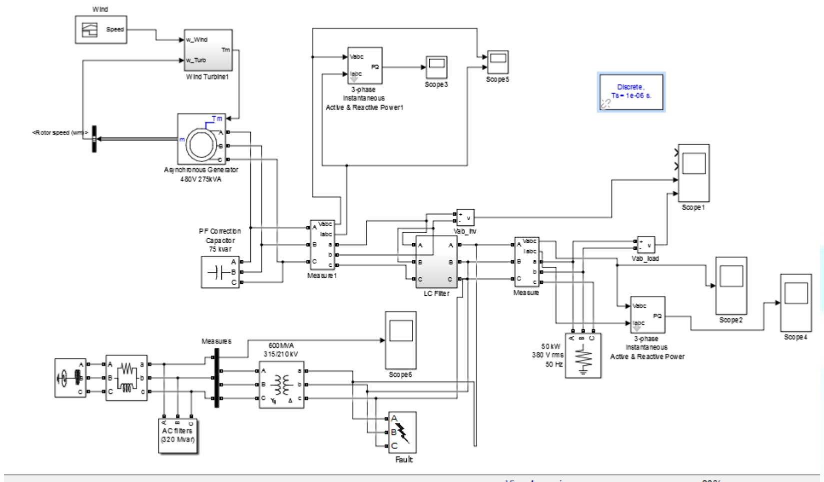

Fig. 8 Simulink of SFIG with STATCOM, grid load and a fault generation block

From figure 9 we can conclude that load side village is dipped to zero after applying 3 phase fault from 0.5 to 0.55 second. After fault has removal output voltage still dipped.

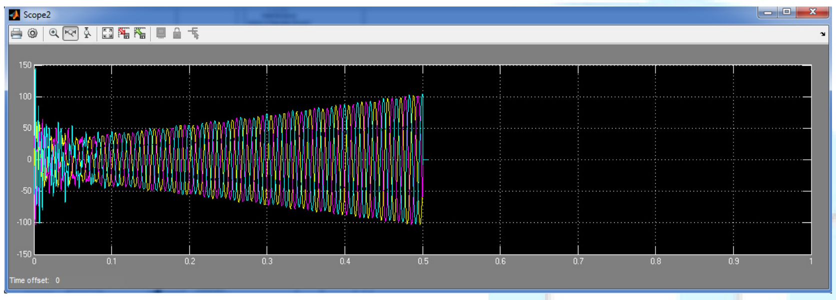

Fig. 9 Output voltage at load side in case of 3 phase fault

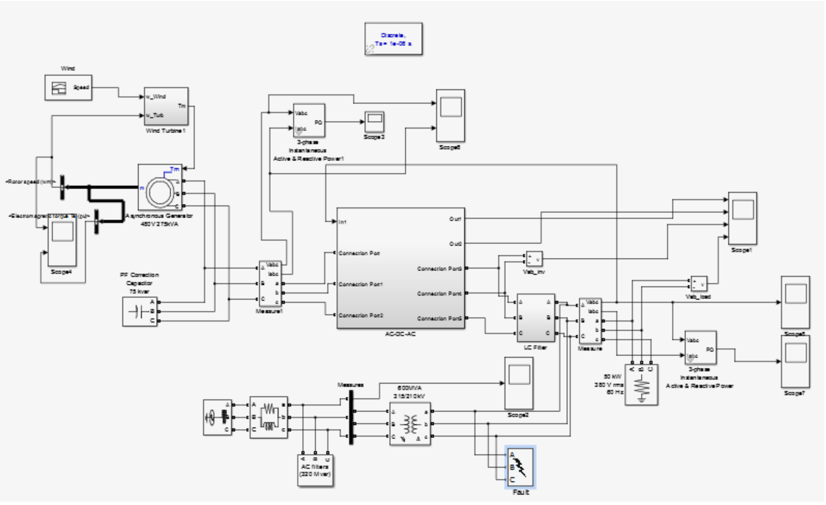

Fig. 10 SFIG model connected grid load with STATCOM

After connecting a 50kVA STATCOM on same system we can monitor load side voltage in figure 11. From 5 second to 0.55 second a voltage dip occurred in system due to 3 phase fault but after disconnection of fault voltage again maintained to its previous value.

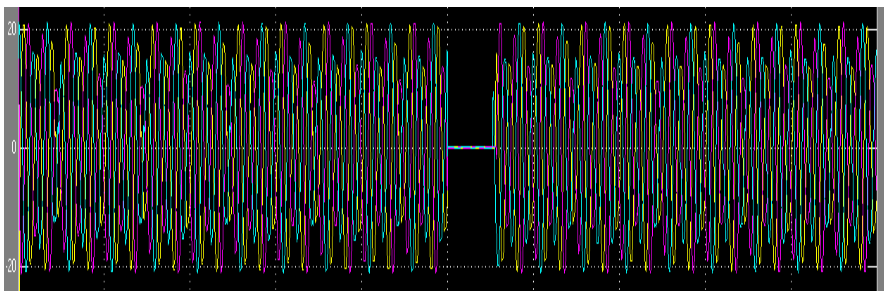

Fig. 11 Load side voltage in case of STATCOM

VII- CONCLUSION

A voltage control structure for a STATCOM applied on an FSIG-based wind farm with unbalanced grid voltage fault analysed. The proposed structure controls the voltage dip occurred due to grid fault. Voltage control by the STATCOM and the related effect on the wind turbine behaviour is analysed in this paper. While the voltage dip compensation leads to an increased voltage stability of the wind farm, the negative-sequence voltage compensation leads to increasing the lifetime of the wind generator drive train.

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