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Voltage Compensation Using STATCOM During Asymmetrical Faults in Wind Farms

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***Abstract*—** Power quality problem is the most sensitive problem in a power system. Most of the pollution issues created in power system is because of the nonlinear nature of loads. Due to large amount of non-linear equipment, impact and fluctuating loads problems of power quality is becoming more and more serious problem with time. A wind turbine connected to a grid connected induction generator results in asymmetric faults. To attenuate these faults static compensator has gained more attention because of its excellent performance of fault mitigation and reactive power compensation .But still performance of the static compensator depends upon different control strategies. This proposed project presents detailed analysis to compare and the performance of wind turbine under asymmetric faults with and without static compensator. A static compensator control structure is used to compensate the positive and negative sequence voltage compensation under different fault conditions as the negative sequence voltage causes heavy torque oscillations that reduce the life of the drive train. The direct quadrature axis theory is the vector control method used in static compensator. This method aims to compensate positive and negative sequence voltages. Simulations are to be carried out with PI controller for the direct quadrature control strategy of different asymmetric faults and analyzing the current, voltage, torque, speed, active and reactive power. It is expected that positive, atequence and co-ordinate positive and negative sequence voltages and currents are compensated.

***Keywords*—** wind turbine, static compensator, vector control method, voltage compensation etc.

I. INTRODUCTION

The conventional energy sources are limited and pollute the environment. So more attention and interest have been paid to the utilization of renewable energy source such as Wind Energy, Fuel Cell, Solar Energy etc**.,** Wind Energy is the fastest growing and most promising renewable energy source among them as it is economically viable. The wind power penetration has increased dramatically in the past few years, hence it has become necessary to address problems associated with maintaining a stable electric power system that contains different sources of energy including hydro, thermal, coal, nuclear, wind, and solar. In the past, the total installed wind power capacity was a small fraction of the power system and continuous connection of the wind farm to the grid was not a major concern. With an increasing share derived from wind power sources, continuous connection of wind farms to the system has played an increasing role in enabling uninterrupted power supply to the load, even in the case of minor disturbances. The wind farm capacity is being continuously increased through the installation of more and larger wind turbines. Voltage stability and an efficient fault ride through capability are the basic requirements for higher penetration.[2] Wind turbines have to be able to continue uninterrupted operation under transient voltage conditions to be in accordance with the grid codes. Grid codes are certain standards set by regulating agencies. Wind power systems should meet these requirements for interconnection to the grid. Different grid code standards are established by different regulating bodies, but Nordic grid codes are becoming increasingly popular.

One of the major issues concerning a wind farm interconnection to a power grid concerns its dynamic stability on the power system . Voltage instability problems occur in a power system that is not able to meet the reactive power demand during faults and heavy loading conditions. Standalone systems are easier to model, analyze, and control than large power systems in simulation studies. A wind farm is usually spread over a wide area and has many wind generators, which produce different amounts of power as they are exposed to different wind patterns[3] [4].

Flexible AC Transmission Systems (FACTS) such as the Static Synchronous Compensator (STATCOM) and the Unified Power Flow Controller (UPFC) are being used extensively in power systems because of their ability to provide flexible power flow control. The main motivation for choosing STATCOM in wind farms is its ability to provide bus bar system voltage support either by supplying and/or absorbing reactive power into the system. [6] The applicability of a STATCOM in wind farms has been investigated and the results from early studies indicate that it is able to supply reactive power requirements of This i explores the possibility of enabling wind farms to provide voltage support during normal conditions, as well as under conditions when system voltages are not within desired limits. The transient behavior of wind farms can be improved by injecting large amounts of reactive power during fault recovery. This thesis examines the use of STATCOMs in wind farm investigations to stabilize the grid voltage after grid disturbances such as line outages or severe system faults.

The wind turbines (WTs) considered in this thesis are Doubly Fed Induction Generators (DFIGs) that are capable of variable speed operation. A DFIG has a power electronic converter by which both real power and reactive power can be controlled.[4] A STATCOM was employed to regulate the voltage at the bus, to help maintain constant DC link voltages at individual wind turbine inverters during disturbances. This

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feature will facilitate the continuous operation of each individual wind turbine during disturbances, thus enabling the wind farm to participate in the grid side voltage and power control. The STATCOM with a higher rating capacity was developed based on the study of an available low capacity STATCOM model. The complete power grid studied in this thesis is a combined case study of interconnected two wind turbines, a synchronous generator, a STATCOM and a typical load all forming a four bus system.[7]

This paper proposes develop a STATCOM to compensate faults in high voltage bus as well as faults in wind generator bus (i.e. for faults inside wind form).The STATCOM will be designed to compensate the reactive power for faults in any part of power system, ie for faults inside the wind farm and for faults external to wind farm.

This paper structured as follows. Basic investigation of wind turbines is described inspection II.The investigated power structure in section III is followed by the presentation of the proposed STATCOM control structure in section IV.An analysis by Dq theory induction generator characteristics in section V.unbalanced grid faults results in section VI.simulation results also followed in VII.A conclusion Closes this paper.

II. BASIC INVESTIGATION OF WIND TURBINES

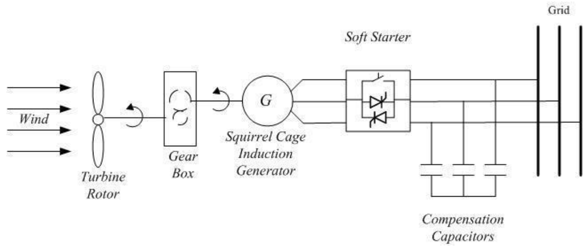


Figure1: Type A: constant speed wind turbines.

Type A: Constant Speed Wind Turbines

Usually, such turbines are equipped with squirrel cage induction generators, as shown in In this configuration concept, a gear box is used to couple the turbine shaft to the generator shaft. Such wind turbines have no pitch angle control and their rotors are designed so that their efficiency decrease at high wind speeds thus reducing the amount of mechanical power that can be extracted from the wind power. Also, compensation capacitors are used to provide sufficient reactive power for the induction machines. Sometimes synchronous generators are used, but in these cases, no compensation capacitors (and in some cases, no gear box) are required. These types lack the presence of active and reactive power control resulting in large fluctuation in the output power.

Type B: Variable Speed Wind Turbines

These types are equipped with doubly fed induction generators. In this concept, a gear box is also used. These types of wind turbines have back-to-back voltage source converters for feeding the rotor windings. These turbines have a pitch angle control to limit the power extracted at high wind speeds conditions. No compensation capacitors are used.

TABLE-I
PERCENTAGE SHARING OF THE DIFFERENT WIND TURBINE CONCEPTS

Concept/year	1998	1999	2000	2001	2002
Type A	39.6	40.8	39	31.1	27.8
Type B	17.8	17.1	17.2	15.4	5.1
Type C	26.5	28.1	28.2	36.3	46.8
Type D	16.1	14	15.6	17.2	20.3
Total Installed Capacity (MW)	2349	3788	4381	7058	7248

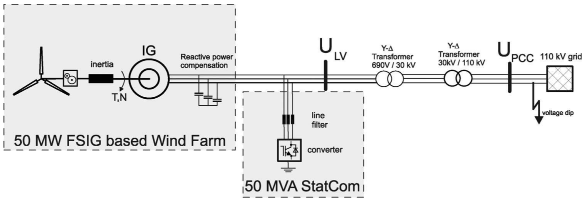


Figure2: layout of investigated FSIG system with STATCOM connected to the grid.

III. POWER SYSTEM LAYOUT

The investigated power system is shown in Fig 2 and consists of a 50-mw wind farm with squirrel cage induction generators directly connected to the grid and a 50-MVA STATCOM.An assume model of the wind farm is used as usual here, which means that the sum of the turbines is modeled as one generator using standard T-equivalent circuit the STATCOM is modeled as controlled voltage sources. Both devices are connected to the same low voltage bus andthen connected to the medium voltage bus by a transformer. the medium voltage level is connected to the high voltage level by a second transformer.\both transformers are rated for the sum of the wind farm and STATCOM power and have a series impedance of 5% and 10% per unit. the grid fault is assumed at the high voltage level of the grid this is modeled by its thevenin equivalent.

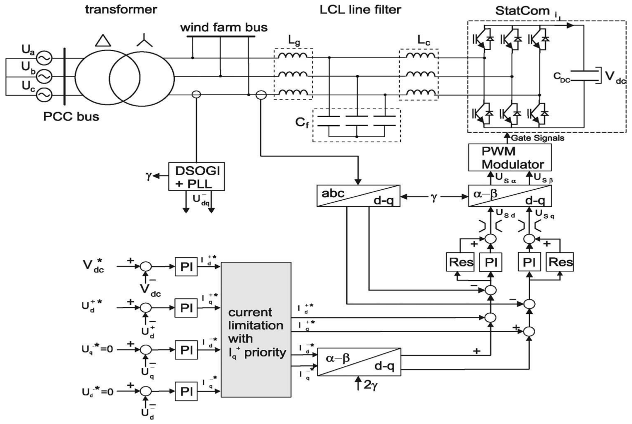


Fig. 3. Proposed control structure of the STATCOM to control the positive- and the negative-sequence voltage independent

TABLE-II
WIND FARM INDUCTION GENERATOR AND STATCOM SIMULATION PARAMETERS

WIND FARM INDUCTION MOTOR	SIMULATION PARAMETERS
Base apparent power Rated active power Rated voltage(line to line)	57,5MW 50MW 690V
Stator resistance (Rs) Stator stray impedance ($X_{s\sigma}$) Mutual impedance(X_h) Rotor resistance(R'_r) Rotor stray impedance($X'_{R\sigma}$) Compensation capacitors Mechanical time constant H	0.0108_{PU} 0.107_{PU} 4.4_{PU} 0.01214_{PU} 0.1407_{PU} 0.17F 3_S
STATCOM	
Rated power Rated voltage Line filter L_{filter} DC voltage U_{DC} Current capability	50 Mvar 690V 0.15 pu 1200v 1 pu

IV. STATCOM CONTROL STRUCTURE

The complete control strategy of the machine is divided in two ways, one is scalar control and the other is vector control. The limitations of scalar control give a significance to vector control. Though the scalar control strategy is modest to implement but the natural coupling effect gives sluggish response. The inherent problem is being solved by the vector control. The vector control is invented in the beginning of 1970s. Using this control strategy an IM can be performed like dc machine. Because of dc machine like performance vector control is also known as orthogonal, decoupling or vector control. Different Vector control strategies have been proposed to control the active and reactive power of an induction generator. The basic of the vector control theory is d-q theory. To understand vector control theory knowledge about d-q theory is essential.

The PI controller transfer function is

$$G_{PI(S)} == V_R \frac{1 + s \cdot T_n}{s \cdot T_n} \quad \text{-------------} \ (1)$$

Resonant controllers (Res) function is

$$G_{Res}(s) = K_{res} \frac{s}{s^2 + (2 \cdot \omega 0)^2} \quad \text{------------------} \ (2)$$

V. Dq THEORY

The d-q theory is also known as reference frame theory. The history says in 1920, R. H. Park suggested a new theory to overcome the problem of time varying parameters with the ac machines. He formulated a change of variables which replace the variables related to the stator windings of a synchronous machine with variables related with fictitious winding which rotates with the rotor at synchronous speed. Essentially he transformed the stator variables to a synchronously rotating reference frame fixed in the rotor. 3

With such transformation (Park„s transformation) time varying inductances that occur due to an electric circuit in relative motion and electric circuit with varying magnetic reluctances can be eliminated. Later in 1930s H. C. Stanley showed that time varying parameters can be eliminated by transforming the rotor variables to the variables associated with fictitious stationary windings. In this case the rotor variables are transformed to the stationary reference frame fixed on the stator. Later G. Kron proposed transformation of stator and rotor variables to a synchronously rotating reference frame which moves with rotating magnetic field. Latter, Krause and Thomas had shown that the time varying Inductances can be eliminated by referring the stator and rotor variables to an arbitrary reference frame.

Transformation from three phase stationary axes to two phase rotating axes

Consider a symmetrical three phase induction machine with stationary a phase, b phase and c-phase axes are placed at 120° angle to each other as shown in Fig 4.1. The main aim is to transform the three phase stationary frame variables into two phase stationary frame variables(ds-qs) and then transform these to synchronously rotating reference frame variables (d-q), and vice versa.

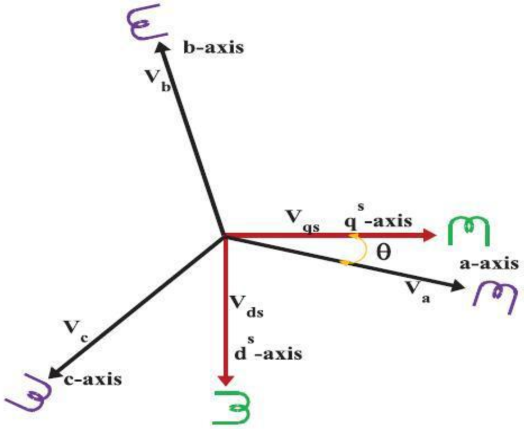


Fig 4: Transformation of a-b-c to ds-qs axes

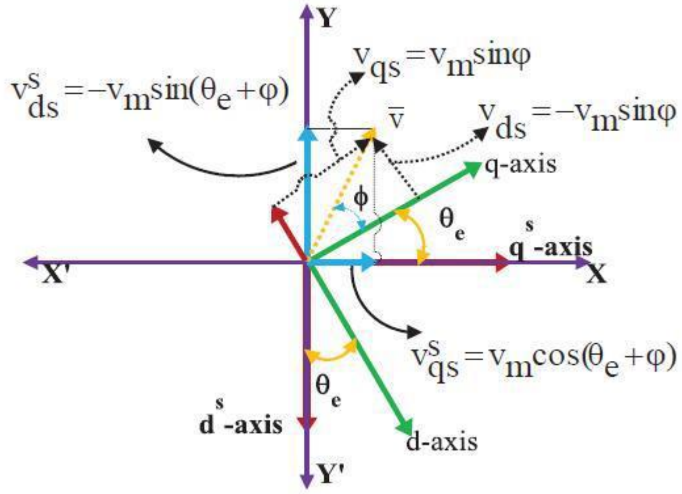
Let ds-qs axes are oriented at an angle from a-b-c axes as shown in Fig 4.2 The voltage (V_{dss} andV_{qss}) can be resolved into a-b-c components and can be represented in the matrix form as

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 120°) & \sin(\theta - 120°) & 1 \\ \cos(\theta + 120°) & \sin(\theta + 120°) & 1 \end{bmatrix} \begin{bmatrix} Vs\,qs \\ Vs\,ds \\ Vs\,0s \end{bmatrix}$$

The corresponding inverse relation is

$$\begin{bmatrix} Vs\,qs \\ Vs\,ds \\ Vs\,0s \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - 120°) & \cos(\theta + 120°) \\ \sin\theta & \sin(\theta - 120°) & \sin(\theta + 120°) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix}$$

Transformation of two phase stationary axes to two phase synchronously rotating axes



Transformation of stationary ds-qs axes to synchronously rotating frame d-q axes

Fig 4.6 above shows the synchronously rotating d-q axes which rotate at synchronous speed with respect to ds-qs axes. The two phase windings are transformed in to the fictitious windings mounted on the d-q axes.

$$V_{qs} = V^s qs \cos_{\theta e} - V^s ds \sin_{\theta e}$$

$$V_{ds} = V^s qs \sin_{\theta e} + V^s ds \cos_{\theta e}$$

Again resolving the rotating frame parameters into a stationary frame the relations are

$$V^s qs = Vqs \cos_{\theta e} + Vds \sin_{\theta e}$$

$$V^s Ds = -Vqs \sin_{\theta e} + Vds \cos_{\theta e}$$

Other parameters like current, flux linkages can be transformed by similar manner. It is more convenient that q - to set axis is aligned with the a-axis in this case (The alignment of the axes are optional, d-axis can also be aligned with a-axis). The sine components of d and q parameters will be replaced with cosine values, and vice versa if d-axis coincides with a-axis.

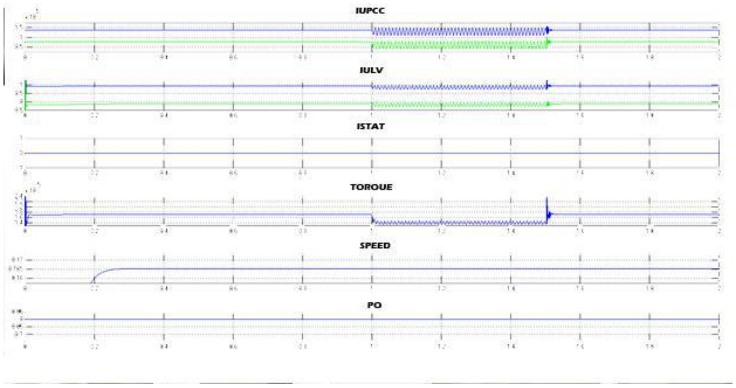
V.SIMULATION RESULTS

In this section, simulation results for the operation of the induction generators and the stabilization by the STATCOM under an unbalanced grid voltage dip of 500-ms duration are presented and discussed.

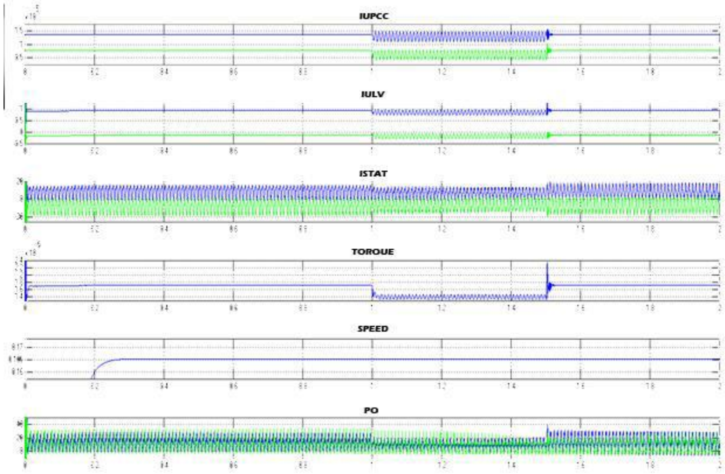
An unbalanced fault (single phase amplitude drops to 50%) is assumed at the high voltage bus of the power system The simulation results are shown in Fig. 4. The un-balanced grid fault leads to a negative-sequence voltage at the medium voltage bus .

In the operation of the system without STATCOM. The reduction of the positive-sequence voltage leads to a decrease in torque and an acceleration of the rotor. The important differences compared to a balanced grid fault are the heavy torque oscillations [of the system caused by the negative-sequence voltage. For this simulation case, the grid voltage fault does not lead to voltage instability because the generator can return to the rated operation point after the fault, but there is very high stress on the mechanical parts of the system due to the torque oscillations.

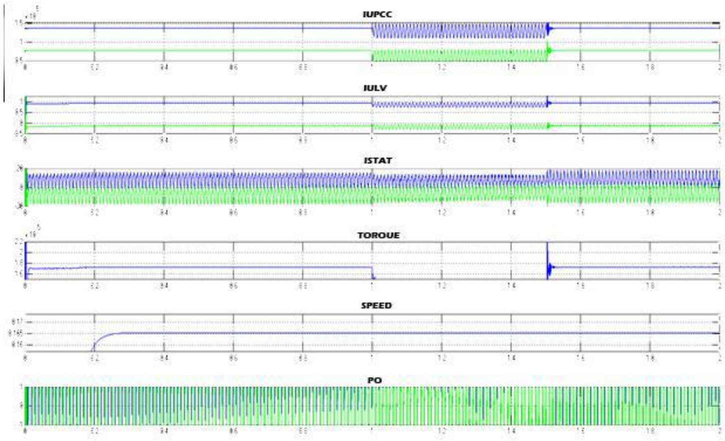
5.5.Wind Turbine Fisg-Without Statcom– 1ph-50 %



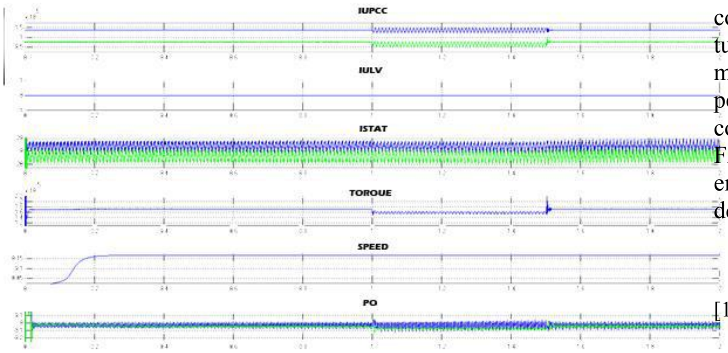
5.5.2 Wth Statcom – 1ph-50 % - Positive Sequence Compensation



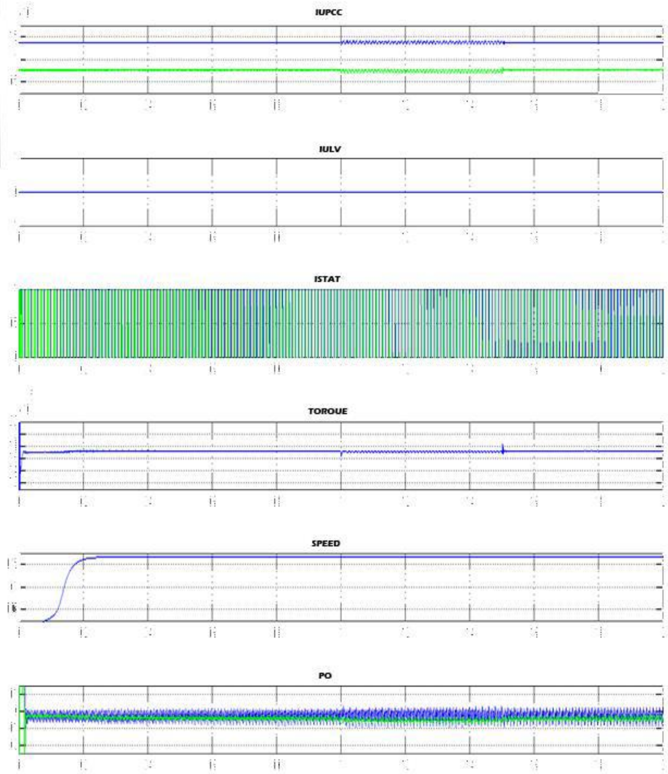
5.5.3 With Statcom – 1ph-50 % - Negative Sequence Compensation



5.5.4 With Statcom – 1ph-60 % - Coordinated Positive - Negative Sequence Compensation



5.5.5 With Statcom – 1ph-0 % - Coordinated Positive - Negative Sequence Compensation



VI. CONCLUSION AND FUTURE WORK

In this project a wind turbine fed fixed speed induction generator is modeled under asymmetric grid fault 1ph-50%.To mitigate these faults a static compensator is injected into the wind turbine fed fixed speed induction generator. It also compensates the positive and negative sequence voltage and current. The respective waveforms are verified for without and with static compensator. Similarly the same procedure is evaluated 1ph-60% and 1ph-0% and the wind turbine characteristics have been worked out. Instead of fixed speed induction generator wind turbine fed doubly fed induction generator can be evaluated under asymmetric grid faults. Instead of STATCOM, DVR (dynamic voltage restorer), Unified power quality conditioner can used to attenuate the asymmetric faults in wind turbine fed FSIG and DFIG as both DVR and UPQC have the fault mitigation capability. The other combination that can be tried is permanent magnet synchronous generator with full back to back converter can be evaluated under asymmetric faults using different FACTS devices. Instead of PI controller, hysteresis controller can be employed and instantaneous theory; pq theory can be used in place of dq theory and evaluated.

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