Power Quality Improvement using Single Phase D-STATCOM in Wind Applications

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Abstract: One of the main problems in wind energy generation is the connection to the grid. Injection of wind power into the grid affects the power quality resulting in poor performance of the system. The wind energy system faces frequently fluctuating voltage due to the nature of wind and introduction of harmonics into the system. The influence of the wind turbine in the grid system concerning the power quality measurements are-the active power, reactive power, variation of voltage, flicker, harmonics, and electrical behavior of switching operation and these are measured according to national/international guidelines specified in International Electro-technical Commission standard, IEC-61400. The paper study demonstrates the power quality problem due to installation of wind turbine with the grid. In this proposed scheme distribution static compensator (DSTATCOM) is connected with a battery energy storage system (BESS) to mitigate the power quality issues. The battery energy storage is integrated to sustain the real power source under fluctuating wind power. The DSTATCOM control scheme for the grid connected wind energy generation system for power quality improvement is simulated using MATLAB/SIMULINK in power system block set. Finally the proposed scheme is applied for both balanced and unbalanced nonlinear loads.

Keywords: D-STATCOM, Hybrid-Clamped Topology, MMC Topology, Multi-Level Inverter, OHSW Harmonic Elimination Technique.

I. INTRODUCTION

One of the most common power quality problems today is voltage dips. A voltage dip is a short time (10 ms to 1 minute) event during which a reduction in R.M.S voltage magnitude occurs. It is often set only by two parameters, depth/magnitude and duration. The voltage dip magnitude is ranged from 10% to 90% of nominal voltage (which corresponds to 90% to 10% remaining voltage) and with a duration from half a cycle to 1 min. In a three-phase system a voltage dip is by nature a three-phase phenomenon, which affects both the phase-to-ground and phase-to-phase voltages. A voltage dip is caused by a fault in the utility system, a fault within the customer’s facility or a large increase of the load current, like starting a motor or transformer energizing. Typical faults are single-phase or multiple-phase short circuits, which leads to high currents. The high current results in a voltage drop over the network impedance. At the fault location the voltage in the faulted phases drops close to zero, whereas in the non-faulted phases it remains more or less unchanged. Voltage dips are one of the most occurring power quality problems. Off course, for an industry an outage is worse, than a voltage dip, but voltage dips occur more often and cause severe problems and economical losses.

Utilities often focus on disturbances from end-user equipment as the main power quality problems. This is correct for many disturbances, flicker, harmonics, etc., but voltage dips mainly have their origin in the higher voltage levels. Faults due to lightning, is one of the most common causes to voltage dips on overhead lines. If the economical losses due to voltage dips are significant, mitigation actions can be profitable for the customer and even in some cases for the utility. Since there is no standard solution which will work for every site, each mitigation action must be carefully planned and evaluated. There are different ways to mitigate voltage dips, swell and interruptions in transmission and distribution systems. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices, both of them based on the VSC principle.

STATCOM is often used in transmission system. When it is used in distribution system, it is called D-STATCOM (STATCOM in Distribution system). D-STATCOM is a key FACTS controller and it utilizes power electronics to solve many power quality problems commonly faced by distribution systems. Potential applications of D-STATCOM include power factor correction, voltage regulation, load balancing and harmonic reduction. Comparing with the SVC, the D-STATCOM has quicker response time and compact structure. It is expected that the D-
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STATCOM will replace the roles of SVC in nearly future. D-STATCOM and STATCOM are different in both structure and function, while the choice of control strategy is related to the main-circuit structure and main function of compensators, so D-STATCOM and STATCOM adopt different control strategy. At present, the use of STATCOM is wide and its strategy is mature, while the introduction of D-STATCOM is seldom reported. Many control techniques are reported such as instantaneous reactive power theory (Akagi et al., 1984), power balance theory, etc. In this paper, an indirect current control technique (Singh et al., 2000a, b) is employed to obtain gating signals for the Insulated Gate Bipolar Transistor (IGBT) devices used in current controlled voltage source inverter (CC-VSI) working as a DSTATCOM. A model of DSTATCOM is developed using MATLAB for investigating the transient analysis of distribution system under balanced/unbalanced linear and non-linear three-phase and single-phase loads (diode rectifier with R and R-C load). Simulation results during steady-state and transient operating conditions of the DSTATCOM are presented and discussed to demonstrate power factor correction, harmonic elimination and load balancing capabilities of the DSTATCOM system.

II. BASIC PRINCIPLE OF DSTATCOM

A DSTATCOM is a controlled reactive source, which includes a Voltage Source Converter (VSC) and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of a DSTATCOM are based on the exact equivalence of the conventional rotating synchronous compensator.

![Fig.1. Basic structure of DSTATCOM.](image)

The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown in Fig.1. The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by a battery source, or could be recharged by the converter itself. If the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the DSTATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. It is to be noted that voltage regulation at PCC and power factor correction cannot be achieved simultaneously. For a DSTATCOM used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead the supply voltages; whereas, for power factor Correction, the supply current should be in phase with the supply voltages. The control strategies studied in this paper are applied with a view to studying the performance of a DSTATCOM for power factor correction and harmonic mitigation.

A. Basic Configuration and Operation of D-STATCOM

The D-STATCOM is a three-phase and shunt connected power electronics based device. It is connected near the load at the distribution systems. The major components of a D-STATCOM are shown in Fig.2. It consists of a dc capacitor, three-phase inverter (IGBT, thyristor) module, ac filter, coupling transformer and a control strategy. The basic electronic block of the D-STATCOM is the voltage-sourced inverter that converts an input dc voltage into a three-phase output voltage at fundamental frequency.

![Fig.2. Basic Building Blocks of the DSTATCOM.](image)

The D-STATCOM employs an inverter to convert the DC link voltage $V_{dc}$ on the capacitor to a voltage source of adjustable magnitude and phase. Therefore the D-TATCOM can be treated as a voltage-controlled source. The D-STATCOM can also be seen as a current-controlled source. Fig.2 shows the inductance $L$ and resistance $R$ which represent the equivalent circuit elements of the step down transformer and the inverter will is the main component of the D-STATCOM. The voltage $V_i$ is the effective output voltage of the D-STATCOM and $\delta$ is the power angle. The reactive power output of the D-STATCOM inductive or capacitive depending can be either on the operation mode of the DSTATCOM. The construction controller of the D-STATCOM is used to operate the inverter in such a way that the phase angle between the inverter voltage and the line voltage is dynamically adjusted so that the D-STATCOM generates or absorbs the desired VAR at the point of connection. The phase of the output voltage of the thyristor-based inverter, $Vi$, is controlled in the same way as the distribution system voltage, $Vs$. 

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The situation of marine power quality inclined to worse. The reasons are listed in the following: i. a large amount of control equipments and power electronic devices are put into marine use in order to promote automatization of ship operation and to save energy. e.g., concerning the variation of main engine cooling water temperature, the conventional control method of regulation of valve baffle position is now substituted by speed regulation of motors of cooling water pumps in order to save energy. As well as more and more frequent application of shaft driven generator has been observed. But the operation of all these equipments and devices contributes to the power quality deterioration to a wide extension. ii. Since the capacity of marine electric facilities is always with a plentiful margin, the power factor of marine power plant under normal operation is rather low.

B. Operation modes of D-STATCOM

III. POWER INJECTION PRINCIPLE

The active power P component is the part of energy that is converted into physical energy form. The reactive power Q component helps create the indispensable magnetic medium needed for most of today's electromagnetic energy conversion devices and systems. For example, the AC electric motor absorbs both active and reactive power components once it is energized by the AC source. The absorbed reactive component creates the needed magnetic field to allow the energy conversion process to take place inside the motor. The active power component is absorbed and converted into mechanical power that moves the coupled mechanical load such as a mechanical conveyor. The electric motor will store the reactive power as fluctuating magnetic energy in its windings as long as the conversion process continues. The majority of industrial and commercial appliances require both active and reactive power components for operation. Both P and Q are needed instantly and in different quantities to meet the requirement of the electrical energy converting device connected to the AC source. To understand P and Q flow in a transmission system, consider a simple system that is made up of sending and receiving buses with a transmission cable in between as shown in Fig.4.
as the simulation starts, the D-STATCOM Inverter begins to provide compensation and the power factor is adjusted. The second graph shows the P and Q provided by the feeder line to the load. Initially, the feeder line is supplying the entire load of 50 kW and 34.8 kVARs. When the DSTATCOM Inverter provides capacitive VAR compensation, the amount of VARS provided by the feeder line to the load is decreased to about 20 kVARs. Additionally, as the output of the wind turbine, shown in Fig 5(b), is increased, the amount of active power provided by the feeder line to the load is decreased by the same amount. In the above figures the maximum output power of the turbine is 11 KW, but the control system works properly for up to 20 KW wind turbines. Overall, the D-STATCOM Inverter is able to provide the feeder line with VAR compensation which is independent of the active power provided by the wind turbine. Fig.6 depicts the voltage of the DC link along with the individual voltages across each of the link and auxiliary capacitors. Fig.7 depicts the power factor of the feeder line, the P and Q on the feeder line, the output power factor of the inverter, the output P and Q of the inverter, the modulation index, the angle delta, and the power produced by the wind turbine/solar array.

Fig.5. (a) Feeder line power factor, feeder line P and Q, D-STATCOM power factor, and delivered P and Q of the D-STATCOM. (b) Modulation index, angle delta, and wind turbine output power.

Fig.6. Variation of capacitor voltages using OHSW.

The top graph of Fig.5 (a) shows the power factor of the feeder line during the course of the 20-second simulation. Starting at the 0th second, the power factor of the line is 0.82 (lagging) as it is defined entirely by the load. As soon

Fig.7. Feeder line power factor, feeder line P and Q,
D-STATCOM power factor, and delivered P and Q of the D-STATCOM the output waveform of the 5-level OHSW should contain no even harmonics, because of quarter-wave symmetry, and the 3rd order harmonic should be eliminated due to the OHSW technique. Results show that while the 3rd and even harmonics have not been eliminated they have been suppressed to a low level. Table 1 summarizes the differences between the simulated and predicted values. The presence of even harmonics is the result of non-optimal switching times in the simulation, inductances and capacitances in the inverter, and variations in the current and voltage waveforms. The contribution to the THD by the even harmonics is of little concern as all of the even harmonics are relatively the same size and the higher order ones can be further suppressed with the use of a small filter. The simulated THD is actually lower than the predicted THD. This is due to some of the harmonics being suppressed by the inductances and capacitances in the circuit.

V. CONCLUSION

In this paper, a new DSTATCOM system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. DSTATCOM compensator is a flexible device which can operate in current control mode for compensating voltage variation, unbalance and reactive power and in voltage control mode as a voltage stabilizer. The latter feature enables its application for compensation of dips coming from the supplying network. The simulation results show that the performance of DSTATCOM system has been found to be satisfactory for improving the power quality at the consumer premises. DSTATCOM control algorithm is flexible and it has been observed to be capable of correcting power factor to unity, eliminate harmonics in supply currents and provide load balancing. It is also able to regulate voltage at PCC. The control algorithm of DSTATCOM has an inherent property to provide a self-supporting DC bus of DSTATCOM. It has been found that the DSTATCOM system reduces THD in the supply currents for non-linear loads. Rectifier-based non-linear loads generated harmonics are eliminated by DSTATCOM. When single-phase rectifier loads are connected, DSTATCOM currents balance these unbalanced load currents.

VI. REFERENCES


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