VOLTAGE STABILITY IMPROVEMENT USING STATCOM WITH SUPER CAPACITOR

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***Abstract*:** To maintain voltage stability of a power system, STATCOM is better solution which can provide the required amount of reactive power under various power system disturbances. This paper proposes a solution to enhance the performance of the STATCOM by adding supercapacitor which is a energy storage device to DC link of the conventional STATCOM. With the fast charge or discharge characteristics of the supercapacitor, the enhanced STATCOM can absorb and eject real and reactive power to the AC Power Grid instantaneously. In addition, this paper also proposes that the enhanced STATCOM can be applied to reduce instability and tripping due to the Rate of Change of Frequency (RCF) protection devices caused by large load impact. The amount of the energy required for the enhanced STATCOM to maintain the stability of the system is also discussed. In this paper, Static Synchronous Compensator (STATCOM) with energy storage system for wind power application has been implemented. This device was proposed to improve voltage stability and power transmission by offering reactive as well as active power compensation. The energy storage system used for this application was designed and simulation results were discussed. For active compensation for wind power, a bank of Super Capacitors for Energy Storage System(SCESS) was used. The super capacitor bank size was designed and used, based upon the short term fluctuations in wind power. These fluctuations are results of constructional factors of the turbines, variation and turbulence in the wind. A super capacitor bank was interface with the DC bus of the STATCOM with the normal half bridge boost converter, to convert voltage level of the bank while maintaining a constant DC bus voltage for good switching operation in the VSC.

Keywords: **STATCOM, Supercapacitor, Voltage profile, power losses.**

I. INTRODUCTION

STATCOM with supercapacitor which was demonstrated the change of dynamic and transient dependability and transmission capacity of the power system. Energy storage type STATCOM controls both active and reactive power absorption/injection to the power system. In a new structure of STATCOM with Super capacitors for improved power system dependability was designed to improve the voltage and system stability. For many cases in AC Power Systems disturbance during transient conditions, the lack of real power support from system compensators may lead to the failure due to low stability margins. A STATCOM with the ability to support both reactive and real power dynamically can provide significant improvement to the security of AC Power Systems, even if the real power is only supported for a short period of time.

The main objectives of this paper are summarized as below:
1) To investigate the use of the STATCOM with energy storage for improving the stability within the system.
2) To investigate the Super Capacitor Energy Storage System (SCESS) applied for enhancing the performance of the conventional STATCOM.
3) To demonstrate the benefits of an AC Power System using the enhanced STATCOM with SCESS.

A STATCOM is a reactive power compensator that exhibits a good dynamic response with a wide control of bandwidth and the capability of providing higher currents at low voltage levels. It is also desirable to use a STATCOM due to the possibility of working with decoupled control of the DC-link voltage and the reactive current.

To compensate the voltage drop which is occurring across the AC transmission lines, lines which are compensated using shunt connected capacitors. Voltage compensation across AC transmission lines is one of the most notable advantages of STATCOM which replaces all the previous methods. The STATCOM is delivering the adequate amount of reactive power for dynamic voltage compensation. For this dynamic compensation STATCOM is controlling its three phase amplitude and phase angle on AC side. STATCOM acts as either inductor or capacitor while absorbing or injecting reactive power. STATCOM acts as an inductor while current flowing from AC side to capacitor and acts as capacitor while current flowing from capacitor to AC side. A capacitor with high capacity is used in STATCOM to deliver the adequate amount of DC power to the voltage source converter. Small signal transient stability and voltage stability of the system is achieved during Power System operations. However, one of the main drawbacks is the low energy density on the DC link capacitor installed in the STATCOM; this limits the reactive and active power capability of the STATCOM. An improved version of the STATCOM is called the STATCOM + ES (Energy Storage). This variant includes a storage device, usually batteries, Supercapacitors etc. The storage device provides more capabilities to the STATCOM, such as power oscillation damping or mitigation of phase-jump-related disturbances. Moreover, the STATCOM + ES can be used for reactive compensation when Low Voltage Ride Through system (LVRT) is implemented.

II. DESIGN CONSIDERATIONS FOR STATCOM PLUS SCESS

As the inverter and the DC-DC converter used in this paper are designed for utilizing the supercapacitors energy, the supercapacitor terminal voltage (Vsc) is then considered as the dominant rating that further defines the other voltage limitations. In order to make the use of the supercapacitor for the STATCOM, the bi-directional DC-DC converter is placed in between the supercapacitor modules and the STATCOM, with one side connected to the supercapacitor unit and the other side connected to the STATCOM's DC-link capacitor. This converter is designed to keep the DC-link voltage constant at 400V by operating at a duty ratio of about 0.5 the optimum point where the stored energy can be extracted from the supercapacitors by the DC-DC converter. With this optimized operating point, as the DC-DC converter is interfaced to the STATCOM's DC-link capacitor, this DC link capacitor is therefore rated at Vdc link= 400V.

To operate the STATCOM with the ability to inject power to the AC power grid, three-phase PWM voltage should have a higher magnitude than the three phase power supply voltage. With the DC-link voltage fixed at 400V, a step down transformer (rating 415V/110 V 4kVA) must be used to lower the supply voltage as shown in Figure, ensuring that the operation of the inverter, by the PWM technique, will be in linear region and will not reach over modulation. The voltage at the point of common coupling in this research is therefore set to be Vpcc=110V (line-to-line RMS voltage).

III. DEIGNING COMPONENTS OF THE SYSTEM:

1. STATCOM

STATCOM has been used in Electrical Power Systems as a shunt-connected compensator for voltage support and to improve power quality. Compared with the conventional compensators such as the synchronous condenser and the Static Var Compensator, the STATCOM has a faster speed of response to deal with dynamic and transient impacts. Although the STATCOM is capable of reactive power support to improve power quality, the ability to support real power is limited due to the insufficient energy storage capability of the conventional DC-link capacitor. Therefore, STATCOM performance is improved by using energy storage element Supercapacitor.

STATCOMs have been used to provide reactive power at a PCC in a transmission network or distribution network for different purposes e.g., control of voltage, load compensation and addressing LVRT; the most relevant feature is its capability of injecting a controllable reactive current independent of the grid voltage. A STATCOM is formed by a DC/AC converter, a capacitor on the DC side and a reactor on the AC side for filtering the high frequency components related to Insulated Gate Bipolar Transistor (IGBT) commutation. The main function of that capacitor is to help to stabilize the DC voltage. This power electronic device is based on the voltage source converter principle. Usually, the control implemented for simulation is a Pulse-Width Modulation (PWM) based in dq coordinates that allows the decoupling between the real and the reactive power.

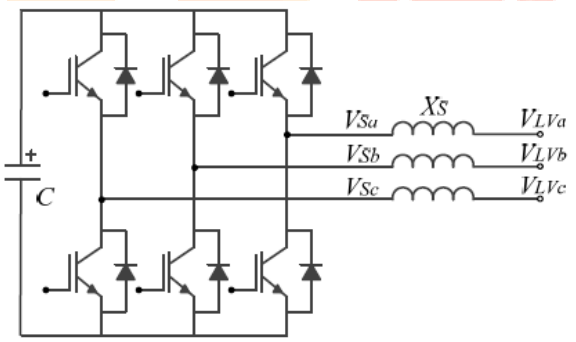

Figure 1: Typical scheme of a STATCOM based on VSI, voltage source inverter.

2. Energy storage system

In wind farms, not only the reactive power, but also the active power is fluctuating. These fluctuations should be controlled, in order to obtain a more stable power system, both with regards to the power transmission and voltage. For this purpose, the STATCOM with an energy storage systems has been proposed in several different techniques for storing energy are available, each having their advantages and disadvantages regarding lifetime, power density and energy density: Batteries, fly-wheels, super capacitors and super conducting inductors. The literature considers normally battery energy storage systems, while some newer, also take into consideration the super capacitors. Due to the power fluctuations in a wind farm, there is a need for high power for a short period in order to maintain a stable voltage. For this purpose, the super capacitor is the most suitable choice, offering high power density, while the energy density is low, compared to for instance batteries. Since the purpose of the device is not to store energy, but smoothen out the active power fluctuations, this is an acceptable trade-off. In addition, the high numbers of cycles the super capacitors can handle are also favorable. By adding the energy storage element, the STATCOM can draw and inject both active and reactive power, adding an additional degree of freedom to the system. By doing so, the power quality is improved. The demanded size of the energy storage system is depending on the demanded control of the power fluctuations. A sensitive control will demand for a higher energy capacity than a rough one.

3. DC/DC-converter for super capacitor

The super capacitor bank needs an interface for the connection to the DC bus. This could span from a simple inductance to filter out the most severe ripples, to a full bridge DC/DC-converter. The choice depends very much on the demanded size of the energy storage, as the cost (and size) of the converter should be compared to that of the super capacitors. The general system, seen from the super capacitor bank is presented in fig.2.The variable load will in the case treated in this text be the grid interfaced with the VSC of the STATCOM.

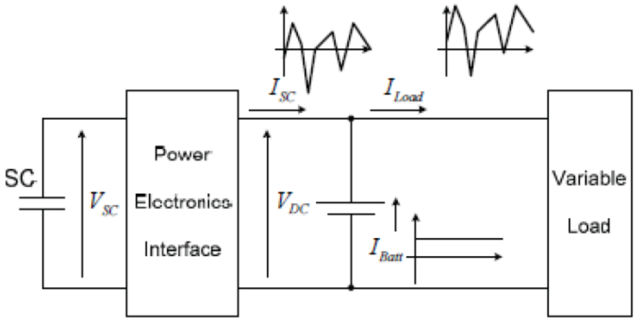

Figure 2: General super capacitor system

A half-bridge buck boost converter is presented. This compromises two bidirectional switches, an inductor and the super capacitor bank. The converter command is a carrier based PWM signal, fed from a cascaded controller. The innermost controls the current, while the outermost feeds this controller based on the active power correction needed in the PCC.

4. Two-Level Three Phase Power Converter

The circuit configuration of a two-level Power Converter connected to the AC grid is shown in Figure 3. In this configuration, for each phase-leg, two switching devices are connected in series (six switches in total). The two switches in the phase-leg are operated in a complementary way. Thus, at any instant of time, only one switch is ON, the other one must be OFF. In order to prevent failure if both the switches are ON at the same time due to the finite transition time of the switches, a small time delay (i.e. blanking time or dead time) is normally included in the switching pattern.

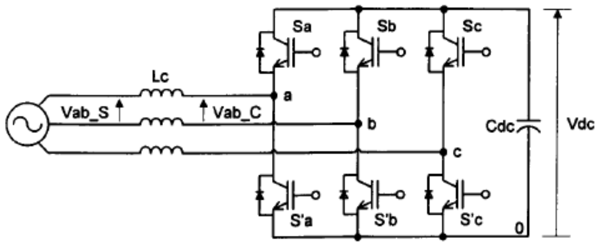

Figure 3: The conventional6-pulse grid connected power converter

An example of the resulting voltage produced by a two-level converter is shown in Figure 4 (circuit without neutral point) where the conduction of the switch in each phase leg is set to 50% duty ratio. When the upper switch (Sa, S, or Sc) is on, the 'a' terminal is connected to Vdc resulting in the voltage Vao equaling Vdc. The other phase legs are connected in the same way, but with a phase delay of 120_0 as in the standard three-phase ac system. These phase voltages indicate that there are two levels in the voltage waveforms (Vdc and zero). The line voltage, for example Yah, is determined by measuring the voltage difference between terminal 'a' and 'b' which is equal Vab =Vao-Vbo
indicating in the top trace of Figure 4.

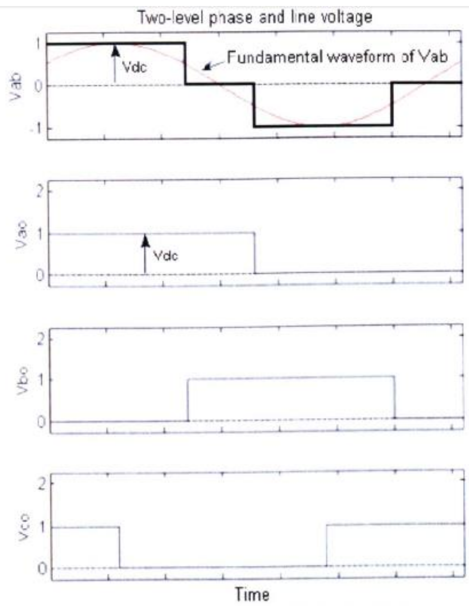

Figure 4: Phase and line voltage of the 2-1evel DC-to-AC converter

The top trace of Figure 4 shows that the resulting line voltage is a 3-level voltage waveform (V_{dc}- zero and -V_{dc}). It can be summarized that the levels of line voltage can be determined by (2M -1) where M is the number of levels of the phase voltage.

IV. WORKING PRINCIPLE OF STATCOM

In this project, a voltage source converter is adopted for use as the main component of the STATCOM. The power circuit diagram of the STATCOM based on a voltage source converter is illustrated in Figure 5, where six IGBTs with its anti-parallel diodes and a DC-link capacitor are used to produce the three-phase voltage. The three-phase inductor Lc is used as the coupling reactor linking the converter to the AC power grid.

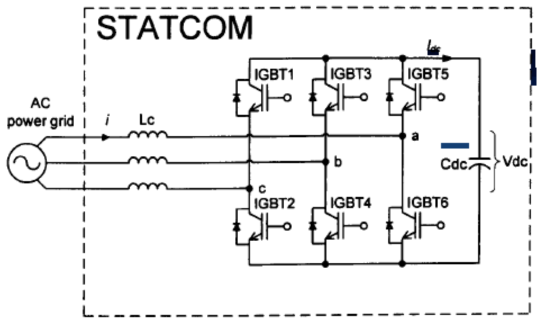

Figure 5: A power circuit diagram of a STATCOMs

The basic principle of operation is that the amplitude and phase of the converter voltage is controlled with respect to the measured ac power grid voltage. This can only be achieved if the DC-link voltage is significantly larger than the peak line-to-line voltage of the AC power grid. The generation of the desired voltage at the front-end of the converter can be achieved by pulse width modulation. Although the output voltage of the converter is a high frequency switching waveform, the coupling reactor acts as a filter and therefore sinusoidal current can be seen flowing in between the AC grid and the STATCOM unit. The strategies used to achieve instantaneous power control.

V. WORKING OF STATCOM

At the time when the main load is switched on, the STATCOM quickly reacts to the sudden voltage drop by supplying the reactive power current (negative Iq) to the AC grid. According to this reactive power current, the magnitude of Vpcc increases rapidly. Consequently, as Vpcc is controlled by the STATCOM, the amount of the reactive power injection is therefore reduced proportional to the increase of the magnitude of Vpcc. due to the STATCOM supplying current to the AC grid, a small drop in the DC-link voltage is seen, as some energy in the DC-link capacitor is needed to supply losses in the system, for example, the switching and conduction losses. According to the STATCOM's DC-link voltage control reacting to this drop in order to maintain the DC-link constant, a small amount of the active power current (LI) is seen. From the results it can be seen that the STATCOM can be applied as a reactive power flow controller. A STATCOM, however, with limited amount of stored energy in a conventional DC-link capacitor, cannot deliver real power to ac grid. Even though the STATCOM can keep the AC bus voltage constant by means of reactive power injection, most of the load current is being supplied by power source side (generator side).

VI. SIMULATION SCENARIOS

1. Simulation of a power system using a conventional STATCOM only

To see the benefits of the instantaneous reactive power compensation to the same power system, the simulation was carried out with a conventional STATCOM connected at Vpcc s-bus. The simulation results are shown in figure. From the beginning of the test at time t=0sec the STATCOM is enabled, therefore the DC-link voltage is regulated at the reference level (400Vdc).

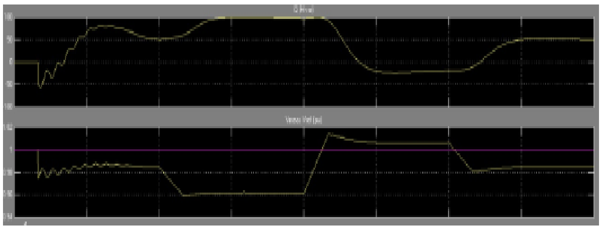

Figure 6: Injected/absorbed reactive power and measured/reference voltage for STATCOM without any energy storage

2. The enhanced STATCOM with Supercapacitors

With the aim to enhance the performance of the STATCOM, the Supercapacitor Energy Storage System (SCESS) has been designed and built interfacing to the STATCOM's DC-link capacitor. In the design for the two mode control of the SCESS (buck and boost modes), the small-signal model representing the change in the supercapacitor voltage related to the change in the reference for the supercapacitor current has been derived and applied in the buck mode controller design, while the relation of the change in the DC-link voltage and the change in the reference for the supercapacitor current has been derived and applied in the boost mode controller design. The improved performance of the enhanced STATCOM, the STATCOM plus SCESS, has been confirmed by the simulation and the experimental results. The STATCOM plus SCESS has a superior performance over the standard STATCOM, it can provide both real and reactive power to the ac grid immediately, while the standard STATCOM can provide only the reactive power. It can be summarized that the enhanced STATCOM can control the support current effectively in all four quadrants, which will be the benefit for the AC power system stability improvement.

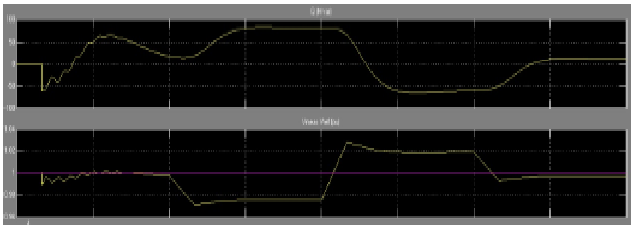

Figure 7: Injected/absorbed reactive power and measured/reference voltage for STATCOM with super capacitor

VII. CONCLUSION

In this paper, the advantages of supercapacitor energy storage have been discussed as the reason for selecting the SCESS as the storage device to improve the performance of the STATCOM. The control of the proposed STATCOM enhanced with supercapacitors (STATCOM plus SCESS) is presented. The simulations verify that the combination of the STATCOM and the SCESS can store and supply the energy instantaneously to the AC grid. Therefore, in terms of frequency stability, this ability can be used as the complement for the frequency variation due to the slow response of generator, and therefore to improve the transient stability of the AC system.

REFERENCES

[1] The European Wind Energy Association. Annual Report 2012; European Wind Energy Association: Brussels, Belgium, 2012.

[2] Energized Regulation TF 3.2.5 Wind Turbines Connected to Grids with Voltages above 100kV.Eltra: http://www.energinet.dk/SiteCollectionDocuments/Engelske documenter/El/Grid Code 3.2.5 Wind Turbines connected above 100 kV.Pdf (accessed on 10 May 2013).

[3] National Grid Electricity Transmission Public Limited Company. The grid code, issue 5, Revision 11. Available online: http://www2.nationalgrid.com/UK/Industry-information/Electricity-codes/Grid-code/The-Grid-code/ ac

[4] A. Ghosh and G. Ledwich, Power quality enhancement using custom power devices. Boston; London,: Kluwer Academic, 2002.

[5] N. G. Hingorani, L. Gyugyi, E. Institute of, and E. Electronics, Understanding FACTS: concepts and technology of flexible AC transmission systems. New York, N.Y.: IEEE Press, 2000.

[6] R.Meinski, R.Pawelek and I.Wasiak, “Shunt Compensation For Power Quality Improvement Using a STATCOM controller Modelling and Simulation”, IEEE Paper, Volume 151, No.March 2004.