DESIGN AND IMPLEMENTATION OF PMSG CONVERSION SYSTEM USING STATCOM MODEL

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ABSTRACT
Power quality is one of the major concerns in the present era. It has become one important, especially, with the introduction of sophisticated devices whose performance is very sensitive to the quality of the power supply. Recent progress as regards technology of the power electronics brings a capacity of reactive power compensation and voltage quality is improved then the voltage sag is completely eliminated by the STATCOM. This is composed of a hybrid control scheme for Energy Storage System (ESS) and Braking Choppers (BC) for fault - ride through capability and a suppression of the output power fluctuation and the elimination of voltage sag is proposed for Permanent Magnet Synchronous Generator (PMSG) wind turbine systems. During grid faults, the dc-link voltage is controlled by the ESS instead of the Line-Side Converter (LSC), whereas the LSC is exploited as a STATCOM to inject reactive current into the grid for assisting in the grid voltage recovery. Interleaved boost converter DC-DC Boost converter is used to improve the voltage quality. The validity of the proposed system is verified by experimental results for a reduced-scale wind turbine simulator as well as simulation results for a 2-MW PMSG wind turbine system.

Index Terms—Braking chopper (BC), dc-link voltage control, energy storage system (ESS), permanent-magnet synchronous generator (PMSG), ride-through, STATCOM, wind turbine, Interleaved boost converter DC-DC Boost.

1. INTRODUCTION
A. Overview
Power quality plays an important role in present day. The voltage sag and reactive power compensation produced by the non linear loads have become major problems in many countries. As WINDPOWER penetration has increased, the power quality from wind generation has been paid much attention. One of the serious issues for the operation of wind turbine systems is Low-Voltage Ride-Through (LVRT) capability, through which the wind turbines are expected to comply with the requirements of grid codes. With this, wind turbine systems are expected to stay connected to the grid during grid faults with consideration of the voltage drop level and voltage-time profile. As an example, the Spanish grid code for an LVRT requirement.

In addition, the amount of the reactive current required to support the grid during the voltage sag and restoration periods. One concern of wind turbine operation in the steady state is the output power fluctuation. The fluctuation may incur an imbalance between the supply and demand of power. The grid frequency may deviate from its rated value. Hence, it is essential to mitigate the output power fluctuation of the wind turbine systems.

B. Objective
To Simulate Analysis and Control of Reactive power with STATCOM model and line model with voltage sag in controlled PMSG system. The improvement of power quality is done by using MATLAB and Implement it using PIC16F844A.

C. Statcom Model
The STATCOM is a shunt connected reactive – power compensation device that is capable of generating and absorbing reactive power and in which the output can be varied to control the specific...
parameters of an electric power system. It is in general a solid state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy storage device at its input terminals. A STATCOM can improve power system performance in such areas such as:

- The dynamic voltage control in transmission and distribution.
- The power-oscillation damping in power transmission system.
- The transient stability.
- The voltage flicker control.
- The control of not only reactive power but also active power in the connected line requiring a dc source.

D. PIC Microcontroller

The advantages of the PIC microcontroller “PIC 16F844A” is that the instruction set of this controller are fewer than the usual microcontroller. Unlike Conventional processors, which are generally complex, instruction set computer (CISC) type, PIC microcontroller is a RISC processor. The advantages of RISC processor against CISC processor are: RISC instructions are simpler and consequently operate faster. A RISC processor takes a single cycle for each instruction, while CISC processor requires multiple clocks per instruction (typically, at least three cycles of throughput execution time for the simplest instruction and 12 to 24 clock cycles for more complex instruction), which makes decoding a tough task. The control unit in a CISC is always implemented by a microcode, which is much slower than the hardware implemented in RISC.

E. Direct driven PMSG wind turbine system

Several techniques are used to convert the wind energy. The most popular and largely used is based on the Induction Generator (IG) system is relatively simple and don’t scope with relatively new grid codes. However Doubly Fed Induction Generator (DFIG) is more complicated and offer the ESS added to wind generation systems, not only more advantages for the exchange of the active and reactive power smoothing the grid and the fulfillment of the grid codes, (FRT) can be achieved effectively. However, the cost of the ESS is too high to solve this problem of 6 MW. They are more efficient when compared to other commercially available devices increases the cost of the whole system. With conventional machines and simpler because of exciter is [19] to apply a braking chopper (BC). However, it is impossible to improve the output power quality of the wind turbine systems since the BC just dissipates the power and cannot return it to the grid. Another method using a hybrid system of the ESS and the BC has been presented, where the ESS consists of electric double-layer capacitors (EDLC) and the BC are connected to the dc-link side of the back-to-back converters in a permanent magnet synchronous generator (PMSG) wind turbine system. This scheme cannot only offer ride-through capability but also suppress the output power fluctuation of

2. SYSTEM CONFIGURATION

The configuration of a direct-driven PMSG wind turbine system. The energy storage system (ESS) consists of an EDLC [1] and a bidirectional dc-dc converter, which is connected at the dc-link of the back-to-back converters. ABC is connected in parallel with the dc-link. The BC will be activated to dissipate the excessive power beyond the capacity of the ESS in cases of deep voltage sags or high wind speed variations. In normal conditions, the LSC controls the dc-link voltage of the back-to-back converters, and the ESS is able to smoothen the power ripples. In grid fault conditions, on the other hand, the LSC functions as a STATCOM, and the ESS controls the dc-link voltage.

A. PMSG Wind Turbine Systems Using STATCOM Model

This chapter deals with the operation principle of Advanced Fault Ride-Through Technique for PMSG Wind Turbine Systems Using Line-Side Converter as STATCOM [19] is proposed for a hybrid control scheme for energy storage systems (ESS) and braking choppers for fault ride-through capability and a suppression of the output power fluctuation is proposed for permanent-magnet synchronous generator (PMSG) wind turbine systems. During grid faults, the dc-link voltage is controlled by the ESS instead of the line-side converter (LSC), whereas the LSC is exploited as a STATCOM to inject reactive current into the grid for assisting in the grid voltage recovery.
the wind turbine systems with relatively low cost. In this method, the ESS is used to control the power which is absorbed from the system or released to the grid for both normal and fault conditions. Meanwhile, the line-side converter (LSC) is used to control the dc-link voltage under both normal conditions and grid sags. However, with deep unbalanced voltage sags, excessively high grid current references, which depend on the grid voltages, are required to control the dc-link voltage.

Hence, the amount of the reactive power provided to the grid by the LSC does not satisfy the grid code requirements due to a limited current capability of the LSC. Another control scheme for LVRT compliance of the wind power systems in grid voltage disturbances was presented in which the dc-link voltage was controlled by the generator-side converter (GSC), and the power mismatched between the turbine and grid sides are stored in the system inertia by increasing the generator speed. However, the amount of energy stored in the turbine inertia is not so large, particularly when the generator operates near the rated speed before grid sag.

Thus, the additional device such as a BC or an ESS is required to absorb the surplus power. In this project, an FRT technique of the PMSG wind turbine system is proposed during the grid fault. By switching the control mode, the ESS is operated to control the dc-link voltage of the back-to-back converters during the grid voltage sag. Meanwhile, the LSC is utilized to supply the reactive current to the grid for satisfying the reactive current requirements of the grid code. By this, the grid voltage can be recovered rapidly without an external STATCOM after fault clearance. Also, the generator active power can be absorbed fully by the ESS and the BC during the voltage sags.

In addition, the output power fluctuation of wind turbine systems operating in steady state is smoothened by the ESS. With this control scheme, the system can still operate well even though the grid voltage is fully interrupted. The validity of the proposed control algorithm is verified by simulation and experimental results.

2. CONTROL OF BACK-TO-BACK CONVERTERS

A. Control of LSC

The LSC controls the dc-link voltage, $V_{dc}$, to be constant under normal conditions. Cascaded control structure with an inner current control loop and the outer dc-link voltage control loop is applied. During grid voltage sags, however, the dc-link voltage is controlled by the ESS.
A maximum power point tracking (MPPT) control method is applied in normal conditions. However, the MPPT control is suspended during grid voltage sags, and the speed reference of the turbine system is set higher than that in the case of pre-sag. The speed reference is renewed by multiplying the previous value at the last sampling period by a k factor, in which the factor k depends on the response of the system (the system inertia constant, \( H(s) \)) and the sampling period of the speed controller (Ts–speed). The new generator speed reference \( \omega_{\text{new}} \) can be expressed as

\[
\omega_{\text{new}} = k \cdot \omega_{\text{init}} \quad \text{if} \quad k \leq 0.85 \quad \text{and} \quad k \leq 0.5 \quad \text{or} \quad k \leq 0.5 \quad \text{and} \quad k \leq 0.85
\]

Then, an increase of the generator speed is expressed as

\[
\Delta \omega(\% ) = \Delta T / T \cdot 100
\]

From (2.6) and (2.8), the factor k is calculated as

\[
k = \sqrt{\omega_{\text{new}} / \omega_{\text{init}}} \quad \text{and} \quad k \leq 1
\]

From (9), the k is obtained as 1.0005 from the parameters of \( \Delta T = 0.5 \) s, Ts–speed = 2 ms, and \( H = 4 \) s.

**Figure 5 Control block diagram of the PMSG.**

By increasing the generator speed, the generator output power delivering to the grid is reduced due to the following reasons. First, the turbine output power is also reduced since the tip-speed ratio is not optimal. Next, some portion of the turbine power can be stored in the system inertia during the increase of the system speed.

**4. CONTROL OF ESS AND BC**

The ESS and the BC [1] are used to suppress the generator output power fluctuation in normal conditions by absorbing or releasing the pulsed power component from or to the grid, in which the power command, \( P_{\text{ESS}} \), is obtained through a high-pass filter to the generator power. The ESS power is
regulated by an outer PI regulator, whereas the EDLC current is controlled by an inner PI regulator.

**A. DC-Link Voltage Control**

During grid sags, the dc-link voltage of the back-to-back converters is controlled by the ESS instead of the LSC. Hence, an outer PI voltage controller is employed, which produces a current reference for an inner current controller. It shows the overview control block diagram of the ESS and the BC in both normal and grid sag conditions. Neglecting the power losses of the converters and considering the active power negligible flowing into the grid, the dynamic equation of the inductance voltage is expressed as

\[ V_{\text{dc}} = L_f \frac{dI_f}{dt} \]

Where \( L_f \) is the boost inductance, and \( \omega_0 \) is the angular frequency.

From (15), in order to keep the dc-link voltage constant, the ESS and the BC should be able to absorb the generator power. From the control block diagram shown in Fig. 5, the output of the dc-link voltage controller, \( V_{\text{dc}} \), is given as

\[ V_{\text{dc}} = L_f \frac{dI_f}{dt} \]

Where \( L_f \) and \( K_2 \) are PI controller gains of the dc-link voltage control. In Fig. 5.8, \( I_{\text{ESS}} \_\text{max} \) represents the maximum current of the ESS. To reduce the total system cost, the rating of the ESS is chosen as 30% of the full power rating of the system.

By expanding a Taylor series of the dc-link voltage at operating point \( V_{\text{dc}0} \), the following can be obtained:

\[ V_{\text{dc}} = V_{\text{dc}0} + 2 V_{\text{dc}0} (V_{\text{dc}} - V_{\text{dc}0}) \]

From (5.10) – (5.13), the dc-link voltage equation can be rewritten in the “s” domain as

\[ \text{CV}_{\text{dc}} s V_{\text{dc}} = V_{\text{ESS}} s \frac{K_2}{(s + \omega_0)^2 + 2 \omega_0 \omega_2 + \omega_2^2} \]

The transfer function of the voltage controller is derived as

\[ V_{\text{dc}}(s) / V_{\text{dc}}(s) = V_{\text{ESS}} s \frac{K_2}{(s + \omega_0)^2 + 2 \omega_0 \omega_2 + \omega_2^2} \]

Where \( \zeta \) is the damping ratio and \( \omega_0 \) is the natural frequency.

**A. EDLC Current Control**

To establish the current control law for the dc/dc converter, a voltage across the inductance, \( V_{\text{dc}} \), is investigated. The dynamic equation of the inductance voltage is expressed as

\[ V_{\text{dc}} = L_f \frac{dI_f}{dt} = D_{\text{ESS}} V_{\text{dc}} - V_{\text{ESS}} \]

Where \( L_f \) is the boost inductance, and \( D_{\text{ESS}} \) is the duty cycle. As shown in Fig. 6 the output of the current controller, \( V \), is given as

\[ V_{\text{dc}} = K_{\text{PC}} (\Gamma_{\text{ESS}} - I_{\text{ESS}}) + K_1 / s (\Gamma_{\text{ESS}} - I_{\text{ESS}}) \]

(17)

Where \( K_p \) and \( K_1 \) care PI controller gains of the current control. In this project, the PI controller gains are chosen as

\[ D_{\text{ESS}} = V_{\text{ESS}} + V_{\text{dc}} \frac{1}{s (\Gamma_{\text{ESS}} - I_{\text{ESS}})} \]

Then, the gating signals for switches \( S_1 \) and \( S_2 \) are generated by comparing the duty cycle with the carrier wave of 2 kHz.

**B. BC Control**

During the grid disturbance, the ESS may not absorb the full generator power, and then the BC will be activated to dissipate the rest of power. The BC as

\[ P_{\text{BC}} = P_{\text{gen}} - P_{\text{ESS}} \]

The BC is controlled by the switch \( S_3 \) shown in Fig. 6. The duty ratio \( D_{\text{SS}} \) for the switch depends on \( P_{\text{BC}} \), which is expressed as

\[ D_{\text{SS}} = R_{\text{bc}} / V_{\text{dc}} \]

Where \( R_{\text{bc}} \) is the braking resistance.

**5. INTERLEAVED DC-DC BOOST CONVERTER**

The schematic of the dual interleaved boost dc-dc converter is shown in Fig. 7. The interleaved boost dc-dc converter consists of two parallel connected boost converter units, which are controlled by a phase-shifted switching function (interleaved operation). To illustrate interleaving operation, Fig. 7 shows the timing diagram of control signals to the switches. Since this converter has two parallel units, the duty cycle for each unit is equal to \( (V_{\text{out}} - V_{\text{Vin}}) / V_{\text{out}} \), and it is same for each unit due to parallel configuration. A phase shift should be implemented between the timing signals of the first and the second switch.

**Figure 6 Control block diagram of the ESS and BC**

Since there are two units parallel in this converter, the phase shift value is 180 degree. It is used to improve the voltage quality.

**Figure 7 Interleaved Boost DC –DC Converter Timing Diagram of control signals**
6. HARDWARE AND SOFTWARE
A. HARDWARE
- Wind pitch
- PMSG
- Power converters
- Interleaved Boost converters
- Pulse amplifier

B. SOFTWARE
- Operating System: Windows 7
- Tools: MATLAB 7
- Language: C++

7. SIMULATION CIRCUIT AND RESULTS
The simulation circuit of conventional method and proposed system and the waveforms are given below as:

Figure 8: Simulation block diagram of STATCOM Model

Figure 9: Simulation circuit without STATCOM Model & Line model with load voltage

Figure 10: Real power & Reactive power

Figure 11: Simulation circuit with STATCOM model

Figure 12: RMS Voltage & Real power

Figure 13: Reactive power & Grid output voltage with STATCOM Model

Figure 14: Interleaved boost converter with STATCOM Model & Grid output voltage

8. HARDWARE IMPLEMENTATION DIAGRAM

This project has presented a hardware prototype Advanced Fault Ride-Through Technique for PMSG Wind Turbine Systems Using Line-Side Converter as STATCOM. These are verified with the experimental results.

9. CONCLUSION
This work has presented the procedures for the design and implementation for PMSG Wind Turbine Systems Using Line-Side Converter as STATCOM model. This project has proposed a cost-effective solution which combines the ESS and the BC for the LVRT in PMSG wind turbine systems. Controlling the dc-link voltage by the ESS, the LSC is
able to comply with the reactive current requirements of the grid code. By this, the grid voltage can be recovered rapidly without an external STATCOM after fault clearance. Also, the output power fluctuation of the wind turbine system operating in steady state is smoothened by the ESS. This control scheme offers an FRT capability for the wind turbines even though the grid voltage is fully interrupted. The voltage quality is improved. The validity of the proposed control algorithm is verified by simulation and experimental results. The Simulation results coincide with the theoretical results.

REFERENCES