Application of SMES to Enhance the Dynamic Performance of DFIG during Voltage Sag and Swell

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Abstract- The integration of wind turbines into modern power grids has significantly increased during the last decade. Wind turbines equipped with doubly fed induction generators (DFIGs) have been dominating wind power installation worldwide since 2002.

In this paper, superconducting magnetic energy storage (SMES) unit is proposed to improve the dynamic performance of a wind energy conversion system equipped with DFIG during voltage sag and voltage swell events. The converter and the chopper of the SMES unit are controlled using a hysteresis current controller and artificial neural network based controller respectively. Detailed simulation is carried out using MATLAB/SIMULINK software to highlight the impact of the SMES unit in improving the overall system performance under voltage sag and voltage swell conditions.

Index Terms- Doubly fed induction generator (DFIG), ANN (Artificial neural network controller), hysteresis current controller (HCC), superconducting magnetic energy storage (SMES), voltage sag, voltage swell and wind energy conversion system (WECS).

I. INTRODUCTION

Utilization of renewable energy sources is becoming more attractive due to the detrimental impact of conventional energy resources on the environment. Implementation of carbon tax in some countries has also been considered as a trigger to accelerate the utilization of renewable energy sources. The future prospects of the global wind industry are very encouraging, and it is estimated to grow by more than 70% to reach 160 GW by the year 2012. It is estimated that, by the year 2020, wind power will supply at least 10% of global electricity demands. Owing to the rapid development of power electronics technology, the number of wind turbines equipped with converter stations has increased. The doubly fed induction generator (DFIG) is one of the most popular variable speed wind turbine generators (WTGs). In this technology, the rotor winding is connected to a coupling transformer through a back-to-back partial-scale voltage source converter (VSC), whereas the stator winding is directly connected to the grid at a point of common coupling (PCC) through the coupling transformer. The VSC decouples the mechanical and electrical frequencies and make variable-speed operation possible. Global trend shows that the market share of the installed wind energy conversion system (WECS) has been dominated by DFIG-based wind turbines since 2002 [4]. In the earlier stages of integrating WECSs into the electricity grids, WTGs were disconnected from the grid during faults at the grid side to avoid any possible damages to wind turbines. Recently, existing WTGs, however, will have to be designed/managed to comply with the recent requirements of new grid codes to assure the continuity of supplying power to the grid during transient and abnormal operating conditions. There are two strategies that can be applied to improve the performance or the fault ride through (FRT) capability of the DFIG.

This paper presents a new application of the SMES unit to improve the performance of a wind turbine equipped with DFIG during voltage sag and voltage swell at the grid side. A new control system for the SMES unit based on hysteresis current control in conjunction with artificial neural network Controller is proposed. The Simulink/Matlab software is used to simulate the wind turbine, the SMES unit, and the model under study. Results are analyzed to highlight the improved dynamic performance of WECSs in conjunction with the SMES unit.

II. SYSTEM UNDER STUDY

The system under study shown in Fig. 1(a) consists of six 1.5-MW DFIGs connected to the ac grid at the PCC.
The DFIG consists of an induction generator with stator winding connected directly to the grid through a Y/Δ step-up transformer, whereas the rotor winding is connected to a bidirectional back-to-back insulated gate bipolar transistor (IGBT) VSC, as shown in Fig. 1(b). The grid that is represented by an ideal three-phase voltage source of constant frequency is connected to the wind turbines via a 30-km transmission line and Δ/Y step-up transformer.

The reactive power produced by the wind turbines is regulated at zero MVAR under normal operating conditions. For an average wind speed of 15 m/s, which is used in this study, the turbine output power is 1.0 pu, and the generator speed is 1.2 pu. The SMES unit is connected to the 25-kV bus and is assumed to be fully charged at its maximum capacity of 1.0 MJ.

III. SMES CONTROL APPROACHES

Generally, there are two major configurations of SMES, i.e., current source converter (CSC) and VSC. Traditionally, CSC is connected through a 12-pulse converter configuration to eliminate the ac-side fifth and seventh harmonic currents and the dc side sixth harmonic voltage, thus resulting in significant savings in harmonic filters. However, because this configuration uses two 6-pulse CSCs that are connected in parallel, its cost is relatively high. The VSC, on the other hand, must be connected with a dc–dc chopper through a dc link, which facilitates energy exchange between the SMES coil and the ac grid. Reference estimates the total cost of the switching devices of the CSC to be 173% of the switching devices and power diodes required for equivalent capacity of the VSC and the chopper. Moreover, a VSC has a better self-commutating capability, and it injects lower harmonic currents into the ac grid than a comparable CSC. The use of IGBTs in this configuration is more beneficial than GTO since the switching frequency of an IGBT lies on the range of 2–20 kHz, whereas, in case of GTO, the switching frequency cannot exceed 1 kHz.

The proposed SMES configuration used in this paper consists of a VSC and dc–dc chopper, as shown in Fig. 2. The converter and the chopper are controlled using a hysteresis current controller (HCC) and a ANN controller, respectively. The stored energy in the SMES coil can be calculated as where $E$, $I_{SMES}$, and $L_{SMES}$ are the stored energy, current, and coil inductance of the SMES unit, respectively.

$$E = \frac{1}{2}I_{SMES}^2L_{SMES} \quad (1)$$

While the control system of the dc–dc chopper is presented, the control approach for the VSC as part of the SMES configuration is not presented. In contrast with, the dc–dc chopper control system is not presented. The configuration of SMES is new, but its application is limited for low WTG capacity, and since the SMES coil is proposed to be connected to the individual DFIG’s converters, this topology will be only appropriate for new
WECS installations. Application of the SMES system to micro grids is presented in, where the SMES is used to stabilize the entire micro grid system. The control scheme presented in this work is very complex because it is working for three different levels of controls; this will lead to high implementation and maintenance cost. Moreover, it requires a robust computational system. The proposed control algorithm in this paper is much simpler and closer to realistic applications, compared with the similar controller proposed in and. In the aforementioned papers, four proportional–integral (PI) controllers are proposed, which require more computational time to optimally tune its parameters to maintain overall system stability and to achieve satisfactory dynamic response during transient events.

Moreover, the control system for the dc–dc chopper in these studies considered only the DFIG-generated active power (PG) as a control parameter, but it ignored the energy capacity of the SMES unit. The control scheme in this paper comprises only two PI controllers and considers the SMES coil current to take the SMES stored energy capacity into account, along with the DFIG generated power as control parameters to determine the direction and level of power exchange between the SMES coil and the ac system. This control system is efficient, simple, and easy to implement, as will be elaborated here.

A. HCC

The HCC is widely used because of its simplicity, insensitivity to load parameter variations, fast dynamic response, and inherent maximum-current-limiting characteristic. The basic implementation of the HCC is based on deriving the switching signals from the comparison of the actual phase current with a fixed tolerance band around the reference current associated with that phase. However, this type of band control is not only depending on the corresponding phase voltage but is also affected by the voltage of the other two phases.

Fig. 3. (a) Class-D dc–dc chopper topology with an SMES coil.
(b) Operation range of the SMES coil.

The effect of interference between phases (referred to as interphase dependence) can lead to high switching frequencies.

To maintain the advantages of the hysteresis methods, this phase dependence can be minimized by using the phase-locked loop (PLL) technique to maintain the converter switching at a fixed predetermined frequency level. The proposed SMES with an auxiliary PLL controller is shown in Fig. 2. The HCC is comparing the three-phase line currents (Iabc) with the reference currents (Iabc), which is dictated by the Id and Iq references. The values of Id and Iq are generated through conventional PI controllers based on the error values of Vdc and Vs. The value of Id and Iq is converted through Park transformation (dq0 – abc) to produce the reference current (Iabc).

B. ANN CONTROLLER

Neural networks are simply a class of mathematical algorithms, since network can be regarded as a graphic notation for a large class of algorithms. The ANN controllers designed in most of the work uses a complex network structure. The aim of this work is to design a simple ANN controller with possible, less number of neurons while improving the performance of the controller. In this work a two layer feed forward neural network is created with two neurons in the input layer and one neuron in the output layer. The activation functions used for the input neurons are pure linear and the tangent sigmoid activation function is used for output neuron.
A supervised back propagation neural network training algorithm is used with a fixed error goal. The ANN is trained with the error goal of 0.001 in 100 epochs, and the training stopped when target error was reached. The error (e) and change in error (ce) are the inputs to the controller. The output corresponds to the change in the duty cycle which is given to the comparator unit.

IV. SIMULATION RESULTS AND DISCUSSION

A. Voltage Sag Event

A voltage sag depth of 0.5 pu lasting for 0.05 s is applied at \( t = 2 \) s at the grid side of the system under study. Without the SMES unit, the real power produced by the DFIG will drop to 0.6 pu, and it reaches a maximum overshooting of 40% during the clearance of the fault, as shown in Fig 5(a). As can be seen in Fig 5(a), with the SMES unit connected to the system, the DFIG output power will drop to only 0.875 pu. Fig 5(b) implies that, with the connection of the SMES unit and during the event of voltage sag, the reactive power support by the DFIG is reduced, and the steady-state condition is reached faster, compared to the system without SMES.

The fig.6.35 is the waveform of active power during voltage sag with SMES. Here the power drop is reduced up to 0.9pu.
B. Voltage Swell Event

Voltage swell can occur due to switching off a large load or switching on a large capacitor bank. In this simulation, a voltage swell is applied by increasing the voltage level at the grid side to 1.5 pu. The voltage swell is assumed to start at $t = 2$ s and lasts for 0.05 s. In this event, the DFIG-generated power will increase upon the swell occurrence and will be reduced when it is cleared, as shown in Fig. 6(a).

The maximum power overshoot is slightly reduced with the SMES unit connected to the system. To compensate for the voltage rise, DFIG will absorb the surplus reactive power, as shown in Fig. 6(b). The amount of reactive power absorbed by the DFIG is lesser with SMES connected to the PCC since the voltage profile at the PCC is rectified to a level below 1.3 pu with the connection of the SMES unit.

CONCLUSION

A new control algorithm along with a new application of the SMES unit to improve the transient response of WTGs equipped with DFIG during voltage sag and voltage swell events has been proposed. Simulation results have shown that the SMES unit is very effective in improving the dynamic performance of a power system with wind turbine equipped with DFIG during voltage sag and voltage swell at the grid side. The proposed control algorithm of
the SMES unit is simple and easy to implement and is able to improve the FRT of the DFIG. The SMES unit, on the other hand is still a costly piece of equipment; however, due to the development of high temperature superconducting materials, its application in power systems is expected to become viable in the near future.

REFERENCES


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