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Fuzzy and Hysteresis Current Control Based SMES to Improve the Performance of DFIG for Wind Energy Systems

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ABSTRACT:

Owing to the rapid development of power electronics technology, the number of wind turbines equipped with converter stations has increased. Wind turbines equipped with doubly fed induction generators (DFIGs) have been dominating wind power installation. An SMES device is a dc current device that stores energy in the magnetic field. The dc current flowing through a superconducting wire in a large magnet creates the magnetic field. In this project, wind energy system with DFIG is used to improve the voltage sag and swell with the use of SMES having hysteresis current control (HCC) and fuzzy logic control (FLC).

The basic implementation of the HCC is based on deriving switching signals from the comparison of the actual phase current with a fixed tolerance band around the reference current associated with that phase. To control power transfer between the SMES coil and the ac system, a dc–dc chopper is used, and fuzzy logic is selected to control its duty cycle (D) with input variables real power generated by the DFIG and the SMES coil current. The project is simulated under the MATLAB/SIMULINK environment which shows the improved performance of the system when the wind energy system is in conjunction with the SMES with hysteresis current and fuzzy logic controller.

I. INTRODUCTION:

Wind power has been used as long as humans have put sails into the wind. For more than two millennia wind-powered machines have ground grain and pumped water. Wind power was widely available and not confined to the banks of fast-flowing streams, or later, requiring sources of fuel.

DFIG for Double Fed Induction Generator, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip ring assembly, but there are problems with efficiency, cost and size. A better alternative is a brushless wound-rotor doubly fed electric machine. The principle of the DFIG is that rotor windings are connected to the grid via slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents. Thus rotor frequency can freely differ from the grid frequency.

The doubly fed generator rotors are typically wound with 2 to 3 times the number of turns of the stator. This means that the rotor voltages will be higher and currents respectively lower. Thus in the typical ± 30% operational speed range around the synchronous speed, the rated current of the converter is accordingly lower which leads to a lower cost of the converter.

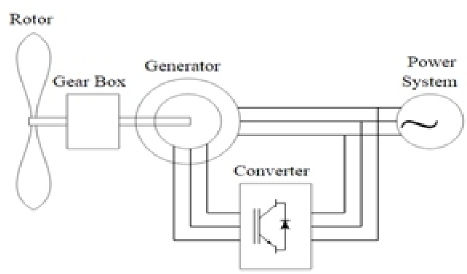

Fig1.1: Principle of a DFIG connected to wind turbine

The drawback is that controlled operation outside the operational speed range is impossible because of the higher than rated rotor voltage. Further, the voltage transients due to the grid disturbances (three- and two-phase voltage dips, especially) will also be magnified.

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In order to prevent high rotor voltages - and high currents resulting from these voltages - from destroying the IGBTs and diodes of the converter, a protection circuit called crowbar is used. Fig1.1shows the Principle of a DFIG connected to wind turbineAs a summary, a doubly fed induction machine is a wound-rotor doubly fed electric machine and has several advantages over a conventional induction machine in wind power applications. First, as the rotor circuit is controlled by a power electronics converter, the induction generator is able to both import and export reactive power. This has important consequences for power system stability and allows the machine to support the grid during severe voltage disturbances. Second,

The control of the rotor voltages and currents enables the induction machine to remain synchronized with the grid while the wind turbine speed varies. A variable speed wind turbine utilizes the available wind resource more efficiently than a fixed speed wind turbine, especially during light wind conditions. Third, the cost of the converter is low when compared with other variable speed solutions because only a fraction of the mechanical power, typically 25-30%, is fed to the grid through the converter, the rest being fed to grid directly from the stator. The efficiency of the DFIG is very good for the same reason.

II. SMES:

Superconducting Magnetic Energy Storage (SMES) SYSTEMS store energy in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature.

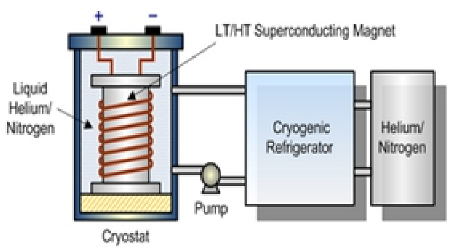

Fig 2.1 Basic diagram of SMES

A typical SMES system includes superconducting coil, power conditioning system and cryogenically cooled refrigerator. Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely. The Basic diagram of SMES is as shown in the figure 2.1.

The stored energy can be released back to the network by discharging the coil. The power conditioning system uses an inverter/rectifier to transform alternating current (AC) power to direct current or convert DC back to AC power. The inverter/rectifier accounts for about 2–3% energy loss in each direction. SMES loses the least amount of electricity in the energy storage process compared to other methods of storing energy. SMES systems are highly efficient; the round-trip efficiency is greater than 95%.Due to the energy requirements of refrigeration and the high cost of superconducting wire, SMES is currently used for short duration energy storage. Therefore, SMES is most commonly devoted to improving power quality.

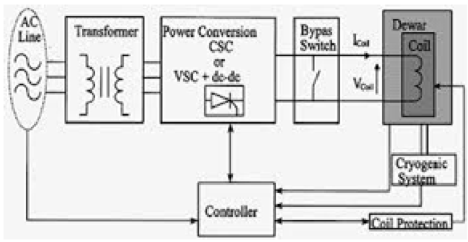

Fig2.2 Schematic diagram of SMES Connected to grid

The magnetic energy stored by a coil carrying a current is given by one half of the inductance of the coil times the square of the current. $E = \frac{1}{2}LI^2$

Where

E = energy measured in joules

L = inductance measured in henries

I = current measured in amperes

Schematic diagram of SMES Connected to grid is as shown in figure 2.2. In SMES systems; it is the power conditioning system (PCS) that handles the power transfer between the superconducting coil and the ac system. According to topology configuration, there are three kinds of PCSs for SMES, namely, the thyristor- based PCS, voltage source converter (VSC)-based PCS, and current source converter (CSC)-based PCS. The thyristor-based SMES can control only mainly the reactive power, and has a little ability to control the reactive power; also the controls of active and reactive powers are not independent. On the other hand, both the VSC- and CSC-based SMES can control both active and reactive powers independently and simultaneously. Therefore, the applications in which mainly active power control is required, the thyristor-based SMES is used, while the applications in which reactive power or both active end reactive power controls are required, the VSC- or CSC-based SMES is used.

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III. CONTROL TECHNIQUE:

A. Hysteresis control method:

The current control methods play an important role in power electronic circuits, particularly in current regulatede PWM inverters which are widely applied in ac motor drives and continuous ac supplies where the objective is to produce sinusoidal ac output.

Nevertheless, due to lack of coordination among individual HCC's of three phases, high switching frequency may happen, and the current error is not strictly limited the actual current waveform is not only determined by the hysteresis control depending on operating conditions, the current slope may vary widely and the current peaks may appreciably exceed the limits of the hysteresis band.

The converter i.e. VSC can be controlled using HCC. This control is widely used because of its simplicity, insensitive to load parameter variations, fast dynamic response, and inherent maximum-current-limiting characteristics.

The basic implementation of the HCC is based on deriving 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 dependent not only on the corresponding phase voltage but also affects the voltage of other two phases referred to as "interphase dependence".

Inter-phase dependence may lead to high switching frequencies. Depending on load conditions switching frequency may vary during the fundamental period, resulting in irregular inverter operation. To maintain the advantages of the hysteresis methods, this phase dependence should be minimized. This can be done by using phase-locled loop (PLL) technique to maintain the converter switching at a fixed predetermined level.

PLL generates an output signal whose phase is related to the phase of an input signal. Keeping the input and output signal in lock step implies keeping input and output frequencies the same. PLL is also used to synchronise DFIG and the grid by injecting some phase angle and frequency.

B. Fuzzy logic control:

To control power transfer between the SMES coil and the ac system, a dc-dc chopper is used, and fuzzy logic is selected to control the duty cycle (D). The superconducting coil is charged or discharged by a two-quadrant dc-dc chopper. The dc-dc chopper is controlled to supply positive (IGBT is turned on) or negative (IGBT is turned off) voltage to SMES coil and then the stored energy can be charged or discharged. Therefore, the superconducting coil is charged or discharged by adjusting the average voltage across the coil which is determined by the duty cycle of the two-quadrant dc-dc chopper. When the duty cycle is larger than 0.5 or less than 0.5, the stored energy of the coil is either charging or discharging.

Fuzzification is the representation of systems made through fuzzy IF-THEN rules. In many situations, for a system whose output is fuzzy, it is easier to take a crisp decision if the output is represented as a scalar quantity. This conversion of fuzzy set to single crisp value is called "defuzzification". The output of FLC is the duty cycle (D) for a class-D dc-dc chopper as shown in Figure 3.1. The duty cycle determines the direction and magnitude of the power exchange between the SMES coil and the ac system.

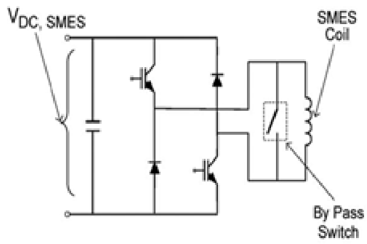

Fig3.1 Class-D dc-dc chopper using an SMES coil

If the duty cycle is equal to 0.5, no action will be taken by the coil, and the system is under normal operating conditions. Under this condition, a bypass switch that is installed across the SMES coil as shown in Fig 3.1 will be closed to avoid draining process of SMES energy during normal operating conditions. The bypass switch is controlled in such a way that it will be closed if D is equal to 0.5; otherwise, it will be opened. When the grid power is reduced, D also will reduce accordingly to be in the range of 0 - 0.5 and the stored energy in the SMES coil will be transferred to the ac system. The charging process of the SMES coil takes place when D is in the range of 0.5 - 1.

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Duty Cycle (D)	SMES Coil Action
D = 0.5	Standby condition
0 ≤ D <0.5	Discharging condition
0.5 < D ≤ 1	Charging condition

IV.SIMULATION RESULTS AND DISCUSSION:

A. Voltage Swell Event
:

Swell event at the grid side is rarely to occur. But if it occurs, it causes the voltage rise at the PCC that may violate grid code requirements. As swell refers to increase in voltage, this increase in voltage leads to increase in power. The voltage increase should be within the grid codes so that the wind turbine generators need not be disconnected from the grid. A voltage swell lasting for 0.05 secs is applied at t = 0.2 secs at the grid side. In this simulation, voltage swell is applied by switching on a large capacitive bank. The results thus obtained are shown in the next pages. Due to occurrence of voltage swell disturbance at the grid side, charging mode will take place. In this case, the value of D lies in the range of 0.5 – 1. When voltage swell occurs at t = 0.2 secs, the energy is transferred from the AC system into the SMES coil as designated by fuzzy set of rules. After the fault is cleared at t = 0.25 secs, normal operation is restored.

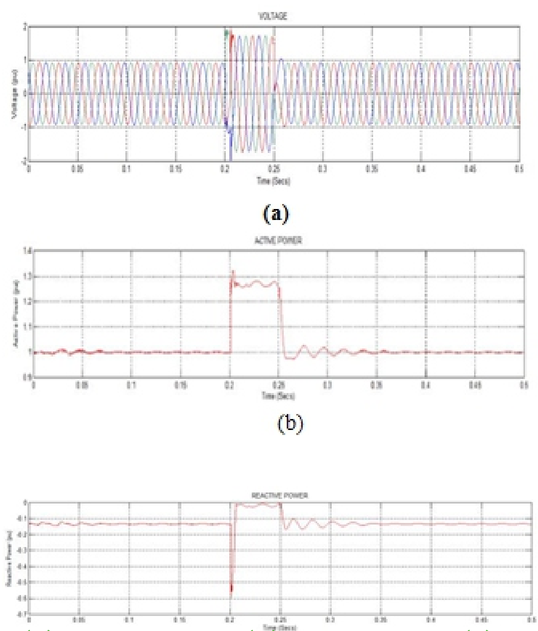

Fig.4.1 (a) Voltage swell. (b) Active power (c) Reactive power.

B. Voltage Sag Event:

The simulation model consists of six 1.5 MW DFIGs connected to ac grid at the PCC. The DFIG consists of an induction generator with stator winding connected directly to the grid through a Wye-Delta step-up transformer whereas the rotor winding is connected to bidirectional back-to-back insulated gate bipolar transistor VSC. The grid is represented by an ideal three-phase voltage source of constant frequency, which is connected to wind turbine via a 30-km transmission line and Delta-Wye step-up transformer. A fault is created in the above mentioned system and the performance of the system is analyzed.A voltage sag lasting for 0.05 secs is applied at t = 0.2 secs at the grid side. In this simulation, voltage sag is created by switching off large inductive load(2). The results thus obtained are shown in the next pages. Because of voltage sag, the normal operation is affected only during the interval of fault. Once the fault is cleared, normal operation is restored. Due to voltage sag disturbance at the grid side, discharging mode will take place. In this case, the value of D lies in the range of 0-0.5. When voltage sag occurs, the energy stored in the coil is being delivered to AC system during this mode. The coil will be recharged at t = 0.25 secs exactly at the time when fault is cleared according to the rules of designated fuzzy logic controller for real power generated by DFIG and the SMES coil current.

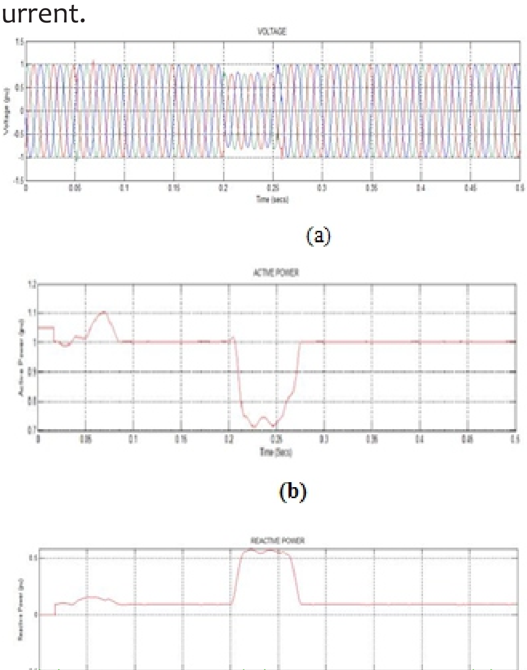

Fig.4.2 (a) voltage sag (b) Active power (c) reactive power

V. CONCLUSION:

The dissertation introduces an original philosophy for integrating wind turbines into modern power grids, which ensures continuous and reliable supply to loads. Normally wind turbine generators are sensitive to grid faults and hence continuous power cannot be supplied to the grid. To overcome this problem, application of an SMES unit is proposed to improve the dynamic performance of DFIG so as to supply continuous power to the grid during transient and abnormal operating conditions. the hysteresis and fuzzy logic control technique for SMES unit is simple and easy to implement and is effective in improving performance with wind turbine equipped with DFIG during voltage sag and voltage swell at the grid side.

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