VOLTAGE RECOVERY OF INDUCTION GENERATOR USING INDIRECT TORQUE CONTROL METHOD

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ABSTRACT

This paper proposes a voltage recovery method for a disturbance caused due to grid fault on Induction Generator (I.G.) using static synchronous compensator (STATCOM). Voltage source SVC such as STATCOM can be used to improve the voltage of induction generator by indirectly controlling its torque. By controlling terminal voltage with the STATCOM, the electromagnetic torque of the generator is indirectly smoothed. This control concept has analysed the extent to which the transient stability margin can be increased by the use of STATCOM. Since the torque of Induction Generator is controlled by considering intervening voltage of STATCOM, the method suggested in this paper is called as indirect torque control (ITC) method. A system model build in PSCAD can be used to show the simulation of this control concept.

Keywords - STATCOM (Static Synchronous Compensator), Transient Stability Margin, Low Voltage Right through (LVRT), Indirect Torque Control (ITC)

I. INTRODUCTION

Wind turbines making use of Induction Generator are being introduced into the power systems which are likely to be subjected to various disturbances when connected to the grid. These induction generators directly connected to the grid have no direct electrical control of torque or speed, and would usually disconnect from the power system when the voltage drops more than 10-20% below rated value [1]. Dynamic and transient stability limit of induction generators can be investigated with the help of Low voltage right through (LVRT) capability of wind turbines [2-3].

For improvement of LVRT capability, reactive power compensation of induction generator subjected to grid fault is the matter of concern. In order to increase LVRT capability by reactive power compensation it is necessary to increase the torque capability of induction generator at a speed other than normal operating range [4]. The basic approach is to use a standard STATCOM control for improving LVRT capability. In addition to this type of control, in direct torque control (ITC) method is also implemented, as the torque of induction
generator can be indirectly influenced by use of STATCOM to modulate the terminal voltage and also the flow of reactive current in the induction generation. As any transient condition cause drop in voltage level, by use of direct torque control (ITC), we can increase the maximum torque during the voltage recovery process [5].

For the purpose of limiting the maximum torque of induction generator during recovery process after great fault, the method suggested in this paper is recovery of voltage by using STATCOM to increase the LVRT limit of grid connected induction generator. A model can be developed to simulate with the help of PSCAD/ MATLAB software in order to illustrate the functionality of the suggested ITC method [4].

![Figure 1: Schematic Arrangement of Induction Generator Connected to Grid for Recovery of Voltage Against L-L-L Fault](image)

From figure 1, it can be assumed that when the grid is subjected to three phase fault, the grid connected induction generator is driven by a wind turbine through a gear box to convert the low speed of the turbine shaft into a high speed up to the level of the rated speed, the terminal voltage of the induction generator will be influenced thus indirectly decreasing the torque of induction generator.

The proposed method shown in the figure 1 will be active only during the recovery process after a grid fault, thus not influencing the normal operation of the STATCOM and induction generator [4].

The implementation of STATCOM can also be done to improve the transient stability and critical clearing time of the induction generator [5].

II. EVALUATION OF LVRT IN WIND ENERGY

The low voltage right through (LVRT) was first introduced by E-ON Netz, the major German transmission operator [6]. A LVRT grid code developed by E-ON Netz has been accepted worldwide in most of the countries supplied by wind power generation. The enhancement of LVRT capability is one of the most demanding requirements which have been included in the above grid codes. To evaluate induction generator stability limit subjected to the grid fault, a new analytical approach makes use of speed-torque curves when having shunt reactive compensation such as STATCOM or SVC or the LVRT solution for the wind generation [6]. The use of STATCOM to increase the transient stability margin gives rise to the most demanding requirement that the system operator grid code will impose to wind turbines and wind forms is the low voltage right through (LVRT) capability. This requirement can be fulfilled by considering an example of LVRT suggested by E-ON Netz, which is illustrated in figure 2. The LVRT requirement shown in the figure 2 depicts that the
wind turbine coupled induction generator remains connected to the grid despite of any voltage dips as low as 5% of nominal voltage [3].

Figure 2: LVRT Profile of Wind Generation as Suggested by E-ON Netz

III. IMPLEMENTATION OF STATCOM

STATCOM gives larger contribution to the transient stability margin and thus enhanced LVRT capability because of the fast responding speed [7]. This margin is the length of the fault that the wind generation is capable of riding without losing its stable operating condition. Regarding the LVRT, the most relevant features of STATCOM is to inject controllable reactive current independently of the grid voltage [3]. There are several techniques to control the operation of STATCOM but this paper suggests the vector current control technique due to its past dynamic and developed control ability. This technique is used to control the DC link voltage and reactive current which is decoupled like in the control of torque and flux in the field oriented control of motor drives [8].

Figure 3: Line Diagram of Grid Connected Induction Generator Using STATCOM
a) Voltage Phasor Diagram under Normal Condition

For Cos $\phi = 90^\circ$

$$V_t = \sqrt{V_g^2 + V_L^2}$$

Where,

$V_t =$ Terminal voltage in volts.

$V_g =$ Ground voltage in volts.

$V_L =$ Inductor voltage in volts.

b) Voltage Phasor Diagram during Grid Fault

$$V_t = \sqrt{V_{gf}^2 + V_L^2}$$

Where,

$V_t =$ Terminal voltage in volts.

$V_{gf} =$ Ground fault voltage in volts.

$V_L =$ Inductor voltage in volts.

Figure 4: Phasor Diagram of Schematic Arrangement Shown in figure 3

Figure 3 shows the schematic configuration of the system under consideration for the compensation with a STATCOM. The figure 4 shows the Phasor diagrams of the systems (a) and (b) in normal condition. It is shown that STATCOM compensates the reactive current
drawn by the generator, which reduces the voltage drop on transmission line and therefore increases the terminal voltage. STATCOM increases the terminal voltage of the generator in a similar way during the grid fault, as shown in the figure 4 b). Comparing figures 4 (a) and (b), we prove that the STATCOM needs to supply huge amount of reactive current to increase the voltage during grid fault, which requires high rating and thus high cost.

IV. CONCEPT OF INDIRECT TORQUE CONTROL (ITC) USING STATCOM

During the recovery process of a grid fault, the same approach used with the help of LVRT can be implemented indirectly controlling the torque of induction generator by controlling the terminal voltage of STATCOM.

Figure 5 shows the control system of STATCOM including the indirect torque control in addition to the STATCOM control for the torque transient alleviation during the recovery process after a grid fault. The indirect torque control can be implemented by reducing the voltage reference of the STATCOM control system after reclosing and by that the reactive compensation when stability is ensured but before the grid voltage and the speed of the generator has returned to the pre-fault values [5]. Thus the

**Figure 5:** Block Diagram of Control System for a STATCOM with Indirect Torque Control

STATCOM can improve the system stability by enhancing the torque capability of the induction generator. We are concerned about the recovery process after breaker reclosing operation for being one of the cases that represent high transient torques for induction generator. An example of 3-phase grid failure can be used in order to use the proof that the torque transients appear after the reclosing. The system control strategy is shown in figure 5 which indicates how the indirect torque control functionality is used to define a temporary speed dependent value of grid voltage reference. The rest of the control structure will be used to work under normal STATCOM operation [4-5]. As the voltage reference value 1.0 p.u. has considered under normal STATCOM operation will limit the voltage, whereas the indirect torque control concept will override this reference value during the recovery process after a grid fault.
V. VERIFICATION OF INDIRECT TORQUE CONTROL CONCEPT BY USING TIME DOMAIN SIMULATION

For verification and to illustrate the functionality of the suggested indirect torque control concept a system with an induction generator directly connected to the grid and a similar connected at the generator terminals is simulated with the PSCAD/EMTD software. The system shown in figure 1 consists of an induction generator with rating of 2 MW and the main parameter of the other equipments connected is shown in the table 1.

Table 1: Main Parameters of Simulation Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base value of apparent power</td>
<td>$S_b = 2.2$ MVA</td>
</tr>
<tr>
<td>Rated power of SGIG</td>
<td>$P_n = 2$ MW</td>
</tr>
<tr>
<td>Stator resistance $r_1$</td>
<td>0.010 pu</td>
</tr>
<tr>
<td>Stator leakage inductance $x_1$</td>
<td>0.179 pu</td>
</tr>
<tr>
<td>Rotor resistance $r_2$</td>
<td>0.008 pu</td>
</tr>
<tr>
<td>Rotor leakage inductance $x_2$</td>
<td>0.074 pu</td>
</tr>
<tr>
<td>Magnetising reactance $x_m$</td>
<td>4.376 pu</td>
</tr>
<tr>
<td>Rated generator voltage $V_{n,LL}$</td>
<td>690 V rms</td>
</tr>
<tr>
<td>Total Grid reactance $x_g$</td>
<td>0.08 pu</td>
</tr>
<tr>
<td>Total Grid resistance $r_g$</td>
<td>0.03636 pu</td>
</tr>
<tr>
<td>Self damping $D$</td>
<td>0.008 pu</td>
</tr>
<tr>
<td>STATCOM current limit $i_{STATCOM_{max}}$</td>
<td>1.5 pu</td>
</tr>
</tbody>
</table>

The PSCAD/EMTD model comprises of a full fifth order dynamics model of induction generator the simple grid equipment and a STATCOM with a control system based on voltage oriented vector current control[3]. Three situations for the simulation are considered; first situations includes use of constant capacitor compensation to keep nominal voltage under normal operating conditions, second situation makes use of STATCOM for voltage control and increasing low voltage right through capability and last situation is how can achieve indirect torque control using STATCOM as an additional functionality while carrying out those simulation the mechanical input torque is considered to be constant. Also if we use indirect torque control then the torque of induction generator set to limit the torque of induction generator set below 1.1. pu Simulation results appears for only 10s when the system is starting from stationary conditions and is exposed to a 350ms three phase fault at the terminal of the generator after is of simulation time. The main results collected for simulation of the three situations stated above are shown in figure 6 (a), (b), (c).
Figure 6 clearly indicates the operation of indirect torque control, useful to limit torque, speed and voltage during the recovery process. By using this new approach the torque shown in figure 6(a) as the function of time during the three situations also illustrate how, the indirect torque control effectively limits the peak value of torque during the recovery process similarly figure 6 (b) indicates the response of speed as the function of time and also figure 6(c) shows the response of voltage at the generator terminal as the function of time, and where it can be clearly observe that after the stability is ensure the voltage is actively reduced by the indirect torque control during the recovery process to limit the torque, it can also be seen that during the capacitor compensation condition the system voltage cannot be recovered with the use of indirect torque control as a secondary control after the stability is ensured, this type of approach reasonable from the point of view proposed concept.
Figure 6(a) clearly shows the production of torque transient during the fault and also these torque transient does not affect the functionality of STATCOM. During such serious fault causing low voltage the reactive current of the STATCOM, will have rare influence on the system voltage and on the operation of generator due to a large voltage drop STATCOM reach its maximum current limit and the STATCOM act as constant source of reactive current while running into saturation.

Time response generator speed shown in figure 6(b) indicates that how the use of Indirect torque control during recovery process result in an almost linear reduction the generator speed after reclosing. During the fault the average electrical torque close to zero, thus causing a line rise increase in the applied mechanical torque, resulting increase in generator speed.
Now, when the fault is cleared the STATCOM will keep maximum current since the systems cannot immediate recover the voltage due to increase in generator shaft. Since the system is unstable at this situation, the function of STATCOM will be implemented immediately during after the fault is cleared. Thus causing the increase in torque capability and simultaneously decreasing the speed of generator shaft. This increase in torque and decrease in speed is limited

![Figure 6(c): Time Response of Generator Terminal Voltage Before, During and After the Fault](image)

below the set-point value that has to be kept larger than that the applied mechanical torque, as long as the indirect torque control is active. After the generator speed is recovered close to the set value and the voltage has reached its reference value of 1.1 pu the control objective of STATCOM to control voltage at terminal of generator will be shifted back to the normal voltage control.

VI. CONCLUSIONS

The control concept propose an implemented in this paper is use to control the capability of STATCOM simulation result to obtain to recover the voltage of an induction Generator connected to grid after a fault is helpful to study the improvement of stability of that induction generator by use of indirect torque control method. The proposed concept has been tested by using time-domain simulation. It also gives an idea to limit the maximum torque of generator
during the recovery process after the fault. In normal operation the initial control objective of STATCOM is voltage regulation and in case if grid fault the STATCOM is used to improve LVRT capability, these objectives of STATCOM are shown in the simulation result where the system returns to normal operation when the speed of induction machine is back to the initial value before the fault. During analysis of indirect torque control method the maximum inductive current will decrease by increasing the grid induction as the STATCOM is to be operated in both capacitive and inductive region.

VI. REFERENCES


ABOUT THE AUTHOR

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