Proceedings of the 18th World Congress
The International Federation of Automatic Control
Milano (Italy) August 28 - September 2, 2011

Fault Ride-Through Enhancement of Wind Power Plant Using Series Variable Impedance

Teruhisa Kumano*. Naohiro Hasegawa*

*Meiji University, Kawasaki, 214-8571 Japan
(e-mail: kumano@ isc.meiji.ac.jp).

Abstract: Recently, the total capacity of wind generation connected to power system has increased significantly. In this situation, a large amount of disconnection of wind power generation may give a serious influence in the grid. It necessitated the revision of grid code requirements in many countries.

This paper proposes a new control method for a fixed-speed induction generator using series variable impedance composed of power converter and energy storage device. We compared the stabilizing effect of the proposed control system to the case of STATCOM from the viewpoint of rotating speed and device capacity (cost). According to this study, the proposed method can stabilize the plant by smaller output compared to STATCOM.

Keywords: Wind power generation, Fault Ride-Through, voltage sag, SSSC, STATCOM

1. INTRODUCTION

In recent years special attention has been paid to renewable energy and so called global environmental problem such as exhaustion of fossil fuel and green house effect. In particular, wind power generation is now under vigorous effort of development and installation owing to its comparatively cheap generation cost. In case of DFIG (Doubly Fed Induction Generator) and DC link type, voltage fluctuation due to the nature of wind can be controlled and significantly contributes to stabilization of grid. However, the type of the squirrel cage induction generator can give serious effects on power grid because its speed is fixed.

In case of a fault in a grid with wind generators, voltage level deteriorates, leading to output decrease from the generator. It might cause over speeding of its rotor or instability. In LVRT (Low Voltage Ride-Through) standard, wind generators are needed to remain in grid above the voltage level shown in Fig. 1. This is explained in the works of Schlabbach (2008) and Arulampalam (2007) etc.. As the penetration of wind power generation goes on, similar situation may also appear in Japan.

In order to satisfy LVRT requirement, speed stabilization will be required for the generators. For example, Muyeen (2006a) proposes to utilize pitch control, whereas power electronic device such as SVC or STATCOM was proposed to use for this purpose by Ahmed (2004) and Muyeen (2006b). Static damping resistor is also a candidate to overcome this instability as explained in Causebrook (2007).

This paper studies the stability enhancement by SSSC (Static Synchronous Series Compensator), a series connected power electronic device, applied to fixed speed squirrel cage induction generator. SSSC can continuously generate voltage of the phase 90 degree shifted from the current, which

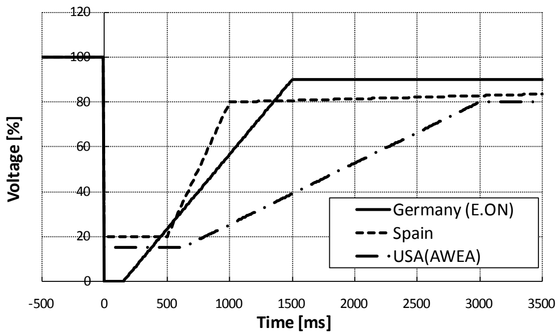

Fig. 1. Comparison of grid codes in each country.

implies varying the series reactance. This paper assumes an energy storage device compound together, which means we can vary not only reactance component but also resistance component of the series impedance. Numerical simulation is done to verify its stabilizing effect to the rotor speed. Quicker operation can be expected compared to the case of mechanically switched damping resistor.

2. EFFECTS BY VARYING SERIES IMPEDANCE

2.1 Induction Machine Speeding

In case of the model system shown in Fig. 2, the air gap power can be calculated as

$$P_{gen}(s) = \frac{3R_r X_m{}^2 V_g{}^2 (1-s)/s}{\left\{\frac{R_1 R_r}{s} - (X_0)\right\}^2 + \left\{\frac{R_r}{s}(X_1 + X_m) + R_1(X_r + X_m)\right\}^2} \qquad (1)$$

where,

$X_0 = X_1 X_r + X_r X_m + X_m X_1$,

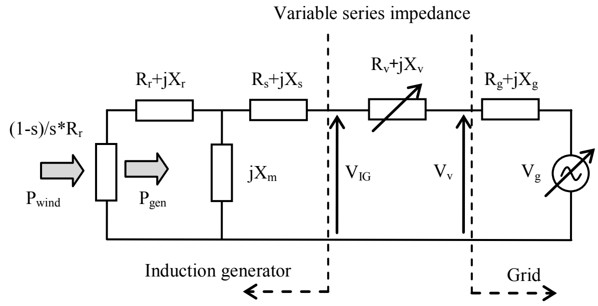

Fig. 2. Equivalent circuit of grid and wind farm

R_1=R_s+R_v+R_g X_1=X_s+X_v+X_g
and

R_r,X_r : rotor resistance and reactance

R_s,X_s : stator resistance and reactance

X_m : magnetizing reactance

s : slip

V_g : grid voltage

R_v,X_v : variable resistance and reactance

R_g,X_g : line resistance and reactance

P_{wind} : mechanical input power

P_{gen} : air gap power

In case of voltage decrease, the air gap power goes down proportional to the square of system voltage, accelerating power appears proportional to $\Delta P=P_{wind}-P_{gen}$. Enhancement of LVRT needs either reduction of mechanical input or increase of electrical output in case of voltage deterioration. In the proposed method varying series impedance can increase electrical output.

2.1 *Effects of Series Variable Impedance*

Using the parameters shown in Fig. 7 and Table 1, effects of inserting equivalent series impedance is numerically calculated. Fig. 3 shows the result of calculating steady state P_{gen}-n (n: speed) using (1) under the condition that series resistance of 0.1pu or series capacitive reactance of 0.05pu is inserted respectively. In both cases the output is enhanced but they are deferent in the following three aspects.

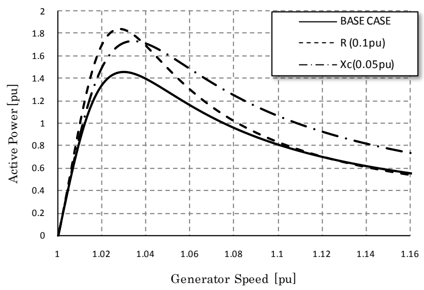

Fig. 3. Effect of series variable impedance

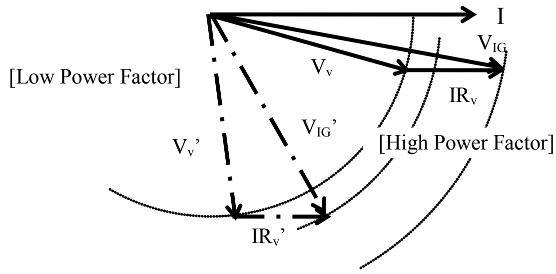

Fig. 4. Phasor diagram of series resistance insertion

Firstly, the series resistance does not give effect if the generator speed is over 1.1pu. It is due to the electrical characteristics of induction machine that large amount of reactive power is consumed in the speeding condition. As the low power factor case shown in Fig. 4, the terminal voltage does not rise significantly by the phase relation. Inserting capacitive reactance can successfully compensates the series reactance, leading to high output enhancement.

Secondly, inserting resistance needs absorption of active power, which requires certain energy storage element. The capacitive reactance insertion needs no storage device.

Finally, capacitive reactance insertion has a shortcoming that it makes electrical distance shorter and the output current becomes larger.

2.2 *Mechanism of Rotor Stabilization by Proposed Method*

2.2.1 Post Fault Impedance Insertion In case of severe voltage depression, impedance insertion during fault might be difficult because of phase jump by fault clearance can make malfunction in controllers. The assumed voltage dip is depicted in Fig.5, and the P_{gen}-n curves are shown in Fig. 6. (a) shows the case of no insertion, whereas (b) shows the case that 0.05pu of capacitive reactance is inserted 0.1sec after the fault clearance (Point A). In these figures the instants of the same number coincide with each other. In (a) the electrical output does not exceeds mechanical input, leading to continuous acceleration or instability. However, in (b) reactance insertion enhances output and it goes bigger than mechanical input, leading to stabilization. In this case, as already shown in Fig. 3, resistive insertion has no effect because the velocity already becomes too large. The capacitive reactance insertion is better.

2.2.2 Impedance Insertion during Fault If SSSC control can ride over the shock of fault clearance, impedance insertion during fault can be a powerful candidate to this issue. Fig. 6 (c) shows the case of insertion of series resistance (0.1pu) 0.1s after the fault occurrence. The output during fault is enhanced and comes back to the normal operating point stably. In this case the maximum speed is lowered, which lessens the danger of activating over speed protection, and the maximum current during the recovery process becomes smaller. Basically SSSC can function so fast as within 2 cycles because it is a power electronic device. This quick operation is a key to stabilize the generator.