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A novel control system design to improve LVRT capability of fixed speed wind turbines using STATCOM in presence of voltage fault

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ABSTRACT

The design and implementation of a new control system for reactive power compensation and mechanical torque, voltage regulation and transient stability enhancement for wind turbines equipped with fixed-speed induction generators (IGs) in power systems is presented in this study. The designed optimal linear quadratic regulator (LQR) controller provides an acceptable post fault performance for both small and large perturbations. Large disturbance simulations demonstrate that the designed controller enhances voltage stability as well as transient stability of the system during low-voltage ride-through transients and thus enhances the LVRT capability of fixed-speed wind generators. Further verifications based on detailed time-domain simulations are also provided. Calculations, simulations and measurements confirm how the increased STATCOM rating can provide an increased transient stability margin and consequently enhanced LVRT capability. A concept of critical clearing time has been introduced and its utility has been highlighted.

Introduction

WIND turbines are one of the renewable energy technologies that, today, face a growing progress. This developments cause rapid progress of economic and environmental issues [1]; therefore, the study about connecting the turbines to the grid is very important [2].

Many countries have their own grid codes which monitor the behavior of the wind turbines connected to the grid [3]. All network grid codes for wind turbines include requirements such as low-voltage ride-through capacity (LVRT), voltage control, power-quality and protection requirements. In 2005, LVRT requirement was introduced the wind turbine rotor speed try to achieve stability on the index which requires a certain voltage, an example of the voltage profile is shown in Fig. 1.

If a fault or voltage drop occurs at stator terminals of wind turbine generator, according to (1), electrical torque will decrease while mechanical torque still exists because wind keeps blowing. According to Eq. (2), these conditions will cause rotor speed to increase. If this voltage drop continues, it may cause rotor of turbine to accelerate and make rotor speed unstable.

$$T_e \propto v_s^2 \tag{1}$$

$$\frac{d}{dt}\omega_r = \frac{1}{J}(T_m - T_e) \tag{2}$$

The maximum voltage drop (either in terms of magnitude or in terms of time) which wind turbine is able to withstand without suffering from rotor speed instability is called wind turbine low voltage ride through capability.

Wind turbine technologies include Fixed and variable speed wind turbines [5]. Since fixed-speed turbines are easy to install, durable and cost- effective, nowadays, most of the installed turbines are chosen from this category [6]. In Iran, about 91 MW of installed wind turbines are fixed-speed squirrel cage induction generator turbines [7]. Squirrel cage induction generators show slight stability margin against voltage drop; consequently, it is necessary to use compensator devices to improve rotor speed stability margin [8]. In order to determine the type and the way of compensation, it is necessary to examine characteristic curves of induction generator.

The absorbed reactive power, slip and slip-torque characteristics of induction machine are shown in Fig. 2(a) and (b) respectively. As it can be observed in these figures, during the normal operation, the generator has a very low slip close to zero, and, in this case, little reactive power is absorbed by generator. But if

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Nomenclature

ω_r	rotor angular speed	i_{ds}, i_{qs}	d-axis and q-axis stator currents
J	moment of inertia	R_s, R_r	stator and rotor resistances
T_m	mechanical torque	ω_S	rotational speed of the reference device
T_e	electrical torque	$\lambda_{ds}, \lambda_{qs}$	d-axis and q-axis stator Flux linkage vectors
v_s	generator stator voltage	$\lambda_{dr}, \lambda_{qr}$	d-axis and q-axis rotor Flux linkage vectors
S	slip	i_{dr}, i_{qr}	d-axis and q-axis rotor currents
S_{cr}	critical slip	ω_r	rotational speed of the generator's rotor
t_{cr}	critical clearing time	L_s, L_r, L_m	stator, rotor and magnetizing inductances
T_{ae}	aerodynamic torque	e_{dr}, e_{qr}	d-axis and q-axis transient voltages
ω_t	rotational speed of wind turbine	P	number of pole pairs
ρ	air density	H_g	inertia constant of the generator
A	area of wind turbine rotor	i_{de}, i_{qe}	d-axis and q-axis STATCOM currents
V_{wind}	speed of wind	L_f, R_f	transformer of STATCOM res. and ind.
C_P	power coefficient	v_{dc}	dc voltage of STATCOM
λ	tip speed ratio	C, R	DC capacitor and resistance
β	pitch angle	α	Phase angle of the STATCOM
H_t	inertia constant	m	modulation index
D_t	wind turbine damping	A, B	system matrices
v_{ds}, v_{qs}	d-axis and q-axis stator voltages	R, Q	LQR matrices

the generator is accelerated, the reactive power absorbed by the generator begins to increase with large gradient. The increase in reactive power absorbed by the generator, will lead to a lack of voltage recovery, after the voltage drop is removed. Lack of prompt voltage profile recovery may also cause rotor speed instability.

In order to analyze the causes of instability, it is necessary to examine characteristics of induction generator more carefully. As shown in Fig. 3(a), in operating points A_1 and E_1 generator slip is S_1 and its voltage is V_1. In these points electrical and mechanical torques are equal and generator is in stable state. The occurrence of low voltage in power grid, results in a sudden voltage drop at the terminals of the stator from V_1 to V_2. Consequently, the electric torque and absorbed reactive power drop from A_1 to B_1 and from E_1 to F_1 respectively. Since Exciting torque is much higher than electrical torque, generator starts to accelerate and its slip reaches to S_2. Consequently, the electric torque and reactive power characteristics start to move towards C_1 and G_1 respectively. After fault handling and recovery of grid voltage, since the rotor slip still remains high, a great amount of reactive power is absorbed by the stator terminals of generator which leads voltage to be recovered to a point where the voltage is less than V_2 i.e. V_3. In this case operating points of generator are D_1 and H_1. Since, in these points, the electrical torque is more than mechanical torque, the rotor slip gradually decreases, which means reducing the absorption of reactive

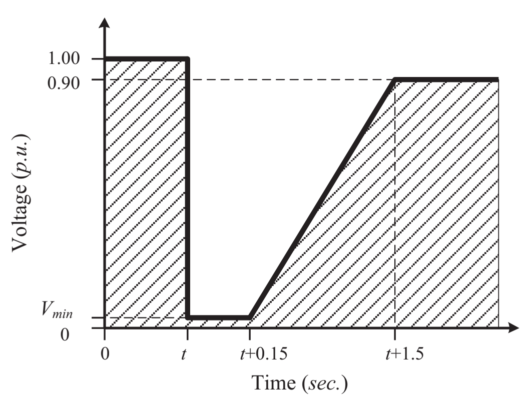

Fig. 1. Example of LVRT requirement to the wind turbine farms [4].

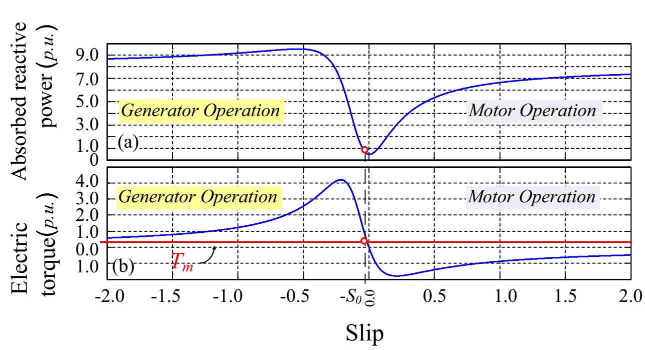

Fig. 2. Characteristics of induction machine (a. reactive power-slip, b. electric torque-slip).

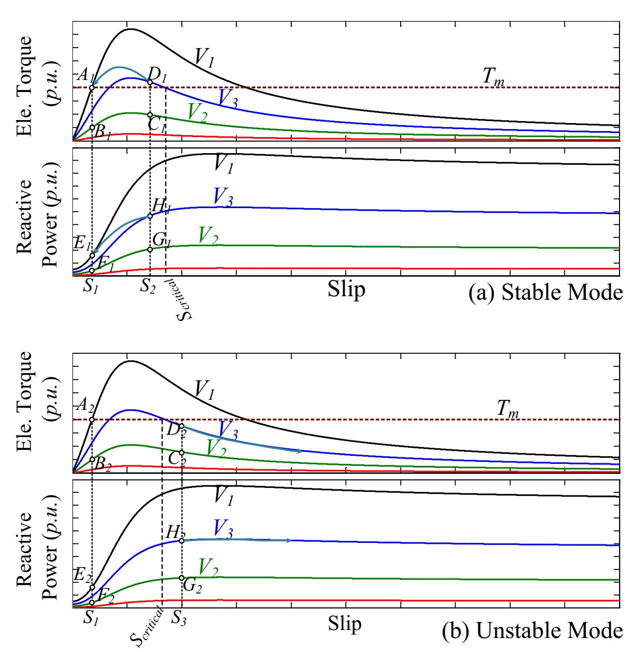

Fig. 3. Characteristics of induction generators when the low voltage occurs (a. stable state, b. unstable state).