POWER COMPENSATION EFFECT OF AN ADJUSTABLE-SPEED ROTARY CONDENSER WITH A FLYWHEEL FOR A LARGE CAPACITY MAGNET POWER SUPPLY

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Abstract

Direct connection of the synchrotron magnet power supply to the utilities causes the effect of pulsed reactive and active power in the ac line. Conventionally, Static Var Control system compensates the reactive power generated by the thyristor converter to reduce the flicker in the power line. However, it is necessary to control not only a reactive power but also an active power for the future large scale synchrotron magnet power supply in order to reduce the dissipation power and to realize the stabilization in the ac line. An adjustable-speed rotary condenser is capable of not only reactive power control but also active power control since it utilize a flywheel effect of the rotor. Research and development on these problems are now under going using a model system of 7.5kW rotary condenser with flywheel (GD^2=3kg-m^2). Control and characteristic of an adjustable-speed rotary condenser and the experiment result will be presented.

1 INTRODUCTION

1.1 Background

The KEK-PS main ring magnet power system works at repetition rate 0.25 - 0.4 Hz for the power to be fed in and fed out from the utility to the magnets by converter and inverter mode operations. The magnet power system, consists of the ring magnet power supply (23.6MVA), the reactive power compensator systems (20 MVar lag for fundamental) and the harmonic filter banks (20 MVar lead) [1].

As a case of the 50 GeV main ring magnet power system of the Japan Hadron Project (JHF), peak power and dissipation power are estimated to be about 120MW and 34.5MW, respectively. For such a large scale magnet power system, the fluctuation of active power produce serious effects on power systems of the installation site of the magnet power supply, even if the reactive power is compensated. Hence, installation of a large-capacity energy storage system to the magnet power supply is now under consideration. For the JHF design, doubly-fed flywheel generating system is under consideration [2]. Attention has been paid to a flywheel energy storage system based on a doubly-fed induction generator-motor for the purpose of power conditioning with aiming at load-leveling over a repetitive period. Figure 1, for example, shows the typical pattern of which active power changes drastically in a range from +55MW to -55MW within 4 sec. It is also referred to as an “adjustable-speed rotary condenser” capable of both active power control and reactive power control, in contrast with a conventional “synchronous-speed rotary condenser” capable of only reactive power control.

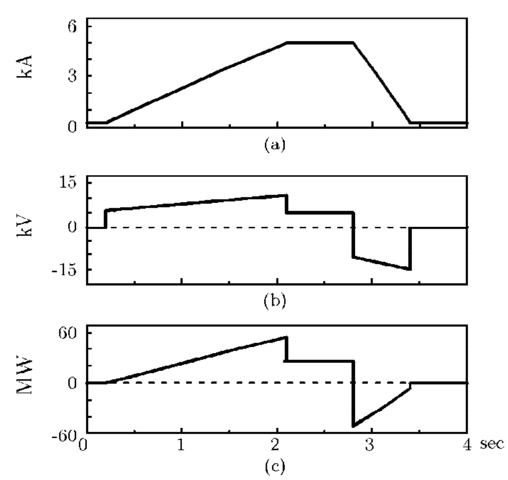

Figure 1 : Typical operating pattern of a magnetic power supply for a proton synchrotron. (a) Magnet current. (b) Magnet voltage. (c) Active power.

1.2 The 200-MJ flywheel energy Storage System

For example, the 200 MJ ROTES (Rotary Energy Storage System) was successfully commissioned at the Chujowan substation on Okinawa island of Japan [3]. The ROTES is an application of adjustable speed pumped storage system technology, and is an excellent system designed to suppress frequency fluctuations caused by sudden and frequent load changes in the power system. With the 200 MJ ROTES, frequency fluctuations have been greatly improved from ± 0.6 Hz to ± 0.3 Hz.

2 SYSTEM CONFIGURATION

A doubly-fed flywheel generator-motor of a wound-rotor induction machine and a cycloconverter or a voltage-source PWM rectifier-inverter which is used as an ac excitor. Adjusting the rotor speed makes the generator-motor either release the kinetic energy to the power system or absorb it from the power system. Thus, the generator-motor has the capability of achieving, not only reactive power control, but also active power control based on a flywheel effect of the rotor.

The control strategy enables the flywheel generator-motor to perform active power control independent of reactive power control even in transient states. The flywheel generator-motor based on leading edge power electronics and electric machine technologies shows promise as a versatile power conditioner, in particular, being capable of repetitively absorbing or releasing electric energy for a periodical operation such as a synchrotron magnet power supply.

The ac excitation on the basis of a rotor-position feedback loop makes it possible to achieve stable variable-speed operation. Adjusting the rotor speed makes the generator-motor either release the electric power to the utility grid or absorb it from the utility grid. Therefore, the flywheel energy storage system is more suitable for repetitively absorbing and releasing electric energy for a short period of time. The required capacity of power electronic equipment for ac excitation is in a range from one-fifth to one-seventh as small as the capacity of the wound-rotor induction machine.

A 40-MJ flywheel energy storage system based on a 70-MVA doubly-fed induction machine should be installed on the ac side of the magnet power supply shown in Fig. 1, in order to achieve perfect load-leveling. Comparison with the 200-MJ system installed for line-frequency regulation leads to the possibility that the 40-MJ system does not need to couple any flywheel with the rotor, because the induction machine rating required to the 40-MJ system is 2.6 times as large as that required to the 200-MJ system. On the contrary, the 40-MJ system needs to achieve much faster charge/discharge of active power than the 200-MJ system.

3 EXPERIMENT SYSTEM AND SIMULATION

3.1 Experiment System

Despite of the 200-MJ successful example, it is necessary to confirm that a new control strategy for a doubly-fed flywheel generator-motor would be effective by an experiment.

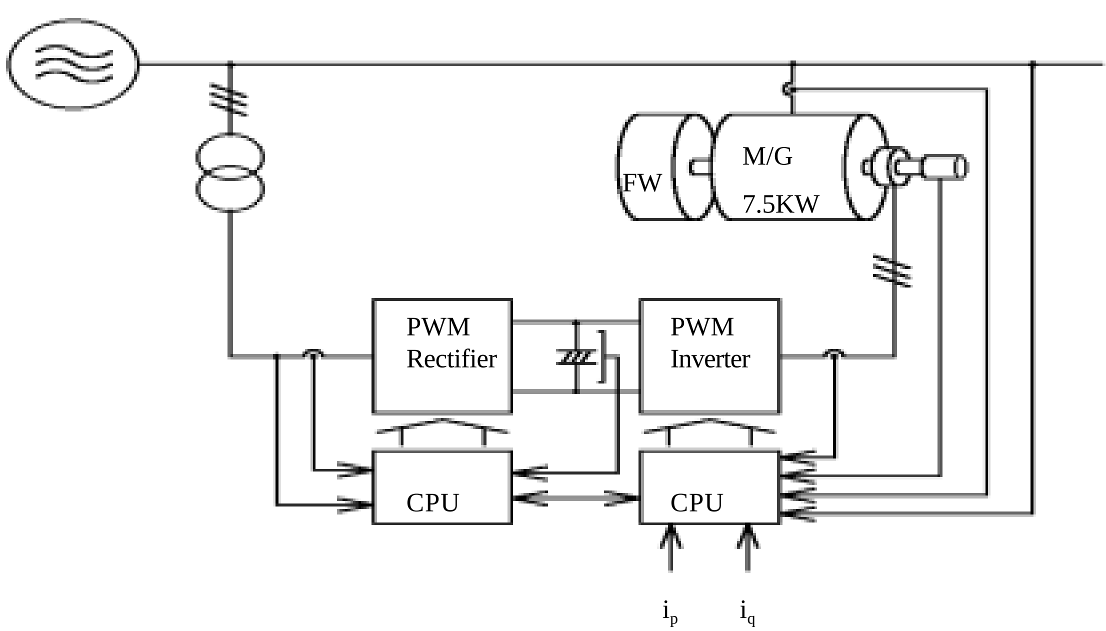

Figure 2 : Experiment system of the 7.5 kW doubly-fed flywheel with IGBT rectifier and inverter

The experiment system consists of a 7.5-kW doubly-fed induction machine equipped with a flywheel of 3 kgm^2, a 2-kVA voltage-source PWM rectifier, a 2-kVA voltage-source PWM inverter, and dual CPUs (Hitachi SH-1). Fig. 2 shows a block diagram of the experiment system. The rectifier and inverter using insulated gate bipolar transistors (IGBTs) rated at 600 V and 30 A, are controlled by the CPUs. Three-phase currents and voltages are detected by CTs or PTs, while the rotor position is detected by a rotary encoder (RE). These signals are sent to the CPUs in order to calculate three-phase inverter output voltages. The inverter excites the secondary winding of the induction machine through slip rings, forcing the active and/or reactive power released to, or absorbed from, the utility to follow its references i_p and i_q. The experiment is now under processing.

3.2 Simulation

Fig. 3 shows simulated waveforms in which the switching operation of the voltage-fed PWM inverter is taken into account [4]. Here, the control system for i_p and i_q has a proportional-plus-integral (PI) controller, the time constant of which is set at 100 ms. The proportional gain is designed to be K = 0.5 [V/A], so that the time constant of i_p and i_q for a step change in i_p^* and i_q^* is T = 2.5 ms. The triangle-carrier frequency of the voltage-fed PWM inverter is 1 kHz, and the dc link voltage is 0.2 pu. The magnitude of the step change in i_p^* and i_q^* is set to be ± 0.25 pu, so that the maximum output voltage of the inverter does not reach the saturation voltage, that is, the dc link voltage of 0.2 pu. If the magnitude of the step change is large enough for the control system to reach saturation, it would be impossible to evaluate the response inherent in the control system from the resulting response to the step change, because the saturation voltage would dominate the resulting response to the step change. Fig. 3 exhibits that the time constant of i_p and i_q is 2.5 ms (ω_c = 400 rad/s) which is equal to its design value, and that no cross-coupling occurs between i_p and i_q. The rotor speed of the induction machine, ω_m varies in Fig. 3 (a), whereas it is held constant at 360 rpm in Fig. 3 (b) because i_p = 0. Detailed results of the simulation will be presented in another place [4].

4 CONCLUSION

This paper has described the control strategy and dynamic performance of a flywheel energy storage system based on a doubly-fed induction machine for power conditioning. The validity of the theory developed in this paper is verified by computer simulation.

The flywheel energy storage system based on a doubly-fed induction machine is expected to be used exclusively as a versatile power conditioner, in particular, being capable of repetitively absorbing and releasing electric energy for a short period of time less than a minute. The experiment result of 7.5 kW model should be expected.

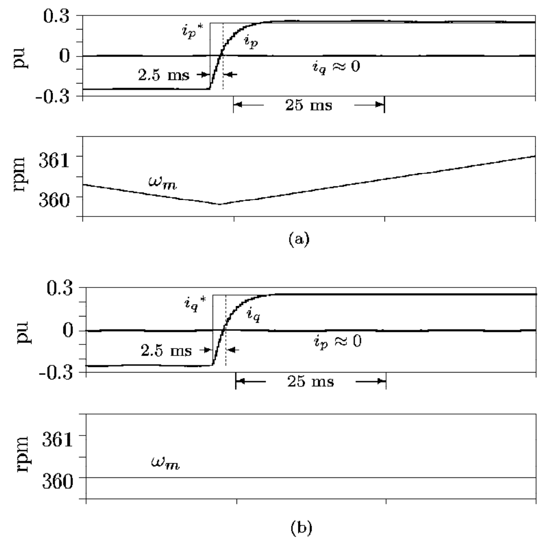

Figure 3 : Simulated waveforms in switching operation of the voltage-fed PWM inverter. (a) Step response of i_p^* under i_q^* =0. (b) Step response of i_q^* under i_p^* =0. ω_m is held constant at 360 rpm in because of i_p = 0.

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