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Comparison of Flywheel Systems for Harmonic Compensation Based on Wound/Squirrel-Cage Rotor Type Induction Motors

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ABSTRACT

This paper describes two different systems which can compensate harmonic currents generated in a power system As non-linear loads increase gradually in industry fields, harmonic current generated in the electric power network system also increases. Harmonic current makes a power network current distorted and generates heat, vibration and noise in the power machinery. Many approaches have been applied to compensate harmonic currents generated in the power system Among various approaches, in this paper, two kinds are compared and evaluated. They are flywheel compensators based on secondary excitation of WRIM(wounded rotor induction motor) and SCIM(squirrel cage induction motor). Both systems have a common structure They use a flywheel as an energy storage device and use PWM inverters. The main differences are the size and rating of the converter used

Key Words : WRIM(wound rotor induction machine), SCIM(squirrel cage induction motor), flywheel, active filter

1. Introduction

The flywheel system is one of promising candidate as an efficient large scale energy storage system. The major role of the flywheel system is an energy storage element. For instant this system may be used as an UPS system. In addition to these roles, the same system can also do a role as a harmonic compensator by just adding control schemes

The basic principle of the flywheel harmonic compensators is similar to the active filter using an inverter. However, the flywheel system cannot be directly compared to the active filter as a harmonic compensator in efficiency This is because the main objective of the flywheel system is energy storage and a harmonic compensation is an additional role. The efficiency of the flywheel system is lot dependent on the machine Some efforts are on going to reduce the loss of the machine like a bearingless drive However overall efficiency of the flywheel system can be lower than that of the active filter system because of the machine loss Thus it may not be a good idea to use the flywheel system just as a harmonic compensator However, once you installed the flywheel system as an energy storage system, it can have advantages by adding a harmonic compensation role to the existing flywheel system instead of installing additional and separate active filters.

In active filters, compensation current is estimated for reducing the harmonics by calculating harmonics of the load current. Then the estimated current is generated by an inverter In the case of an harmonic compensation system using WRIM the inverter controls the secondary side current to generate desired compensation current in the primary side. This means that the capacity and size of the inverter used in the harmonic compensation system using WRIM can be much smaller than the inverter used in the active filters [1, 2, 3]

To control the secondary excitation current, a hysteresis converter can be used. The hysteresis control scheme has the advantage of obtaining the desired current directly of

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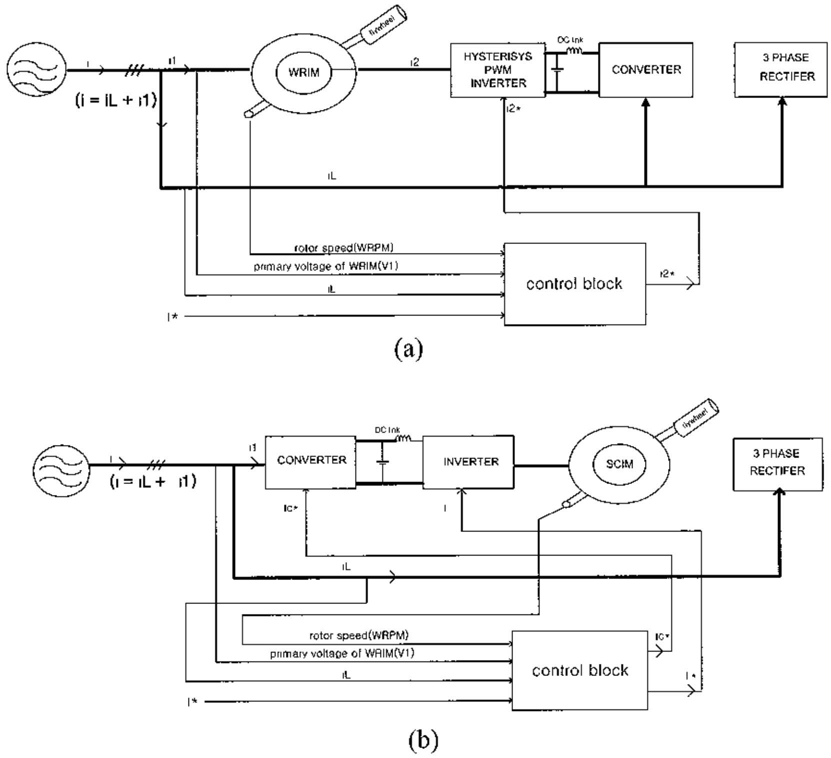

Fig 1 Configuration of the compared systems, (a) System with WRIM (b) System with SCIM

and the control scheme is simple to design because the output parameter of the control block is the current reference value [4, 5].

Compared to WRIM, SCIM has a disadvantage in the aspect converter size, but it has merit in other aspects This paper describes the difference, and the advantages and disadvantages of the two system. Then the system based on WRIM is simulated and implemented for the experiment

2. System Configuration

The structural difference between conventional active filters and flywheel systems is that the machine set is added to the inverter module. Fig 1 shows the main circuit of the two different flywheel system The two systems have a similar structure. A 3-phase diode rectifier is used as an harmonic generator in the power source For simulation and experiments, 3-phase power is connected to the converter. The converter makes dc power. This dc power is used for an inverter power source. In the case of WRIM, the primary side is controlled through the secondary side. However, in the case of SCIM, the primary side is controlled directly while the secondary side is shorted. The energy source during power faults is a flywheel The flywheel stores energy during the motoring mode, and the stored energy is used as a power source to the load during the generation mode

In the case of WRIM, a hysteresis PWM inverter is connected to the secondary side for control of the primary current In the case of SCIM, a space vector modulation (SVM) PWM inverter is connected to the primary side for the improvement of dc-power utilization The input reference values of both systems are power source current, and the controlled primary side current is the compensation current to follow the input reference value

Overall Configuration of the two systems is given in Fig 1 Each system has a different control scheme.

Fig 2 shows control block diagrams of the two systems Fig. 2 (a) is a system with WRIM and Fig. 2 (b) is a system with SCIM

3. Control Scheme

3.1 Harmonic current and power factor compensation

3 1 1 System with WRIM

The harmonic current generated by the load has to be calculated first and then the compensation current

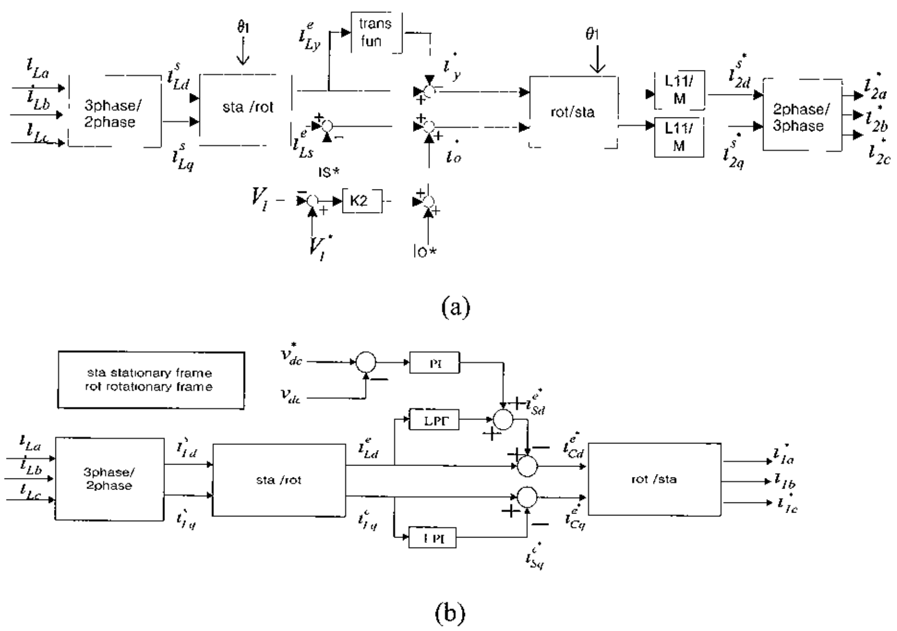

Fig 2 Control block diagram, (a) System based on WRIM (b) System based on SCIM

corresponding to the harmonic current generated in the power source has to be determined This compensation current is the reference value of the primary side current of the motor. As shown in Fig 2 (a) harmonic current in the power source can be reduced by supplying harmonic current to the secondary side of the motor through low power converters. All control parameters are dealt with a two phase reference frame The instantaneous vector of the three phase

load current is transformed into active and reactive components of the rotating reference frame Then the active component of the primary side of the current is obtained through filtering. And this current is converted to the secondary side current of the machine. This is a reference current of the machine which produces compensation current at the primary side of the machine In the case of power factor compensation, reactive current of power source has to be zero By making the reference value of the reactive current zero, the motor supplies reactive current to make a phase angle difference between voltage and current of the power source zero This is also achieved by controlling the secondary side current of the motor through low power converters.

3.1 2 System with SCIM

In this system, the harmonic current generated by the load is calculated as in the former system, and then the active current reference for the primary side current of the motor is determined by considering dc link voltage. A high power converter must be installed in the primary side of the motor as an active filter in this system as shown in Fig. 2 (b). Power factor compensation is also achieved by directly supplying reactive current to the system through high power converters

4. Comparison and simulation

4.1 Comparison

Both systems have advantages and disadvantages, since they have different system structures and control schemes Advantages and disadvantages of the simulated systems are summarized as follows. Advantages of the flywheel compensation system based on WRIM are

1) The primary side power can be controlled directly by low power control of the secondary side.
2) Therefore efficiency is high compared to the SCIM system
3) The size of the inverters can be reduced compared to the conventional static compensators because the WRIM controls the low power secondary side with inverters.
4) The system can work as an uninterruptible power supply without the additional flywheel energy storage device

Disadvantages of the flywheel compensation system based on WRIM are:

1) Since it needs to consider the relation between the primary and secondary side of the wound rotor type motor, the control algorithm can be complicated.
2) Maintenance cost is high for the motors

Advantages of the flywheel compensation system based on SCIM are

1) The control scheme is relatively simple because the inverter directly controls the primary side current of the motor.
2) Maintenance cost is low for the motors

Disadvantages of the flywheel compensation system based on SCIM are·

1) Since the converter and inverter are directly connected to the power source, the power ratings are large, thus it is not suitable for a large-scale system
2) The converter and inverter must have bi-directional power flow capability to operate both motoring and generating modes in the primary side of SCIM. Thus, control algorithms for the converter and inverter are far more complicated than those of the system based on WRIM

As discussed, the system based on WRIM has far more advantages than does the system based on SCIM. Thus the system based on WRIM is simulated and is implemented for the experiment.

4.2 Simulation Results

Computer simulation is performed in three different cases for the system based on WRIM.

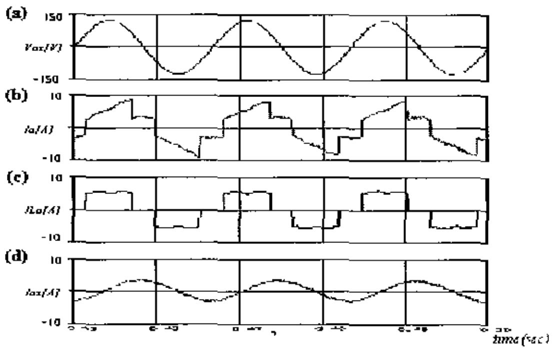

Fig 3. Simulation results without compensation; (a) voltage in the power source (b) current in the power source (c) load current (d) primary side current in the motor

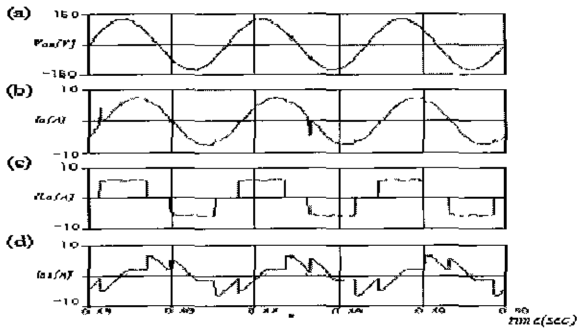

Fig 4 Simulation results with harmonic compensation; (a) voltage in the power source (b) current in the power source (d) load current (c) primary side current in the motor

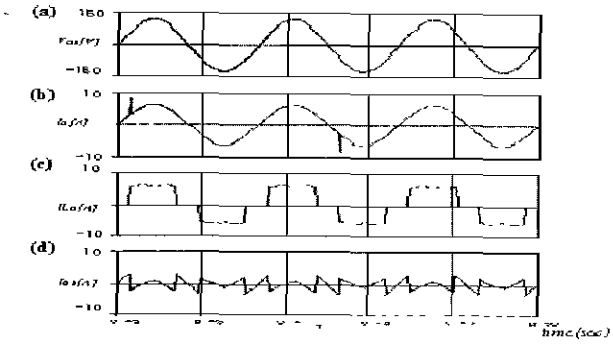

Fig 5 Simulation results with power factor compensation, (a) voltage in the power source (b) current in the power source (c) load current (d) primary side current in the motor

Fig 3 is a case without harmonic compensation and fig. 4 is with compensation.

In Fig 3 we can see that the line current is a sum of a lagging motor current and a load current that has harmonics. In Fig 4, we can see that harmonic current in the power source is reduced by the primary side current of the motor.

Fig 5 is simulation results with power factor compensation In Fig. 5, we can see that the phase angle between voltage and current is synchronized.

5. Experimental Results

The system based on WRIM is implemented with a TMS320C31 DSP and a PWM IGBT inverter as shown in Fig. 6. Actual machine speed is measured from an incremental encoder with 600[pulse/rev] resolution. The voltage phase angle is detected with PT. The sampling time of the current controller loop is 100[μs].

Table 1. Motor Parameters

Rated Power	2.2Kw	L_s	43.75mH
Rated Speed	1122rpm	L_r	44.09mH
Rated Torque	120Nm	L_m	42.1mH
R_s	0.115	J_M	0.16kgm^2
R_r	0.0821	P	6

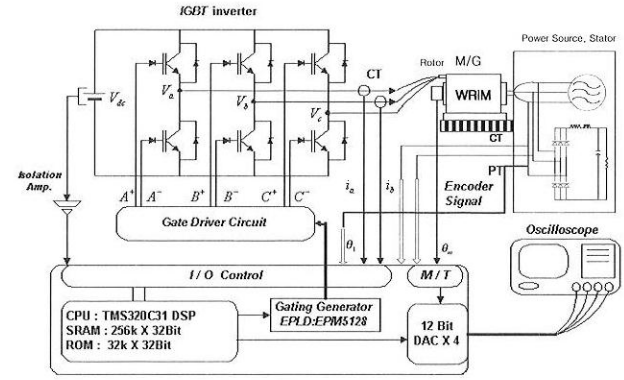

Fig. 6. WRIM implemented system

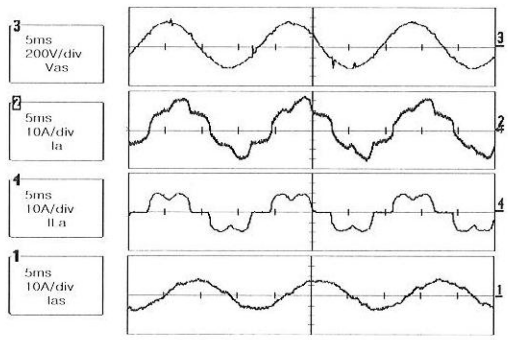

Fig. 7. Experimental output waveforms without harmonic compensation; (a) power source voltage (b) power source current (c) load current (d) motor side current

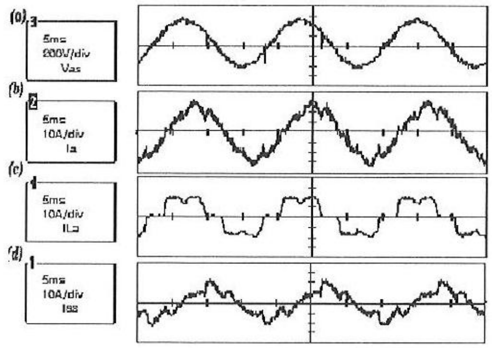

Fig. 8. Experimental output waveforms with harmonic compensation; (a) power source voltage (b) power source current (c) load current (d) motor side current

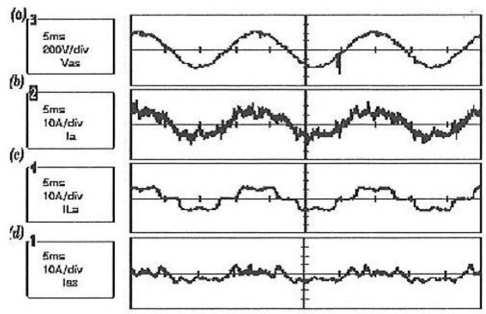

Fig. 9. Experimental output waveforms with power factor compensation; (a) power source voltage (b) power source current (c) load current (d) motor side current

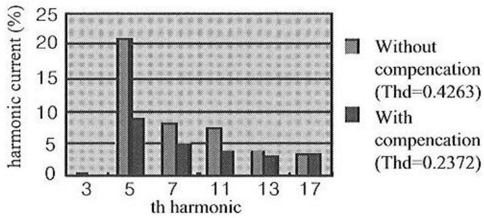

Fig. 10. FFT results of the power source current

The proposed control algorithm was fully implemented with software. Table 1 shows the motor parameters of the implemented system.

Fig. 7 shows experimental output waveforms without compensation. The power source current is distorted a lot because of the load current.

Fig. 8 shows the experimental output waveforms when the source current is compensated by the primary side current of the machine, which is controlled by the secondary side current control of the machine. When the system is not compensated, it can be seen that the power source current has a large amount of harmonic component because of a non-linear load. However when the system is compensated, the fifth and eleventh harmonic components are reduced considerably.

Fig. 9 shows the power factor compensation through control of the motor current. In this case power factor correction is a result of reactive power compensation caused by the motor not by the load.

Fig. 10 is a FFT analysis of power source current with and without harmonic compensation. In figure 10, we can see that the fifth harmonic component is decreased by 50% and the seventh, eleventh harmonic components are reduced by 40% and 45% respectively.

6. Conclusion

In this paper, two different harmonic and power compensation schemes based on a flywheel system are compared and analyzed. And the system operations and performance are verified by computer simulation. Then the system based on WRIM is implemented and the experimental results are discussed. Basically both systems have a similar structure, except that the motors used are WRIM and SCIM respectively. However, the control scheme and inverters used in the systems are different. Two systems show different characteristics in some aspects while some other aspects are common to both. These characteristics can be summarized as follows. The aspects, which are common for both systems, are:

1) Both systems can operate as a harmonic compensator.
2) Both systems can operate as an active/reactive power compensator.

The aspects, which are different from each other, are:

1) The size and rating of the converter used is lower in the system based on WRIM than in the system based on SCIM.
2) In the system based on WRIM, the primary side power can be controlled directly by low power control of the secondary side. Therefore efficiency is high compared to the SCIM system.

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