Journal of the Korean Institute of Illuminating and Electrical Installation Engineers Vol. 19, No.3, pp. 27~34 May 2005 논문 19-3-4

2중 컨버터 구조를 갖는 계통 연계형 UPS의 DC 충전 알고리듬에 관한 연구

(A Study on DC Charging Algorithm of the Line-Interactive UPS with Dual Converter Structure)

이우철* · 유동상
(Woo-Cheol Lee · Dong-Sang Yoo)

요 약

본 논문에서는 2개의 컨버터 구조를 갖는 삼상 계통 연계형 UPS에 대하여 연구한다. 삼상 UPS 시스템은 2개의 능동 전력 보상기 구조로 이루어져 있다. 하나는 직렬형으로 .전원전압과 동상의 전압원으로 동작하여 전원전압의 변동, 왜곡시에도 정현파 전원전류와 고역률을 갖도록 동작한다. 병렬형은 전원전압과 위상을 맞춘 종전의 정현파 전압원으로 동작하여 부하에 안정되고 낮은 THD를 갖는 정현파 전압을 공급한다. 본 논문에서는 직렬형, 병렬형 능동보상기에서 전원전압의 크기에 따라 충전 방법에 대하여 제시한다. 종전의 계통 연계형 UPS는 DC 충전과 출력전압을 동시에 제어하였는데, 2개의 컨버터 구조를 갖는 UPS 시스템에서는 직렬형 보상기도 DC 충전을 할 수 있어 직렬형과 병렬형을 사용한 충전 알고리듬을 연구할 필요가 있다. 따라서 DC link 단의 전압을 안정시켜 본래의 직렬형, 병렬형 구조의 보상기의 안정성 향상에 기여할 수가 있다. 제안된 방법의 타당성은 시뮬레이션과 실험 결과를 통하여 입증된다.

Abstract

This paper presents a three phase Line-Interactive uninterruptible power supply(UPS) system with dual converter structure. The three phase UPS system consists of two active power compensator topologies. One is a series active compensator, which works as a voltage source in phase with the source voltage to have the sinusoidal source current and high power factor under the deviation and distortion of the source voltage. The other is a parallel active compensator, which works as a conventional sinusoidal voltage source in phase with the source voltage, providing to the load a regulated and sinusoidal voltage with low total harmonic distortion(THD). This paper presents in the series and parallel active compensator charging method depending on the amplitude of the source voltage.

The conventional Line-Interactive UPS system is responsible for the DC charging and output voltage regulation at the same time, but UPS system with dual converter structure, a series active compensator can also charge the DC link. Therefore, the charging algorithm using the series and parallel compensator needs to be researched. Therefore, by making the DC link voltage stable, it can contribute the stability of series and parallel compensator. The simulation and experimental result are depicted in this paper to show the effect of the proposed algorithm.

Key Words : Line-Interactive UPS, dual converter structure, DC charging

---

* 주저자 : 한경대학교 전기공학과 조교수
Tel : 031-670-5323, Fax : 031-670-5015, E-mail : woocheol@hknu.ac.kr
접수일자 : 2004년 9월 14일 1차심사 : 2004년 9월 17일 심사완료 : 2004년 9월 30일

1. Introduction

The term on-line UPS, double conversion system was commonly used in the 1970s, addressing the need for continuity and quality in the supply of electrical power to large computer systems. In the 1980s, off-line UPS were developed. The inverter is connected in parallel and acts simply to backup utility power. There are separate battery charge, an inverter and a transfer switch. The situation became more complicated when, in the 1990s, further techniques were developed, and the term 'Line - Interactive' came to be applied to UPS implementing reversible inverters. The Line - Interactive system solved the problem of the off-line UPS, which happens when the blackout. However, conventional Line - Interactive system has a problem for the low input power factor when the source voltage increases or decreases. If for example at high mains voltage (+10[%] to +15[%] of nominal), losses increase. This is because of increasingly higher reactive currents that the inverter has to support when the difference between source voltage and output voltage is high (large voltage across the choke). Hence, the power factor is not unity[1][2].

The Line-Interactive UPS using the series active compensator (series-parallel UPS system) eliminates the drawbacks of the Line-Interactive UPS and comes very close to an ideal solution. This is no source current distortion or voltage distortion and voltage and current are nicely in phase, hence unity power factor can be acquired[3][4]. The UPS system is controlled in two distinct methods[5]. In the first UPS system, called Unified Power Quality Conditioners (UPQC), the series active compensator controls the output voltages and the parallel active compensator controls the source currents. The other UPS system, called Delta conversion UPS, the series active compensator controls the source currents and the parallel active compensator is added to controls the output voltages.

In this paper, the series active compensator compensates for the difference between the source and the output voltage. Therefore, when the source voltage increases and decreases highly, it can solve the problems such as power factor in Line-Interactive UPS[5]. Still more, it can compensate for the imbalance and harmonics of the source voltage becausse the series active compensator detects and compensates for them as a voltage source. The parallel active compensator controls the output voltage constantly. Therefore, when the blackout occurs, it doesn't have to change the control mode like UPQC[6].

This paper presents the battery charging method of the series and parallel active compensator depending on the amplitude of the source voltage. The conventional Line-Interactive UPS system is responsible for the DC charging and output voltage regulation at the same time, but UPS system with dual converter structure, a series active compensator can also charge the DC link. Therefore, the charging algorithm using the series-parallel active compensator needs to be researched, and, by making the DC link voltage stable, it can contribute the stability of series and parallel compensator. Simulation and experimental result for a prototype are presented to verify the good performance of the proposed series parallel UPS system.

2. Line-Interactive UPS

Fig. 1. (a) shows the well proven Line-Interactive scheme, the biggest differences are the replacement of the separate rectifier and charger with a static switch, a choke and the inverter control techniques. The equivalent circuit

is shown in Fig. 1. (b). Therefore, giving the following equation (1) and (2).

In normal operation, the mains static switch is closed and power is taken from the mains. The majority of power is passed on to the load via the choke, thus the power is not converted twice as in the double conversion system. This means very low losses compared to the double conversion system.

$$V_L = j\omega L \times Isa \qquad (1)$$

$$Isa = \frac{V_L}{j\omega L} = \frac{(Via - V2a)}{j\omega L} \qquad (2)$$

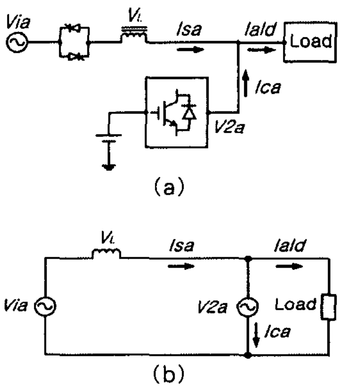

Fig. 1. The Line-Interactive UPS
(a) The configuration (b) The equivalent circuit

However, equation (2) shows that the source current is a directly influenced by the source voltage. This means for the low input power factor when the source voltage increases or decreases[3].

2.1 Topology of the Series-Parallel UPS

The line-interactive UPS with dual converter structure is shown in Fig. 2. Two PWM inverters, coupled with a common DC link, are used to perform the series and parallel active compensator functions. The series active compensator compensates for the difference between the source and the output voltage. Therefore, the unity power factor can be acquired. It also, compensates the imbalance and harmonics of the source voltage. The parallel active compensator is added to controls the output voltage, and both of the series and parallel active compensators can charge the DC link.

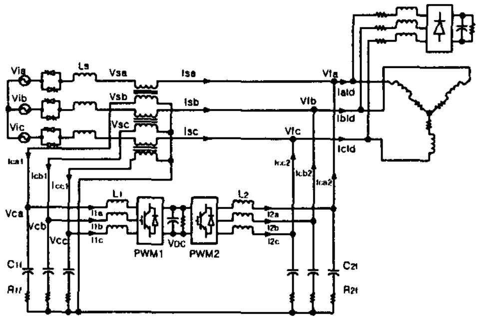

Fig. 2. Line - Interactive UPS with dual converter structure

3. The Proposed Method

Compared to the convention method, the proposed method can charge the link voltage simultaneously

3.1 Series Active Compensator Operation

The block diagrams for voltage compensation are shown in Fig. 3. The control algorithms are developed to provide the compensating reference voltages (V_{ca1}*, V_{cb1}*, V_{cc1}*) for the series active compensator. The control algorithms are performed in Synchronous Reference Frame (SRF). The three - phase source voltages (V_{sa}, V_{sb}, V_{sc}) are transformed into two phase stationary reference frame d_{qs}(V_{sds}, V_{sqs}), and then these quantities are transformed into a two phase synchronous rotating reference frame dqe (V_{sde}, V_{sqe}). These quantities are filtered by High Pass Filter (HPF) to detect the harmonics and imbalance of the source voltage. By compensating for the source harmonic voltage (V_{sde_h}, V_{sqe_h}) and difference voltage (V_{fde}*, V_{fqe}*) between the source voltage and the output voltage of the parallel active compensator (V_{fa}, V_{fb}, V_{fc}), the series active compensator can control the source current to be sinusoidal, balanced and input power factor to be unity under the deviation and distortion of the source voltage. In this case, the voltage reference in the d axes, V_{fde}* component is made zero.

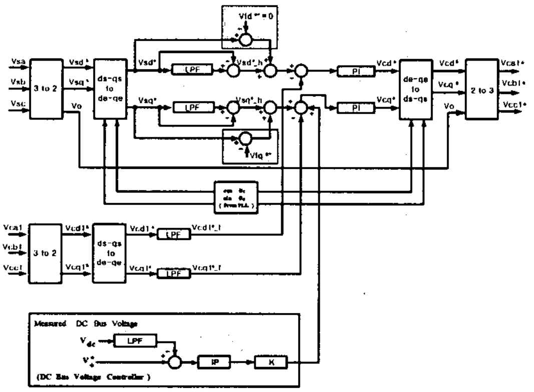

Fig. 3. Block diagram of the voltage control for the series active compensator

In this paper, a DC link voltage controller is added, as shown in Fig. 3. This is needed to regulate the DC link voltage, the DC link voltage is filtered by Low Pass Filter (LPF) with a cut off frequency of 150[Hz]. Gain k(Ω) is multiplied to the output of IP controller to make a voltage referenc, and this value is added to the reference of the active component[7].

3.2 Parallel Active Compensator Operation

The block diagrams for voltage compensation are shown in Fig. 4. The control algorithms are developed to provide the compensating reference voltages (V_{ca2}*, V_{cb2}*, V_{cc2}*) for the parallel active compensator. The three phase output voltages (V_{fa}, V_{fb}, V_{fc}) are transformed into two phase stationary reference frame dqs quantities (V_{fds}, V_{fqs}). Then, these quantities are transformed from two phase stationary reference frame dqs into two phase synchronous rotating dqe reference frame (V_{fde}, V_{fqe}). The voltage at the fundamental frequency ω is a DC value and all the harmonics are transformed into non-DC quantities. To acquire the fundamental values, they are filtered with a low pass filter. V_{fde_f} and V_{fqe_f} represent the fundamental reactive and active components of the output voltage in the dq axes, respectively.

To regulate the output voltage constantly, these values are compared with references (V_{fde}*, V_{fqe}*). The DC components of the SRF (V_{2de}, V2qe) are transformed into the stationary reference frame dqs and yield all fundamental compensating components (V_{ca2}*, V_{cb2}*, V_{cc2}*).

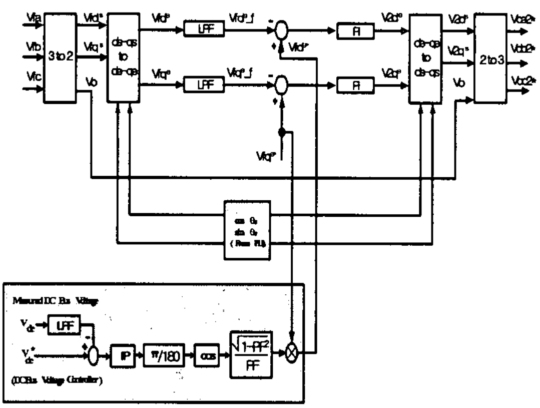

Fig. 4. Block diagram of the voltage control for the parallel active compensator

In addition, DC link voltage controller is added to the reactive voltage (V_{fde_f}) in the d axis, as shown in Fig. 4. The reference of the DC link voltage can be acquired by equation (3).

$$V_{fd}^{e*} = V_{fq}^{e*} \times \frac{\sqrt{1-pf^2}}{pf} \tag{3}$$

4. Simulation and Experimental Result

4.1 Simulation Results

The proposed algorithms were studied by simulation tools, ACSL (Advanced Continuous Simulation Language). System parameters are shown in Table 1.

Table 1. System parameters

Parameters	Value
Source Voltage (V_{ia}, V_{ib}, V_{ic})	220[V], 60[Hz]
Line Impedance (Ls)	25[μH]
DC link Capacitor	9600[μF]
DC link Voltage	400[V]
L_1	1.35[mH]
L_2	0.5[mH]
C_{1f}, R_{1f}	280[μF], 1[Ω]
C_{2f}, R_{2f}	180[μF], 1[Ω]

Fig. 5. shows series parallel active compensator when load variation at between 0.4 sec and 0.5sec in case of charging through only parallel compensator. There is no variation of the source voltage, and the series active compensator does not charge the DC link, so output of the series compensator is almost zero. Therefore, there exists the variation of DC link voltage.

Fig. 6. shows series parallel active compensator when the series compensator also charges the DC link at the same conditions. When the load variation happens, series compensator charges the DC link, so output of the series compensator exists to compensate for the voltage drop in DC link. Therefore, it can reduce the variation of DC link voltage compared to the Fig. 5.

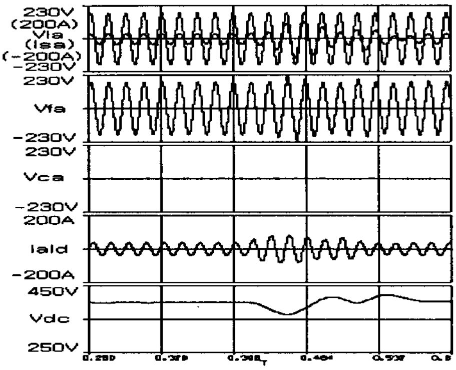

Fig. 5. Series parallel active compensator when load variation at between 0.4[sec] and 0.5[sec]
(In case of charging through only parallel compensator) (a) source voltage(source current) (b) output voltage (c) seriesl compensator voltage (d) load current (e) DC link

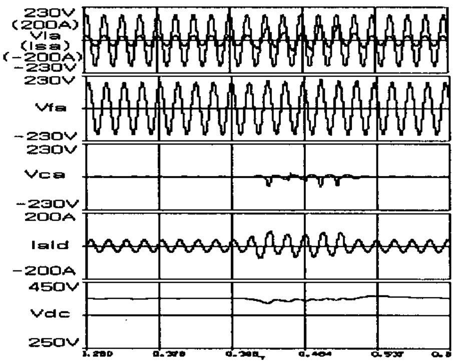

Fig. 6. Series Parallel active compensator when Load variation at between 0.4[sec] and 0.5[sec]
(In case of charging through series parallel compensator) (a) source voltage (source current) (b) output voltage (c) series compensator voltage (d) load current (e) DC link

Fig. 7. shows series parallel active compensator when the source voltage decreases 20[%] at 0.3[sec] and the load increases 100[%] at between 0.4[sec] and 0.5[sec], and only the parallel compensator charges the DC link. When the source voltage drops, the series compensator is activated because it compensates for the difference between the source and the output voltage, so

output voltage is controlled almost constantly, and unity power factor can be acquired, but there exists variation of DC link voltage.

When the load increases at between 0.4 sec and 0.5sec, the output of the series compensator is the same when the source voltage dropped, because it does not compensate for the DC voltage drop caused by load variation. Therefore, there exists the large variation of DC link voltage.

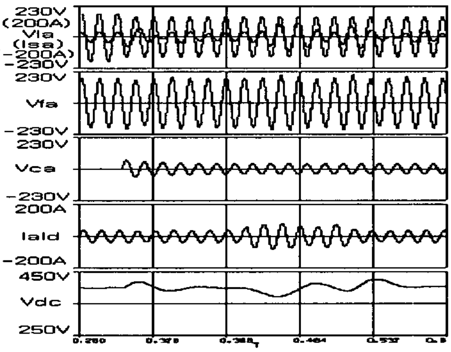

Fig. 7. Series Parallel active compensator when Load variation at between 0.4[sec] and 0.5[sec] in source voltage drop at 0.3[sec] (In case of charging through only parallel compensator) (a) source voltage(source current) (b) output voltage (c) series compensator voltage (d) load current (e) DC link

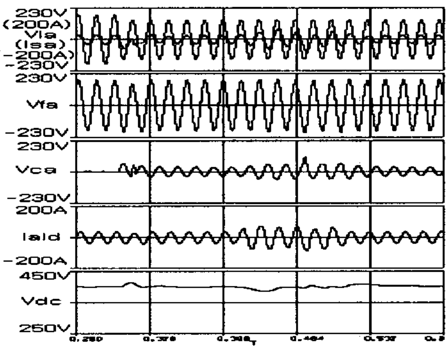

Fig. 8. Series Parallel active compensator when Load variation at between 0.4[sec] and 0.5[sec] in source voltage drop at 0.3[sec] (In case of charging through series-parallel compensator) (a) source voltage(source current) (b) output voltage (c) series compensator voltage (d) load current (e) DC link

Fig. 8. shows series parallel active compensator when the series compensator also charges the DC link at the same conditions. When the load variation happens, series compensator also charges the DC link. Therefore, it can reduce the variation of DC link voltage compared to the Fig. 7.

4.2 Experimental Results

Fig. 9. shows the configuration of the experimental system. Table 2. shows system parameters.

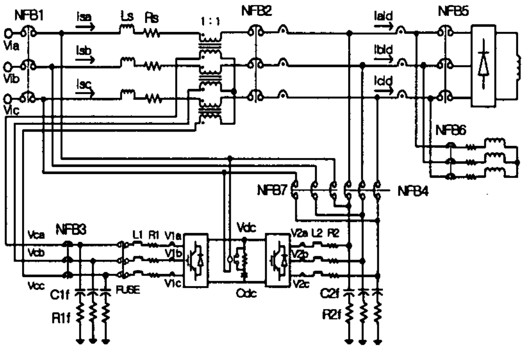

Fig. 9. Experiment system configuration

Table 2. Experiment system parameters

Parameters	Value
Source Voltage(V_{ia}, V_{ib}, V_{ic})	211[V], 60[Hz]
Line impedance (Ls)	0[μF]
DC link Capacitor(CDC)	9600[μF]
DC link Voltage(VDC)	370[V]
L_1, R_{1f}, C_{1f}	1.3[mH], 1[Ω], 250[μF]
L_2, R_{2f} ,C_{2f}	0.6[mH], 1[Ω], 126[μF]

Fig. 10, 11. show the series and parallel active compensator when DC charging from 310[V] to 370[V], respectively while R load was connected.(NFB6 ON) There are transient states when a voltage reference is changing, but we see that the series and parallel compensator can charge the DC link independently.

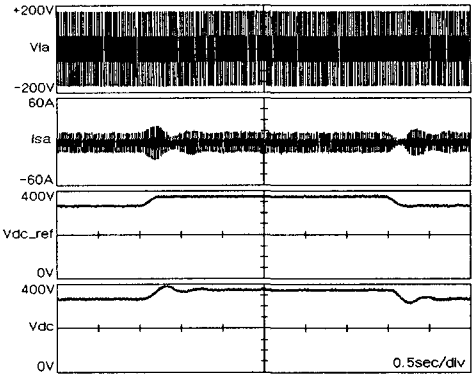

Fig. 10. Series active compensator when DC charging
(a) source voltage (b) source current (c) Vdc reference (d) Vdc

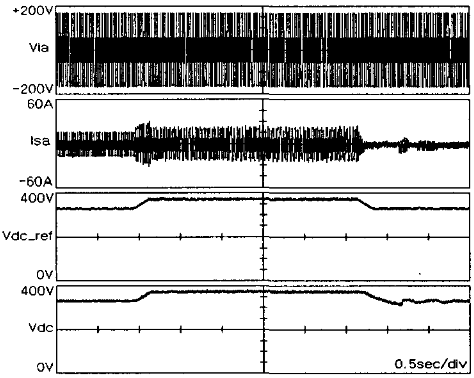

Fig. 11. Parallel active compensator when DC charging
(a) source voltage (b) source current (c) Vdc reference (d) Vdc

Therefore, it is possible to charge the DC link with separate charging circuits, so it is more effective than single charging circuit. Even though experiments of decreasing in input voltage did not perform because of racks of test equipment, but it can be confirmed through simulation results.

Fig. 12. shows series-parallel active compensator when the load increases from resistor load to resistor and rectifier load, and only the parallel compensator charges the DC link. When the load increases or decreases, the series compensator does not charge the DC link Therefore, there exists the large variation of DC link voltage.

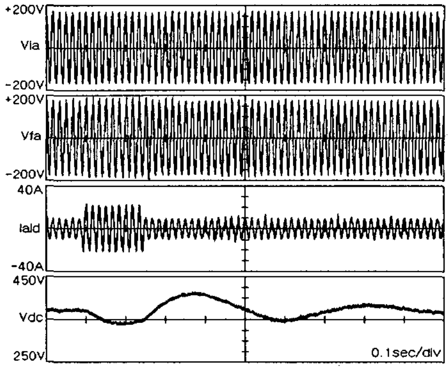

Fig. 12. Series Parallel active compensator when Load variation
(In case of charging through only parallel compensator) (a) source voltage (b) output voltage (c) load current (d) DC link

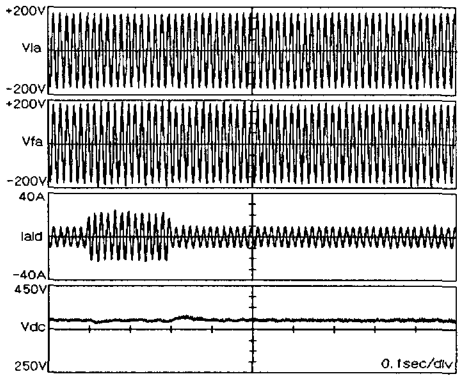

Fig. 13. Series Parallel active compensator when Load variation
(In case of charging through series parallel compensator) (a) source voltage (b) output voltage (c) load current (d) DC link voltage

Fig. 13. shows series parallel active compensator when the series compensator also charges the DC link at the same conditions.

When the load variation happens, series compensator charges the DC link as a concept of feed-forward. Therefore, it can reduce the variation of DC link voltage compared to the Fig. 12.

5. Conclusion

This paper presented a three phase

Line-Interactive uninterruptible power supply (UPS) system with dual converter structure. The series active compensator compensated for the difference between the source and the output voltage, and works as a voltage source in phase with the source voltage to have the sinusoidal source current.

The parallel active compensator works as a conventional sinusoidal voltage source in phase with the source voltage providing to the load a regulated and sinusoidal voltage with low total harmonic distortion .

This paper presents in the series and parallel active compensator battery charging method depending on the amplitude of the source voltage. The conventional Line-Interactive UPS system is responsible for the DC charging, and output voltage regulation at the same time, but UPS system with dual converter structure, a series and active compensator can also charge the DC link, and by making the DC link voltage stable, it can contribute the stability of series and parallel compensator. Therefore, it could have a rapid response characteristic under the variation of the load and source voltage, and the variation of DC link could be reduced.

Acknowledgements

This work was supported by a research grant from Hankyong National University in the year of 2003.

References

[1] W. J. Ho, et al, "A Line interactive UPS Structure with Built in Vector Controlled Charger and PFC", in Power Electronics and Drive Systems, vol. 1, pp. 127-132, 1997.

[2] Kamran, F. and Habetler, T., "A Novel On-Line UPS with Universal Filtering Capabilities." IEEE/PESC, pp. 500-506, 1995.

[3] Soren Rathmann, Henry A. Warner, "New generation ups technology, The delta conversion principle." IAS 96, Conference Record of the 1996 IEEE, vol.4, pp.2389-2395, 1996.

[4] Dougls C. Folts, "The response of Advanced Single Conversion UPS to Power Disturbances." Seventh International Power Quality Conference, October 1993 Proceedings. pp. 93-105.

[5] Sergio augusto Oliveira da Silva, Pedro F. Donoso Garcia, "A comparative analysis of control algorithms for three phase line interactive ups systems with series parallel active power line conditioning using SRF method." PESC00. IEEE vol.2, pp.1023-1028, 2000.

[6] Silva, S.A.O., Donoso-Garcia, p.; Cortizo, P.C.; "A Three-Phase Series-Parallel Compensated Line-Interactive UPS System with Sinusoidal Input Current and Sinusoidal Output Voltage." IAS, Conference Record of the 1999 IEEE, vol.4, pp.826-832, 1999.

[7] Taeck Kie Lee; Woo Cheol Lee; Hoon Jang; Dong Seok Hyun, "A Study on the Line Interactive UPS using the Series Voltage Compensator" IEEE, IECON Conference Proceedings, 2002. vol. 1, pp. 733-738, 2002.

[8] Oliveria da Silva, S.A.; Donoso Garcia, p.; Cortizo, D.C.; "A Three Phase Line Interactive UPS System Implementation with Series Parallel Active Power Line Conditioning Capablilites." IAS, Conference Record of the 2001 IEEE, vol.4, pp.2389-2396, 2000.

[9] Seong Jeub Jeon; Gyu Hyeong Cho, "A series parallel compensated uninterruptible power supply with sinusoidal input current and sinusoidal output voltage" PESC '97 Record, IEEE vol.1, pp.297-303, 1997.

◇ 저자소개 ◇

이우철 (李雨哲)

1964년 3월 24일생. 1987년 한양대학교 전기공학과 졸업. 1989년 한양대학교 대학원 전기공학과 졸업. 1988~1998년 효성중공업 기술연구소 책임연구원. 1995~2001년 한양대학교 대학원 전기공학과 졸업(박사). 2002년~현재 한경대학교 전기공학과 조교수.

유동상 (劉同相)

1963년 11월 25일생. 1985년 서울대학교 전기공학과 졸업. 1987년 한국과학기술원 전기 및 전자공학과 졸업(석사). 1992년 한국과학기술원 전기 및 전자공학과 졸업(박사). 1992~2000년 LG전자 생산기술원 자동화기술센터 책임연구원. 2000년~현재 한경대학교 전기공학과 부교수.