Single Phase PWM Converters with Active Filter Functions Both on AC-Input and DC-Output Sides

Mikihiko MATSUI and Tatsuya KITANO
Dept. of Electronic Eng. Tokyo Institute of Polytechnics
1583 Iiyama Atsugi-shi Kanagawa, 243-0297 Japan
Phone/Fax: +81-462-42-9563

ABSTRACT- A comparative study of single-phase PWM converters having active filtering functions both on ac-input and dc-output sides have been carried out. Based on the function of the dc-output side active filter, two types of configurations, the RPM (ripple power managing) type and the APM (average power managing) type are compared to show their contrastive characteristics. The prototype system using DSP based control algorithms, i.e. deadbeet current control and voltage sensor-less technique using full-order observer, show the availability of the proposed systems.

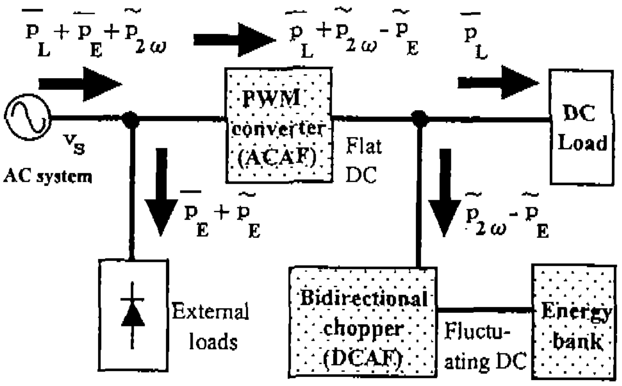
1.INTRODUCTION

The effect of the low order harmonic current generated by the residential or office use static power converters on the power transmission system is becoming a serious problem. Especially, so-called capacitor input type diode rectifiers draw highly distorted current from the ac system line. Switching mode rectifiers (SMRs) using single switching device to improve the input current wave shape is one of the solutions. Though it is suited for small size unidirectional power conversion, it cannot manage bidirectional power flow and not suited for active filtering on ac system line side to cancel the harmonics generated by other converters.

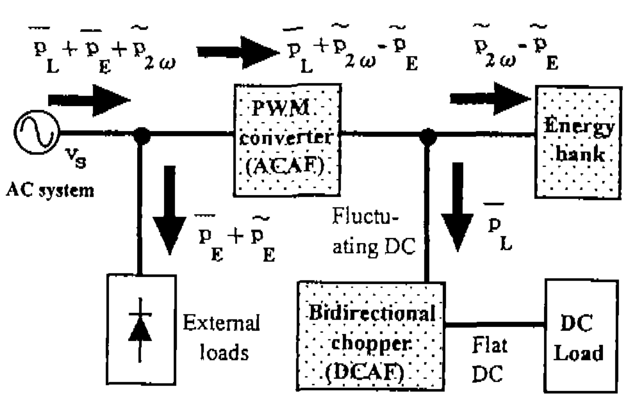
The single-phase PWM converter gives an effective solution in stead, but there remains a problem that its dc-output voltage contains fairly large twice-omega ripple component unless very large size of capacitor is adopted. Especially in the case of connecting a battery to its dc bus for energy storage purpose, it is reported that even a small voltage ripple leads to a large current ripple which heats and damages the battery. Several methods have already been proposed to reduce the dc-output voltage ripple without using a large capacitor, e.g. using a series L-C resonant circuit [1] or a DC active filter [2][3]. However, there remains a problem of simplifying the circuit configuration and the estimation of the resulted characteristics.

This paper carries out a comparative study of single-phase PWM converter circuits having active filtering functions both on ac-input and dc-output sides [4]-[7]. The main circuit configuration should be basically the combination of a PWM bridge converter stage operating as an ac active filter (abbreviated as ACAF in the following) and a step-up/down chopper stage operating as a dc active filter (abbreviated as DCAF in the following). From the view point of the function of DCAF stage, two types of control strategies "RPM-type (ripple power managing type)" and "APM-type (average power managing type)" can be considered, whose conceptual block diagrams are shown in Fig.1. For the control of RPM-type, a new control scheme to improve the DCAF stage's characteristics is proposed by considering the stored energy in the filter inductances into account. It is also shown that the APM-type is advantageous both in the characteristics and ease of implementation than RPM-type with the expense of increased conversion stages.

The prototype system using a DSP based digital control



(a) RPM-type (ripple power managing type).



(b) APM-type (average power managing type).

Fig.1 Conceptual block diagrams of two types of single phase PWM converters having active filtering functions both on ac-input and dc-output sides.

algorithms, i.e. deadbeet (or minimum time settling) current control and full-order observer, realizes a robust and ac voltage sensor-less system. The operating characteristics of RPM-type and APM-type are clarified by both simulation and experiment, which show the availability of the proposed systems.

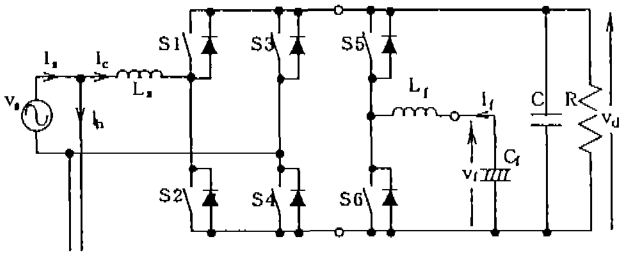
2.CIRCUITS AND CONTROL

Main Circuit Topologies

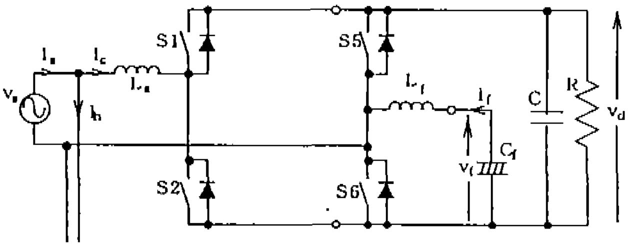
The main circuit topologies for RPM-type and APM-type converters are shown in Fig.2 and Fig.3, respectively. To reduce the number of the power devices, the combined types in which the ACAF stage and DCAF stage are combined to omit one leg is also available. However, only the separated types are studied in the following to show the basic contrastive characteristics between RPM and APM types.

Control Schemes

In the case of RPM-types, the ripple power component is dealt in the DCAF stage. Therefore, the problem is how faithfully is the unnecessary power ripple appearing on dc side cancelled. Fig.4 shows the proposed control block diagram for RPM-types. It has an unique feature of magnetic energy

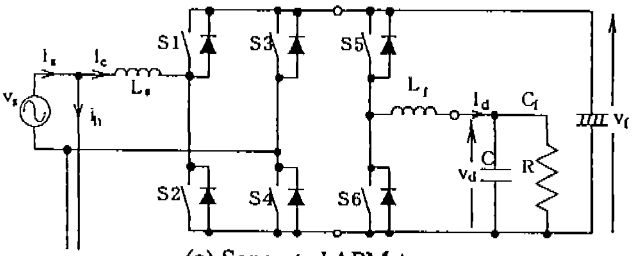


(a) Separated RPM-type.

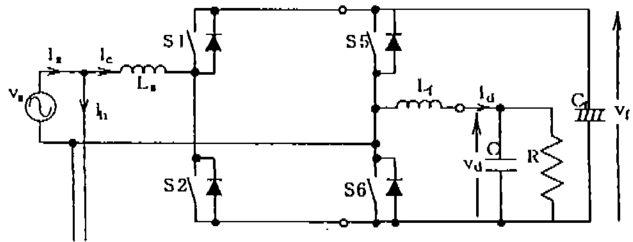


(b) Combined RPM-type.

Fig.2 Circuit topologies of RPM-type converters.



(a) Separated APM-type.



(b) Combined APM-type.

Fig.3 Circuit topologies of APM-type converters.

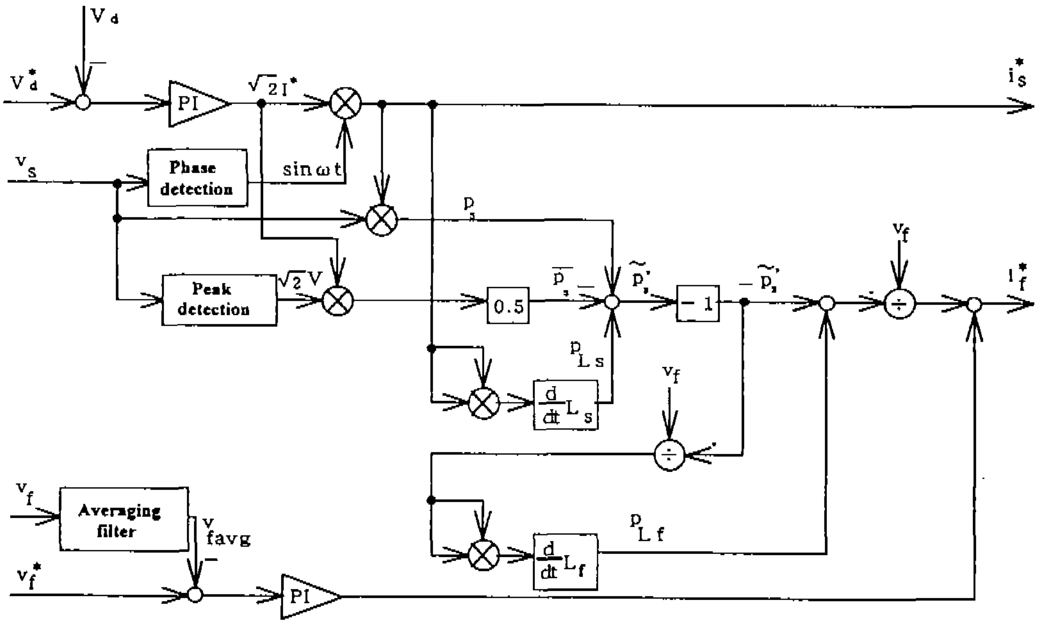


Fig.4 Control block diagram for RPM-types.

compensation of both filter inductances L_s and L_r The effect of this compensation is clearly shown in the following chapter.

In the case of APM-types, on the other hand, the DCAF stage deals with the average power required by the dc load. In other word, the capacitor as an energy bank acts as a dc link between ACAF and DCAF stages. It's control block diagram is shown in Fig.5. In comparison with the former RPM-types, the APM-types have merits of easy control and better characteristics of DCAF stage as shown later.

The current references i_s^* and i_f^* obtained by Fig.4 and Fig.5 are directly utilized in the ACAF and DCAF stages if the hysteresis current control scheme is used. However, if the triangular carrier wave and deadbeat control scheme are applied to get the PWM pulse patterns, the ac system line voltage can be estimated by applying the observer theory. For example, Fig.6(a) shows a block diagram to generate the PWM pulse patterns for separated RPM-type. "S" is the probability switching function of the ACAF stage that presents the normalized input terminal voltage. By using this "S", the appearing voltage at ac-input side v_r is given as $(2S-1)v_d$. Therefore, the ac system voltage can be estimated by using the full-order observer given in Fig.6(b), where carrier frequency is 20kHz and the sampling time is selected to be 50 μs which is fast enough for ac line voltage estimation. Thus the ac voltage sensor-less control is achieved in this system. Fig.7 shows two cases of examples of operating wave forms of the observer. The ac line voltage and current are estimated irrespective of the operating conditions.

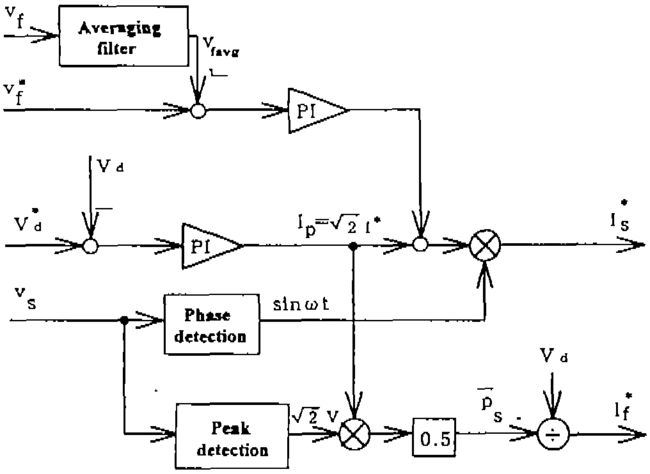
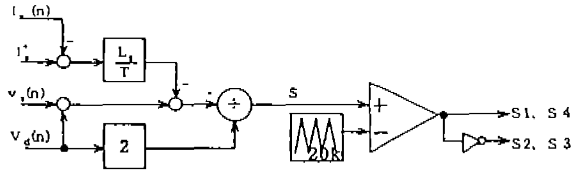
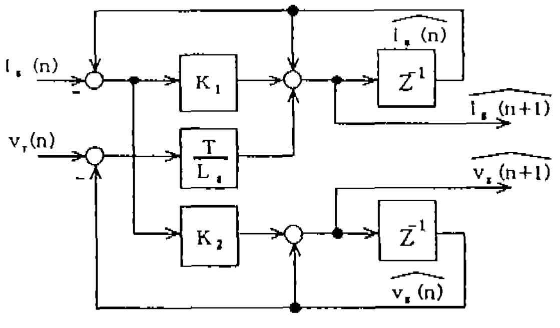


Fig.5 Control block diagram for APM-types.



(a) Dead-beat current control for separated RPM-type.



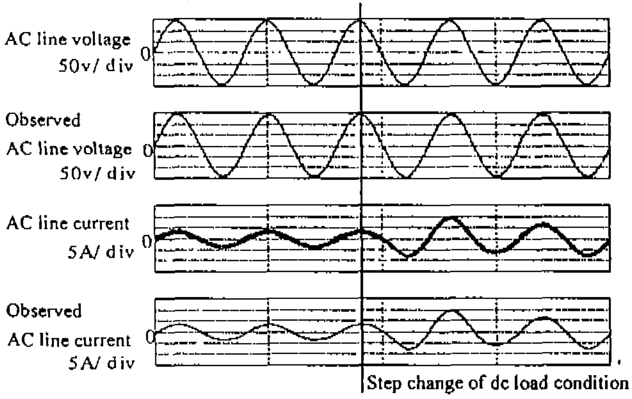
(b) Full-order observer to estimate ac system voltage.

Fig.6 Control block diagram of dead-beat current control and ac system voltage estimation.

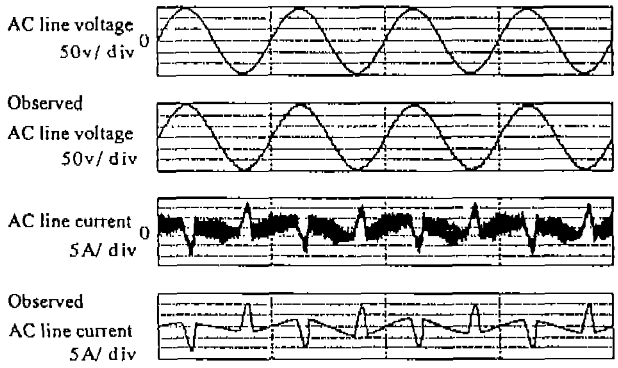
3.EXPERIMENTAL RESULTS

Ac-input side characteristics

The typical operating wave forms of the separated RPM-type converter are shown in Fig.8. In this example, a capacitor input type diode rectifier is connected in parallel with the converter as an external harmonic source, and whose harmonic current is compensated by the ACAF stage of the converter. The simulation results and the experimental ones agree

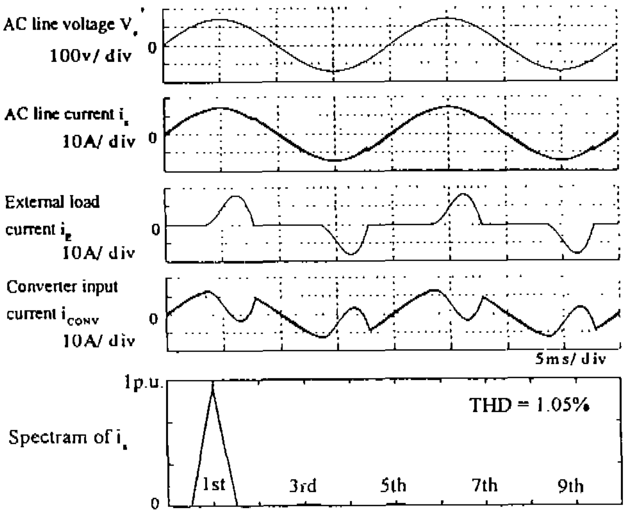


(a) In the case of sinusoidal ac-input current.

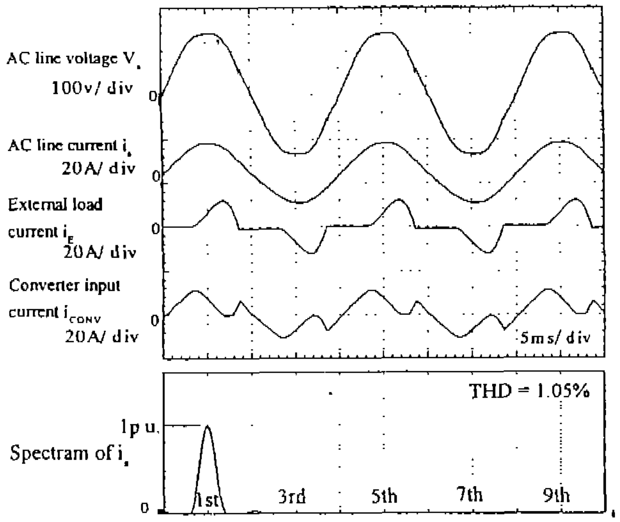


(b) In the case of harmonic ac-input current to compensate the harmonics generated by a diode rectifier on ac side.

Fig.7 Experimental results of observer for ac system voltage sensor-less current control.



(a) Simulation result.



(b) Experimental result.

Fig.8 Operating wave forms of the separated RPM-type converter, where the input harmonic current of diode rectifier ($\bar{p}_E$=500W) is compensated by the separated RPM-type converter with dc loading condition itself ($\bar{p}_L$=500W).

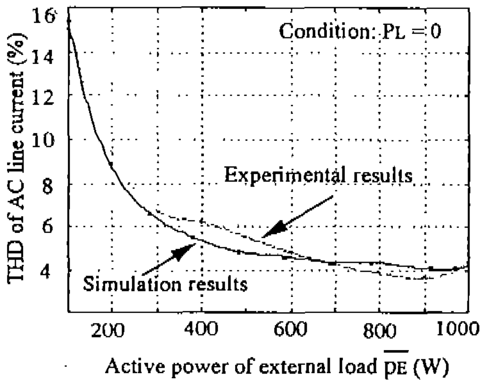


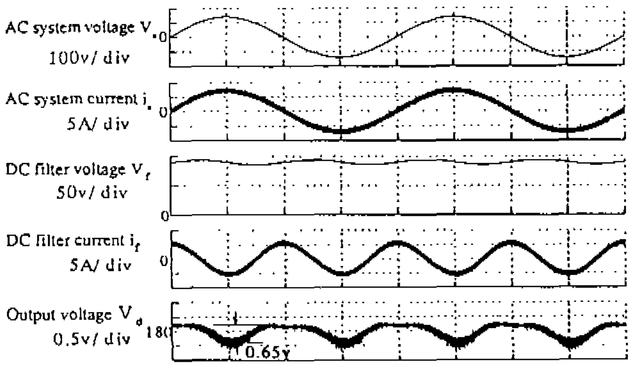
Fig.9 THD of ac line current, where the input harmonic current of diode rectifier is compensated by the separated RPM-type converter with no load condition on dc side.

very well. As for the THD of the ac line current, the worst condition is given under no-load condition (p_L=0) on the dc-output side. Fig.9 shows the relationship between active power of external diode bridge $\bar{p}_E$ and the THD of ac line current under such condition. As $\bar{p}_E$ increases, THD converges to a constant value.

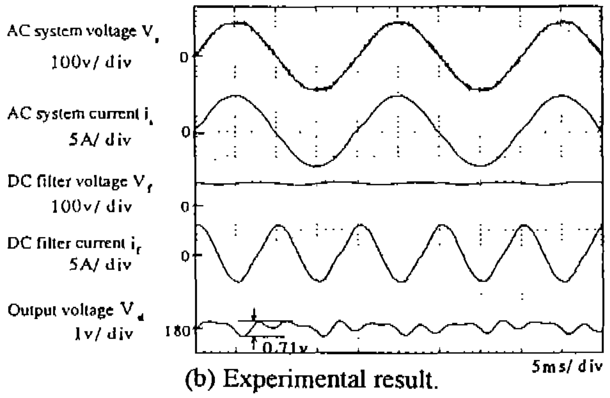
Dc-output side characteristics

As for the DCAF's current control, the effect of considering the magnetic energy of filter inductances L_s and L_f into account is clearly shown by comparing Fig.10 and Fig.11. Without compensation, twice-omega dc-output voltage ripple component still remains. However, once the proposed scheme is applied, the dc-output ripple drastically decreases. A quantitative comparison is given in Fig.12. Although the experimental results are always larger than simulation results, the tendency that the magnetic energy compensation reduces the dc-output voltage ripple to be about one-half is observed. This means that the dc side filter capacitance can be reduced to achieve the same dc-output voltage ripple.

Fig.13 shows typical operating wave forms of separated APM-type, and the dc-output voltage ripple characteristics curves are given in Fig.14. Again, the experimental results are always larger than simulated ones. It is considered be-

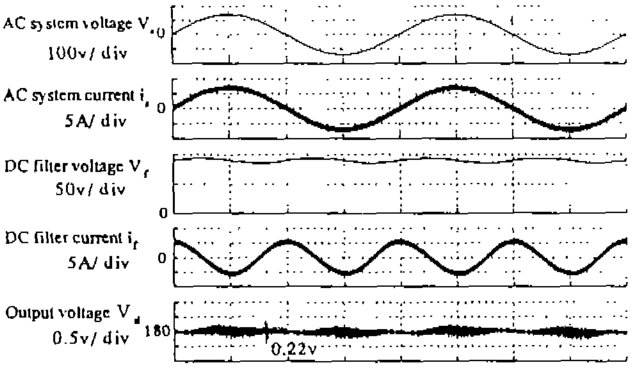


(a) Simulation result.

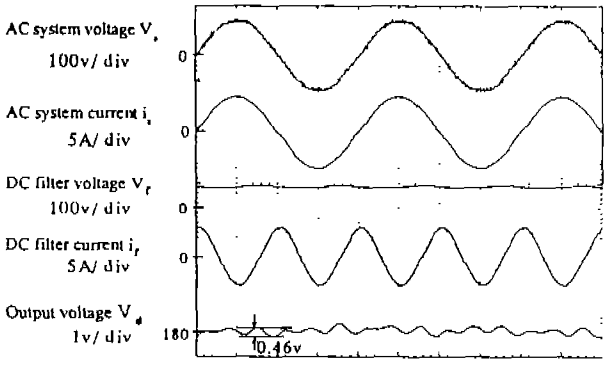


(b) Experimental result.

Fig.10 Operating wave forms of separated RPM-type without compensating the magnetic energy stored in the reactors Ls and Lf.



(a) Simulation result.



(b) Experimental result.

Fig. 11 Effect of magnetic energy compensation of Ls and Lf on the operating wave forms of separated RPM-type.

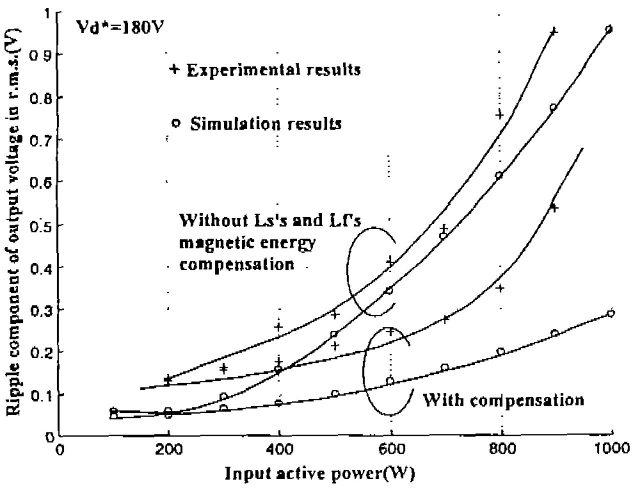
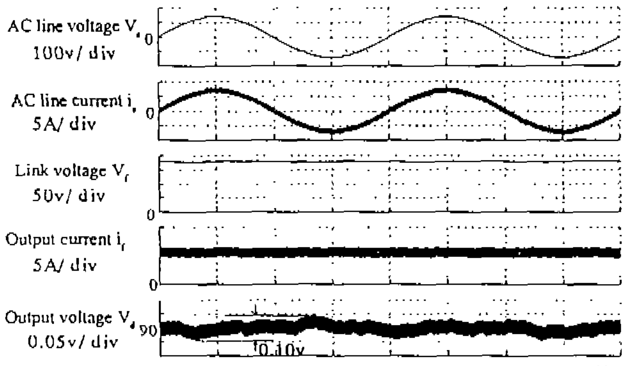
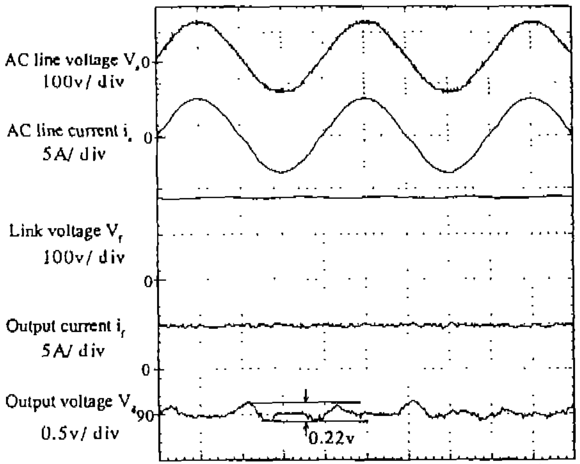


Fig. 12 Relationship curves between ac-input active power and dc-output ripple voltage in separated RPM-type, which shows the effectiveness of magnetic energy compensation of Ls and Lf.



(a) Simulation result.



(b) Experimental result.

Fig. 13 Operating wave forms of separated APM-type.

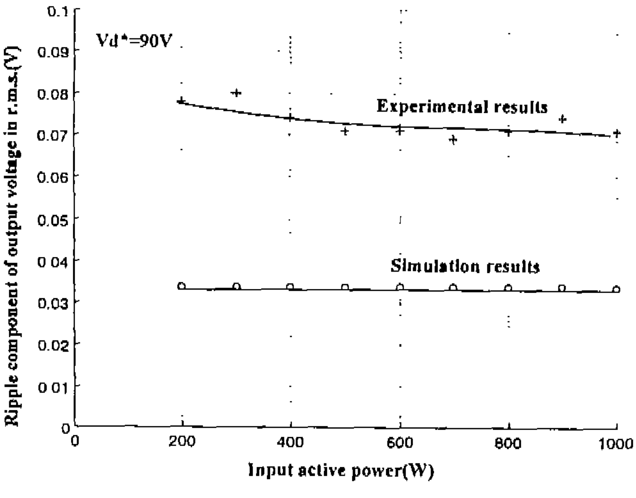
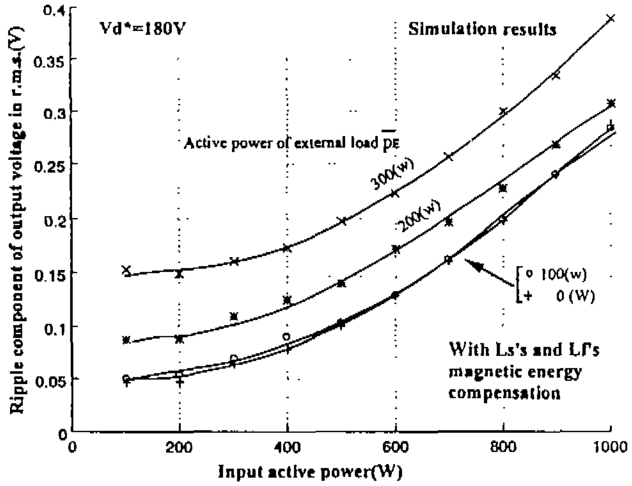
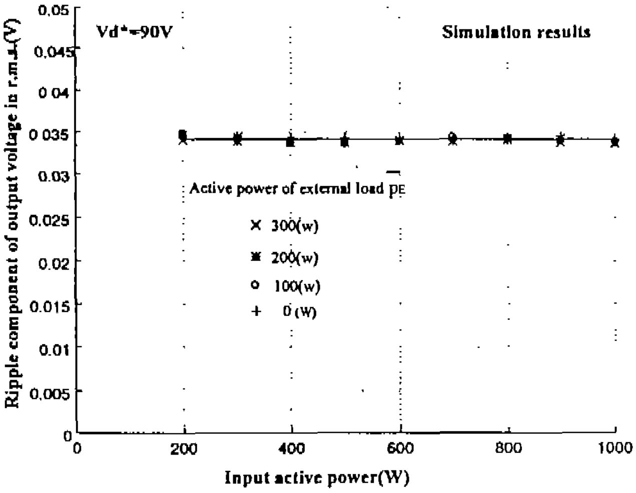


Fig. 14 Relationship curves between ac-input active power and dc-output ripple voltage in separated APM-type.

cause of nontheoretical factors, such as the operational accuracy of DSP, offset errors of sensors, unbalance or time delay of the switching operations of power devices. But it can be seen that the dc-output voltage ripple is almost independent to the operating power level. Fig.15 shows the contrastive dc-output voltage ripple characteristics of RPM and APM types when the active power of the external diode bridge p_E is changed. As p_E increases, the harmonic current disturbance on dc-output side also increases. Since the harmonic current cancellation of RPM-type is approximate and incomplete, the uncompensated voltage ripple also increases. On the other hand, the voltage ripple of APM-type is almost unrelated to the operating conditions, which gives excellent dc active filtering results.



(a) Separated RPM-type.



(b) Separated APM-type.

Fig.15 Comparison of relationship curves between ac-input active power and dc-output ripple voltage in two types.

4.CONCLUSIONS

The main results of the study carried out in this paper are summarized as follows;

1) The dc-output voltage ripple of RPM-type can be reduced by compensating the magnetic energy stored in the filter inductances L_f and L_r

2) As for the dc-output voltage ripple, the APM-type realizes better characteristics than that of RPM-type even with the proposed magnetic energy compensation technique. It is almost robust to the operating conditions of ACAF stage. The only drawback is the increase of the power conversion stages. It is especially suited for the applications connecting batteries on dc side for energy storage purpose.

3) Ac system voltage sensor-less system can be realized by using deadbeat control scheme and full-order observer theory.

4) By locating the proposed converter at upper stream of the power flow, all the harmonics generated by the nonlinear loads at lower stream can be compensated all together.

5) To reduce the numbers of the power devices used, the combined type is also available, however, the amplitude of dc-output voltage should be twice as high as that of separated types.

ACKNOWLEDGMENT

The authors would like to thank the Joint Research Center for High-Technology (JRCH) of Tokyo Institute of Polytechnics for its continuous support on this project.

REFERENCES

[1] Toyama et al. "A reducing method of dc voltage ripple for a single phase PWM converter",IEEJ-1993-Annual Meeting, No.66, P.273 (1993)

[2] Irie et al. IEEJ Transaction, "Ripple compensation of a single phase rectifier using a two-quadrant chopper and a supplemental capacitor", Vol.112-D, No.7, P.623 (1992)

[3] Shimizu et al., "Dc ripple compensation type single phase PWM converter",IEEJ Transaction, Vol.114-D, No.12, P.1298 (1994)

[4] Kitano and Matsui, "Single phase PWM converter with active filter function on both input and output sides", IEEJ-1995-Annual Meeting, No.725,P.4-77 (1995)

[5] Kitano and Matsui, "Single phase PWM converter with active filter function on both input and output sides (Part II)", IEEJ-JASC'95, No.60, P.175 (1995)

[6] Kitano and Matsui, "Reduction of filter capacitance for a single phase PWM converter with dc active filter function", IEEJ-1996-Annual Meeting, No.715, P.4-10 (1996)

[7] Kitano and Matsui, "A single phase PWM converter combined with a dc active filter", IEEEJ-JASC'96, No.70, P.199 (1996)