THE STUDY OF P.F.C APPLICATION FOR AN AIR-CONDITIONER

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ABSTRACT - In this paper, the power factor correction (PFC) system for inverter air-conditioner that has not only good harmonic characteristics but also cost down-merit compared with the conventional inverter type is proposed. The detail design procedures to get cost-down merits are introduced. And it is shown that the PFC system performances also can be improved by the virtue of the stabilization of output voltage. The proto type system is implemented and tested to verify the additional good performances of the proposed system, and its simulation and experimental results are presented.

1. INTRODUCTION

In electrical home appliances, as the concerns of energy saving and high efficiency have increased, to reduce operating loss a lots of inverter technologies have been developed and adopted in many products such as air conditioner. In spite of energy saving merit of the inverter systems, there is somewhat critical problem, that is, these generate many harmonic distortions because of the nonlinearity of rectifying and smoothing part including large capacitor. These harmonic distortions also caused new problems such as the deterioration of transmission capability and peak current stress in power supplying system due to its low power factor. So, not only Europe but also international committee made IEC regulations to limit the harmonic currents and the trend of the adopting the regulation in theirs territories have tempered. The E.U. including major 15-countries in Europe already adopted it as a mandatory article for CE mark acquisition in 1996.

It was well known that the radical way to avoid such harmonic problem is to adopt the active power factor correction (PFC) technology, however when it makes high frequency PFC operation for power factor correction, added switch usually generates added switching losses and caused new problems of cost-up. [1-3]

Despite of these critical problems, because we could focus that the boost up operation of PFC which is able to decrease the current of drive and to stabilize the DC output voltage, so by the virtue of not only harmonic improvement but also cost down merit of derating and performance improvement, we could find a clue that a boost type PFC can be applied in home appliances with enthusiasm.

In this paper, by adopting the PFC technology especially in inverter air-conditioner system, the fact that system performance including the operating efficiency becomes better specially regardless of input voltage or load variation would be verified as the regulation of the applied voltage into the motor can be improved. And surprisingly, in the point of view of cost, because of the derating merit of boost operation by the PFC, the method that total cost can be cheaper than the case of conventional inverter that do not adopt PFC would be presented.

2. DESIGN GUIDELINES FOR AIR-CONDITIONER

First of all, in order to set the design guideline for adopting PFC circuit in practical power range of home appliances, it is required to analyze the power capability of a specific air-conditioner product model. So a representative inverter model which produced by LG recently was arbitrarily choose to investigate necessary power range of PFC. The topology of this 11KBTU class conventional model which adopts passive filter unit is depicted in Fig.1. It operates in the frequency range between 35Hz and 90Hz, and the condition of input voltage variation is 220V$\pm$15%.

1) MAX INPUT POWER

At the maximum operating frequency 90Hz, the rated power of motor is 1,680W then input power is 1,920W. If it is used at +15% over voltage, its input power reaches at 2,208W. As that equals to the output of inverter and we can assume that the efficiency of inverter is about 95%, at

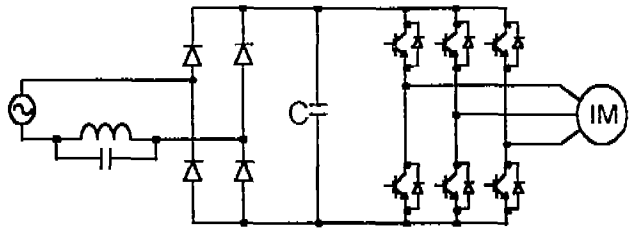


Fig.1 Inverter Air-Conditioner with Passive Filter

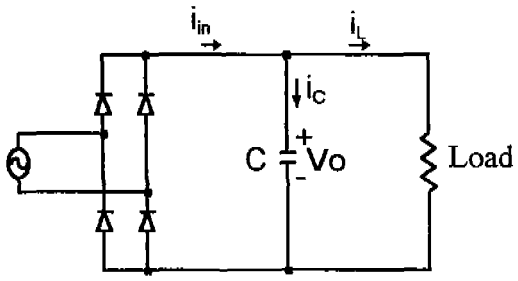


Fig.2 The Analysis Model of Inverter Air-Conditioner with Passive Filter

the overvoltage condition, the input power of inverter reaches at 2,324W. As a result of calculation for required power rating, the maximum power capability of the PFC should be considered over 2,400W in order to apply PFC into selected model.

2) INPUT VOLTAGE CONSIDERATION

In the selection process of switch device, the maximum current can be attained at minimum input voltage condition 187V, so it is considered as a standard analysis of power capacity.

3) LOAD ASSUMPTION

If the output power and output voltage can be set as a constant condition, the motor load of the inverter air-conditioner system can be modeled as a resistor as Fig. 2.

4) THE CONVENTIONAL INVERTER

By using above assumptions, we can analyze each current of Fig.2 as following equations.

- Load Current : $I_L = \frac{P_O}{V_O} = 9.1\,[A_{rms}]$ (1)
- Input Current : $I_{IN} = \frac{P_O}{\eta_{BD} \cdot PF \cdot V_{IN}} = 14.6\,[A_{rms}]$ (2)
- Capacitor Current : $I_C = \sqrt{I_{IN}^2 - I_L^2} = 11.4\,[A_{rms}]$ (3)

As can be seen in above result of analysis, the conventional system which adopts 25A rated rectifying diodes, 2,000μF/400V as smoothing capacitor and 12A/600V rated switches satisfied all the rated values.

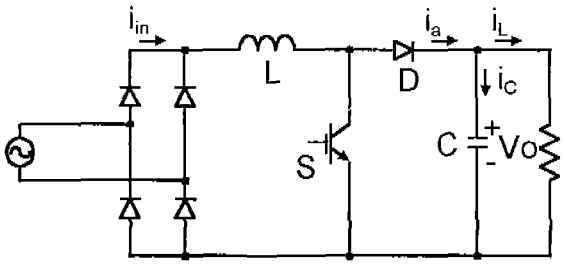


Fig. 3 Inverter Air-Conditioner with Power Factor Correction Circuit

3. DESIGN CONSIDERATION OF PFC FOR AIR-CONDITIONER

The inverter air-conditioner system which adopted PFC circuit can be shown as Fig. 3 In the PFC system which was introduced as an example, boost topology was adopted in order to make use of merit of derating devices. the average current control and fixed frequency control strategy was used not only to get good performance but also to get low EMI stress. Input voltage should be considered as the same condition of aforementioned inverter and the output DC voltage was designed to 380V.

1) THE SELECTION OF INDUCTOR

The maximum current of inductor I_{pk} is same as following equation, where ripple current ΔI was decided below 30% of original current.

$$I_{pk} = \frac{2 \cdot P_{IN}}{V_{IN,\min}} + \frac{\Delta I}{2} \quad (4)$$

In the mean time, at the minimum peak voltage duty D can be noted as following equation.

$$D = \frac{V_O - V_{IN,\min}(peak)}{V_O} \quad (5)$$

As the inductance L can be calculated as following equation at the switching frequency f_S, inductance value 530 μH/30A can be attained.

$$L = \frac{V_{IN,\min} \cdot D}{f_s \cdot \Delta I} \quad (6)$$

2) OUTPUT CAPACTOR CALCULATION

In the selection process of output capacitor, the ripple current value should be considered as the most important element. In order to analyze the ripple current of DC capacitor, the same calculation method can be used as the previous.

- Load Current : $I_L = \frac{P_O}{V_O} = 6.3\,[A_{rms}]$ (7)
- Input Current : $I_{IN} = \frac{P_O}{\eta_{BD} \cdot PF \cdot V_{IN}} = 13.2\,[A_{rms}]$ (8)

$$I_a = I_{IN} \cdot \sqrt{1 - D_{ave}} = 9.62\,[A_{rms}] \quad (9)$$

- Capacitor Current : $I_C = \sqrt{I_a^2 - I_L^2} = 7.27\,[A_{rms}]$ (10)

In the case, D_{ave} is 0.4686 as the average duty factor. The capacitance C depends on allowable ripple current I_C and ripple voltage ΔV as following equation. Where, as allowable ripple voltage was selected 10% and ω is two times of line frequency, C was decided as 680μF/450V.

Table 1. The analysis results of inverter currents

Type	Input Current (I_{in})	Capacitor Current (I_C)	Load Current (I_L)
Conven -tional	14.6A	11.4A	9.1A
PFC	13.2A	6.76A	6.3A

- Capacitance : $C = \frac{I_C}{\omega \cdot \Delta V}$ (11)

By these results of analysis, the current values of each part were noted as Table 1. We can know much smaller capacitance is needed than that of conventional case by adopting PFC circuit, and also know the load current (I_L) can be decreased.

After all, if motor coil can be redesigned appropriately according to output voltage's increasing portion in order to get stable torque characteristics, we can say the cost-down of inverter air-conditioner system is possible without deterioration of basic performance, by adopting the PFC's boost operation and the current derating of switching devices of inverter. Table 2 is showing that the possibility of cost-down can be verified.

4. THE EXPERIMENTAL RESULTS

As previously analyzed results of table 2, by using newly selected devices of derating values, inverter air-conditioner system adopting PFC circuit was implemented and tested in order to verify the cost -down merit of PFC. Fig.4 is showing the appearance of newly implemented system. Fig.5 and Fig.6 are each operation waveforms according to adopting PFC or not. Each test is executed as considering the fluctuation of input line voltage at peak demand of summer. The experimental result is showing that power factor is almost 1($\geq$ 0.99) and T.H.D(total harmonic distortion) is below 10% over the all operation range as can be seen at Fig.7 and Fig.8. And excellent characteristic of 3rd harmonic current can

Fig.4 The appearance of newly implemented system with PFC circuit (circle: PFC unit)

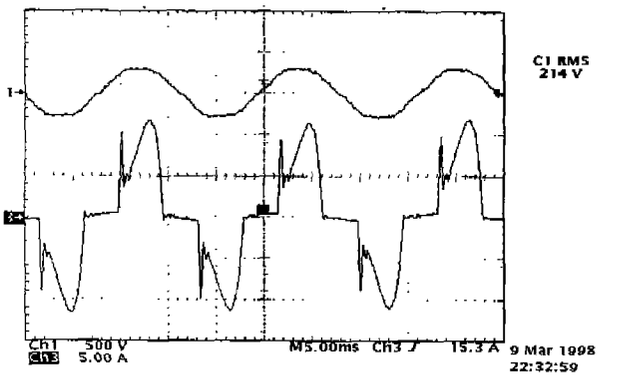


Fig.5 The input current waveform of a conventional inverter system

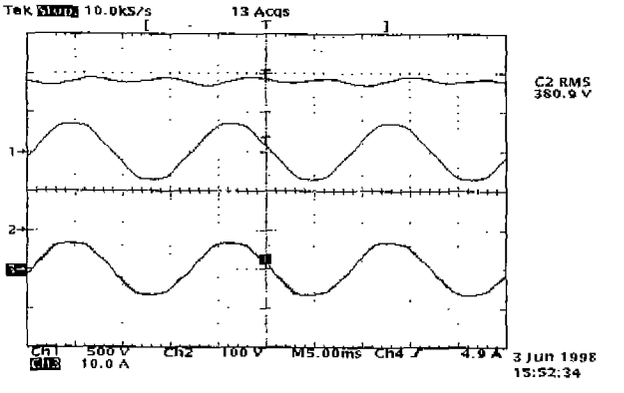


Fig.6 The input current waveform of new inverter system with PFC

be acquired below IEC regulation as can be seen at Fig. 9.

Especially in the point of performance, by the virtue of regulated voltage and low ripple DC-link voltage characteristic of PFC, the stable operation and improved performance can be verified. Fig.10 shows the efficiency comparison result according to adopting PFC or not, the improved system which adopted PFC shows stable efficiency characteristics regardless input voltage variation. On the other hand in the efficiency characteristic of conventional system it shows maximum 3% efficiency variation according to input voltage variation.

Table 2. The derating of device by boost PFC

Type	Rectifying Diode	Capacitor	Inverter Switch
Conven -tional	25A/ 600V	2000 μ F / 400V	12A / 600V
PFC	15A/ 600V	680 μ F / 450V	7A / 600V

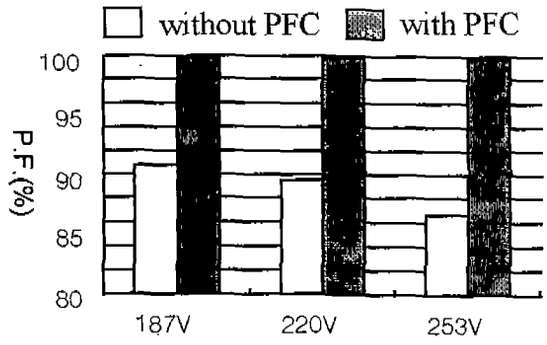


Fig.7 The power factor comparison

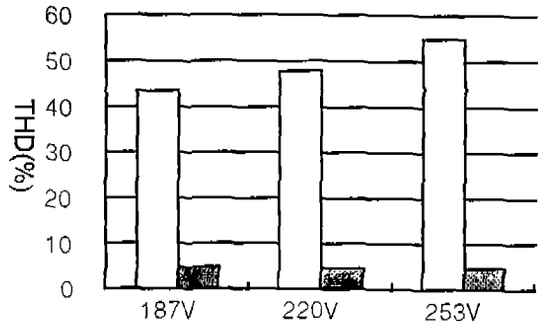


Fig.8 The total harmonics comparison

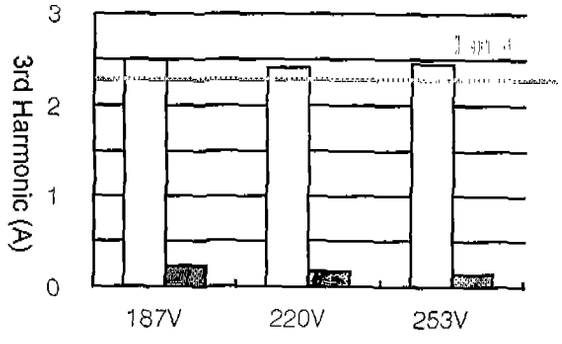


Fig.9 The 3rd harmonic comparison

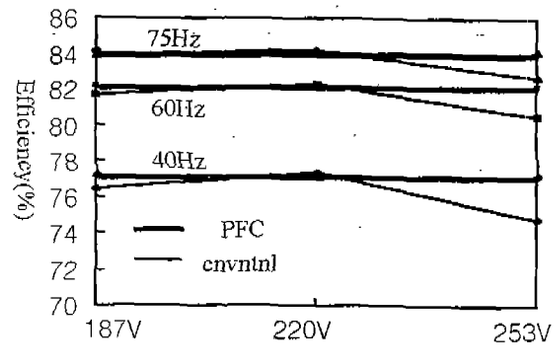
Consequently the fact that improved PFC system can get better performance in practical operating conditions could be verified.

5. CONCLUSION

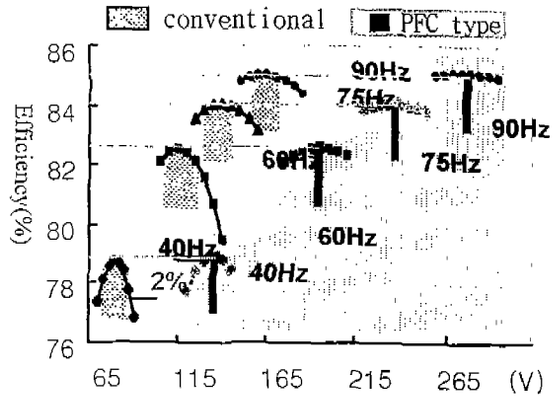
In this paper, by adopting boost type PFC circuit, the fact not only that improved system has better performance which satisfied IEC harmonic regulation but also that its cost can become cheaper than that of conventional system was verified.

In order to show how to down the cost, first the design procedure of selecting optimum devices for PFC and the way of derating devices of inverter, second by implementation of improved system and tests the effects which were previously said were successfully proved.

So, this paper proposed the appropriate way that satisfaction of harmonic regulation can be compatible with cost-down merit which become most important factor in home appliance field.



(a) The efficiency characteristics of induction motor on line voltage



(b) The efficiency characteristics on phase voltage of induction motor

Fig.10 The efficiency characteristics of induction motor

6. REFERENCES

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[2] Lloyd H. Dixon, "Average Current Mode Control of Switching Power Supplies", Unitrode Application Note U-140, pp. 10-398-10-411.

[3] Lloyd H. Dixon, "High Power Factor Switching Preregulator Design Optimization", Unitrode Power Supply Design Seminar Manual, SEM700, pp. I3-1-I3-12, 1991.