INSTANTANEOUS COMPENSATING POWER FLOW DIAGRAM OF ACTIVE POWER FILTER

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ABSTRACT - The goal of this paper is to present an instantaneous compensating power flow of active power filter(APF) by graphical method that could be practicable to compensate the power in both case of behaving in an instantaneous rectifying mode and an instantaneous inverting mode. To ensure the validity of the proposed method, computer simulation is achieved. Proposed method can be present more exquisite and physically meaningful power flow than conventional method in the instantaneous compensating power flow diagram of APF.

1. INTRODUCTION

Power factor improvement and harmonic suppression are very important for obtaining high quality electric energy and for saving electric energy. Up to now, APF stands in the spotlight of efficient strategy which can be acquire high quality electric energy and realize electric energy saving. APF is power conversion system for compensating harmonics and reactive power from nonlinear loads such as thyristor controlled rectifier or variable speed drives.[1-3] Therefore, compensating performance of APF can be directly decide by instantaneous compensating power of APF.[4] If instantaneous compensating power between APF and nonlinear load can be display in graph, then, it is illustrated easily compensating operation and principle of APF. Because conventional compensating power flow diagram of APF[1-2]is very simple and is not display compensating power in detail, it is not enough to present compensation principle and instantaneous compensating power between APF and nonlinear load.

This paper briefly discusses an instantaneous compensating power flow of APF by graphical method that could be practicable to compensate the power in both case of behaving in an instantaneous rectifying mode and an instantaneous inverting mode. The instantaneous compensating power is decomposed into active component, reactive component and harmonic component. Operating modes of APF are represented by each decomposed power component. Harmonic and reactive power of nonlinear load are independently controlled by APF[5], and instantaneous power flow of before/after compensation is presented in graph. To ensure the validity of the proposed method, computer simulation is achieved. Proposed method can be represent more exquisite and physically meaningful power flow than conventional method.

2.OPERATION MODES OF APF

Fig.1 shows equivalent circuits of APF. With two operation modes of rectification and inversion as

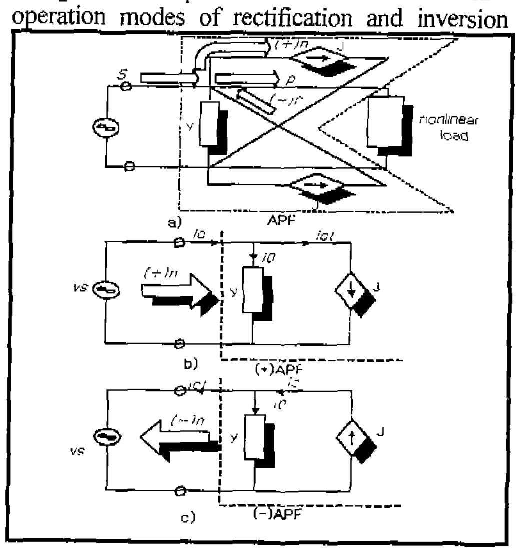


Fig.1. Equivalent circuits of APF
a)Basic configuration of APF
b)Instantaneous rectifying mode
c)Instantaneous inverting mode

shown in Fig.1b) and Fig.1c), APF generates instantaneous power for compensating. First of all, in rectifying mode of interval I, III as shown in Fig.2 and Fig.3, power is transferred from ac source to APF. In the same time, power is transferred from APF to ac source in inverting mode of interval II,IV.

3.INSTANTANEOUS POWER FLOW DIAGRAM OF APF

3.1 Conventional Instantaneous Power Flow Diagram

Fig.4 is conventional instantaneous power flow diagram of APF. As shown in Fig.4, instantaneous compensating power is composed into real power p and imaginary power n. Therefore, it is not enough to present compensation principle of APF and compensating power between APF and nonlinear load, because conventional method is briefly discussed compensating power flow of APF and not can be display compensating power in detail.

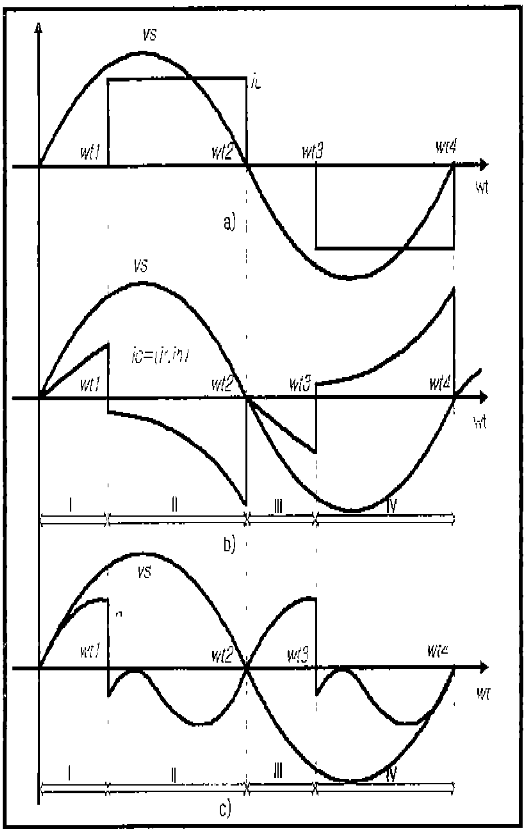


Fig.2. Compensating current and power waveforms of APF

a)Load current i_L and voltage v

b)Compensating current i_C

c)Compensating power n

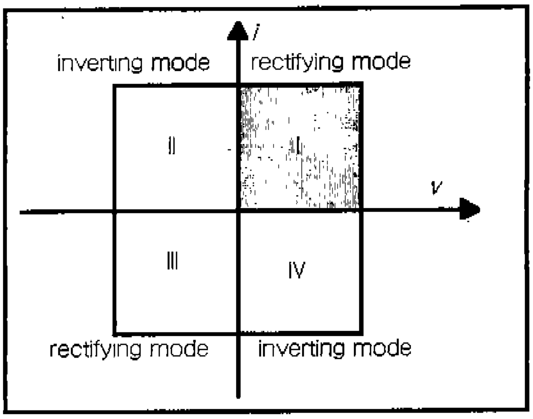


Fig.3. Operation quadrants of APF

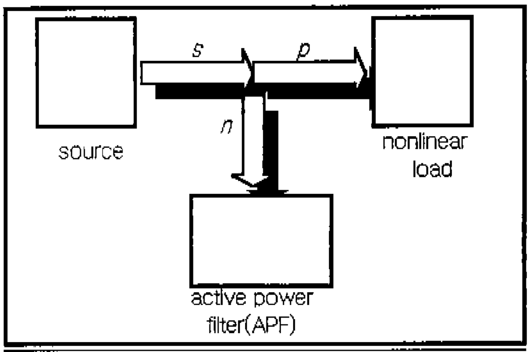


Fig.4. Conventional instantaneous power flow diagram of APF

3.2 Proposed Instantaneous Power Flow Diagram

System power is expressed in terms of three components - instantaneous apparent power s, instantaneous active power p, instantaneous nonactive power n, and their instantaneous values fulfill the following relation.

$$s = n + p \quad (1)$$

Also, compensating current calculated from instantaneous load current described as (2), is formulated by (3). As shown in Fig.2b), compensating current i_c is divided into i_c for rectifying and i_c for inverting.

instantaneous load current:

$$i_L = A_1 \sin(wt) + B_1 \cos(wt) + \mathrm{SUM}[A_n \sin(nwt) + B_n \cos(nwt)] \quad (2)$$

$$ic = B_1 \cos(wt) + \mathrm{SUM}[A_n \sin(nwt) + B_n \cos(nwt)] \quad (3)$$

$$= (+)i_c + (-)i_c \quad (4)$$

where $(+)i_c$ interval I $0 < \omega t < \omega t_1$

interval III $\omega t_2 < \omega t < \omega t_3$

$(-)i_c$ interval II $\omega t_1 < \omega t < \omega t_2$

interval IV $\omega t_3 < \omega t < \omega t_4$

As mentioned the above, $(+)i_c$, the first term of (4) means instantaneous compensating current of rectifying mode and reversely, $(-)i_c$, the second term of (4) means instantaneous compensating current of inverting mode. It implies that instantaneous compensating power n between ac source and APF can be formulated by (5).

$$\begin{aligned} n &= v\, i_c \\ &= v[(+)i_c + (-)i_c] \\ &= (+)n + (-)n \end{aligned} \qquad (5)$$

where

(+)n	interval I	$0 < \omega t < \omega t_1$
	interval III	$\omega t_2 < \omega t < \omega t_3$
(-)n	interval II	$\omega t_1 < \omega t < \omega t_2$
	interval IV	$\omega t_3 < \omega t < \omega t_4$

Now, considering losses of APF such as dc energy storage, PWM converter switching, input LC filters in APF, losses of APF as mentioned the above can be represented by loss current i_0 and loss power n_0. So, for each operating mode, i_α, that is, difference compensating current i_c and loss current i_0 is actually transfered without losses to APF or load.

Rectifying mode:
$$\begin{aligned} (+)n &= (+)i_c\, v \\ &= ((+)i_0 + (-)i_\alpha)\, v \\ &= (+)n_0 + (+)n_t \end{aligned} \qquad (6)$$
$$\begin{aligned} (+)n_t &= (+)i_\alpha\, v \\ &= [(+)i_r + (+)i_h]\, v \\ &= (+)q_t + (+)h_t \end{aligned} \qquad (7)$$

Inverting mode:
$$\begin{aligned} (-)n &= (-)i_c\, v \\ &= ((-)i_0 + (-)i_\alpha)\, v \\ &= (-)n_0 + (-)n_t \end{aligned} \qquad (8)$$
$$\begin{aligned} (-)n_t &= (-)i_\alpha\, v \\ &= [(-)i_r + (-)i_h]\, v \\ &= (-)q_t + (-)h_t \end{aligned} \qquad (9)$$

Hence,
$$\begin{aligned} n &= (+)n + (-)n \\ &= ((+)n_0 + (+)q_t + (+)h_t) + ((-)n_0 + (-)q_t + (-)h_t) \\ &= [(+)n_0 + (-)n_0] + [(+)q_t + (-)q_t] + [(+)h_t + (-)h_t] \\ &= n_0 + q_t + h_t \end{aligned} \qquad (10)$$

In consequence, instantaneous compensating power n is decomposed into losses of APF n_0, reactive power q_t, distorted power h_t as shown in Fig.5. And, Rectifying mode and inverting mode are proceeded gradually with the lapse of time as shown in Fig.6.

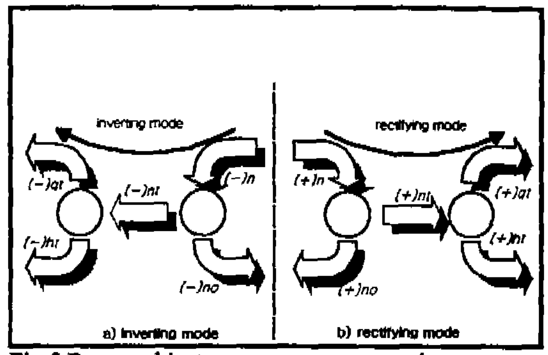


Fig.5.Proposed instantaneous compensating power flow diagram for each operating mode.
a)instantaneous inverting mode
b)instantaneous rectifying mode

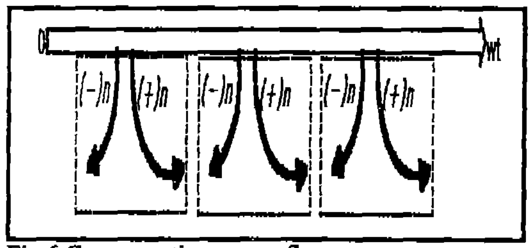
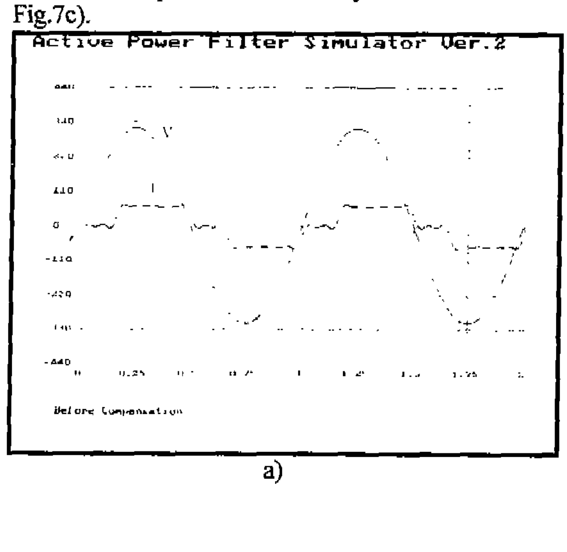


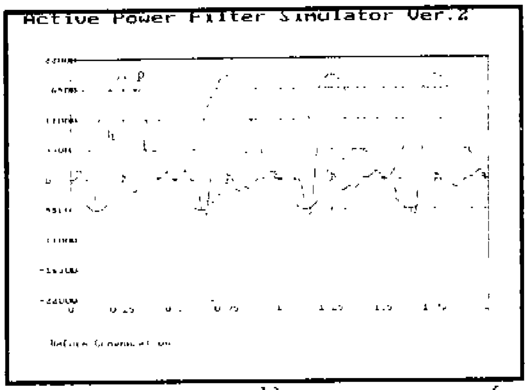
Fig.6.Compensating power flow sequence

4.COMPUTER SIMULATION AND DISCUSS

For obtaining an instantaneous power flow diagram of APF by proposed graphical method, computer simulation is achieved. Instantaneous sysem power before compensated by APF is decomposed into active power, reactive power and harmonic power as shown in Fig.7b). At this time, these power components are visualized on 3-D instantaneous power coordinate system as shown in Fig.7c).



a)



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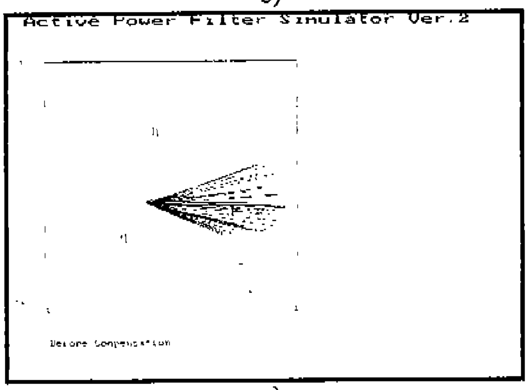
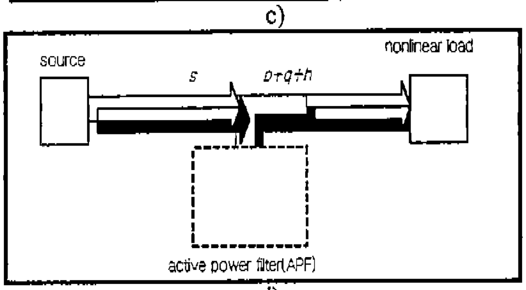


c)



d)

Fig.7 Before active power filter is operating

a)a.c voltage and current

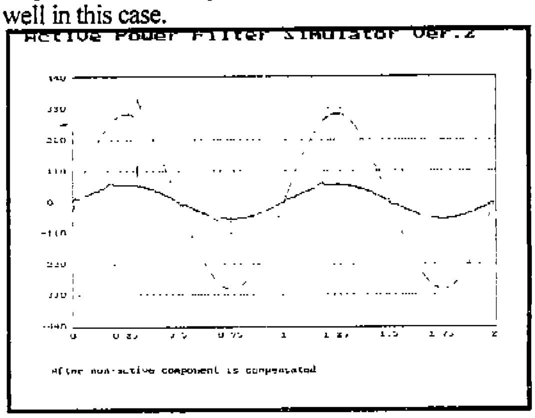
b)Decomposed instantaneous system power

c)3-D instantaneous power coordinates

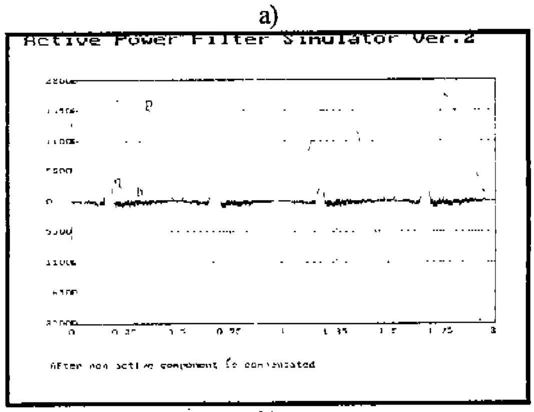
d)Instantaneous compensating power flow diagram

Because active power has one side direction, instantaneous values of power components are concentrated toward one side space of active power axies, centering origin, on 3-D instantaneous power coordinate system. Graphical representation in Fig.7d) is very useful for describing the compensating power and the operation principle of APF not described in Fig.7b) and Fig.7c). In case of Fig.7d), no compensating power exist between APF and ac source, because APF is not operated. But, if APF is operated, compensating power exit between APF and ac source. Fig.8) shows in case while nonactive power components-harmonic and reactive components are compensated by APF, especially, Fig.8d) shows instantaneous power flow diagram in this case. It is easy to understand the process absorbing harmonic and reactive power of nonlinear load by APF, and also, to analyze instantaneous rectifying and inverting operation with compensating power components of APF.

Fig.9) shows compensation results in case while harmonic power is controlled independently by APF. Because harmonic power is controlled by APF, compensating power between APF and ac source is only harmonic component and Fig.9d) shows very well in this case.



a)



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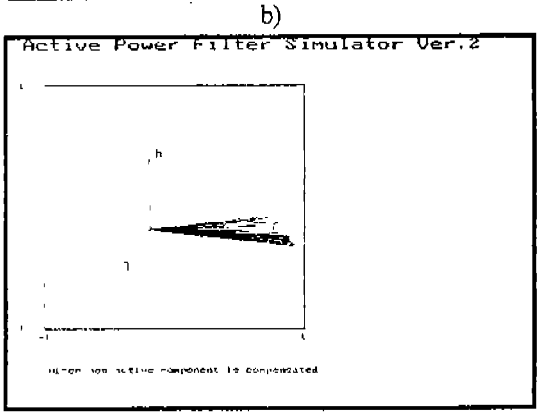
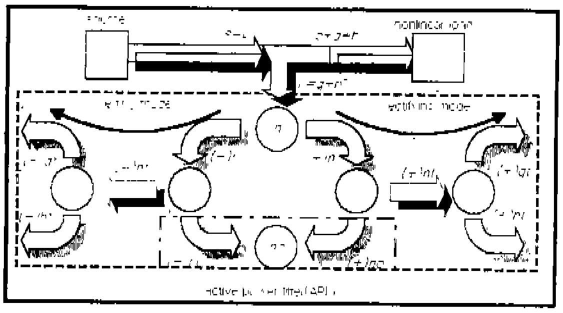
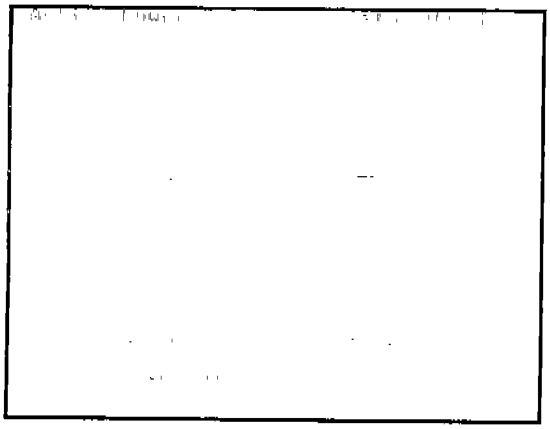


c)

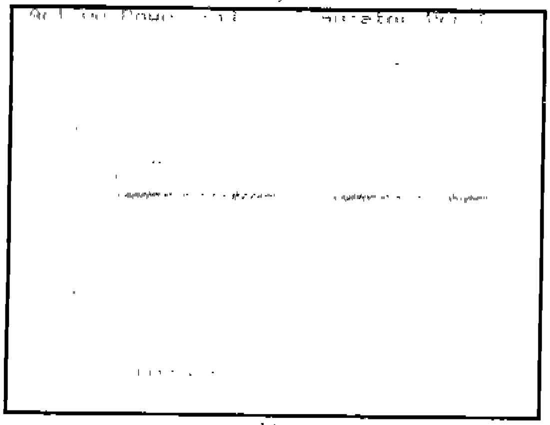


d)

Fig.8 After active power filter is operating(q,h)
a)a.c voltage and current
b)Decomposed instantaneous system power
c)3-D instantaneous power coordinates
d)Instantaneous compensating power flow diagram.



a)



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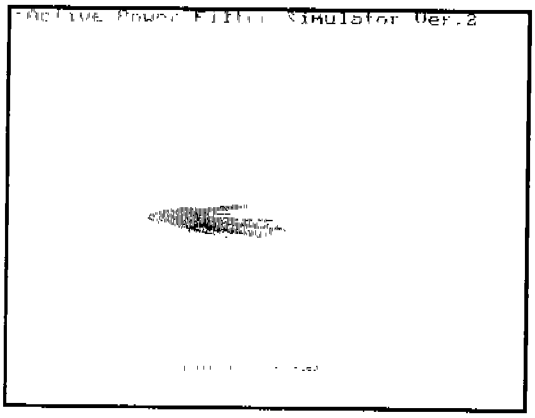
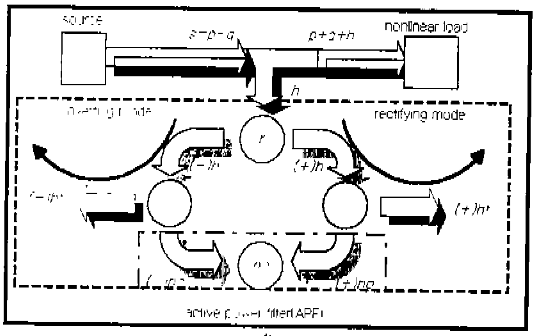


c)



d)

Fig.9.After active power filter is operating (h)
a)a.c voltage and current
b)Decomposed instantaneous system power
c)3-D instantaneous power coordinates
d)Instantaneous compensating power flow diagram.

5.CONCLUSIONS

This paper shows graphical method to present an instantaneous compensating power flow of APF, considering rectifying and inverting mode. The following conclusions can be derived from the results of this study.

(1)It is confirmed that proposed instantaneous compensating power flow diagram is very useful to present the compensating principle of APF by graphical method.

(2)The equivalent circuits of APF are obtained into rectifying mode and inverting mode in order to suit proposed instantaneous power flow diagram.

(3)In case while harmonic and reactive power of nonlinear load are controlled independently by APF, proposed method is more easy to analyze of power flow than conventional method.

(4)It is expected to instantaneous power flow diagram, considering loss of APF, in the further studies.

6.REFERENCES

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LIST OF SYMBOLS

p	instantaneous active power
s	instantaneous apparent power
n	instantaneous nonactive power for compensating
q	instantaneous reactive power
h	instantaneous harmonic power
	[Rectifying mode]
$(+)i_c$	instantaneous compensating current
$(+)i_{ct}$	instantaneous(i_c- i_o)compensating current
$(+)i_0$	instantaneous compensating loss current
$(+)i_r$	instantaneous reactive current
$(+)i_h$	instantaneous harmonic current
$(+)n$	instantaneous compensating power
$(+)n_0$	instantaneous compensating loss power
$(+)n_t$	instantaneous (n- n_o)compensating power
$(+)q_t$	instantaneous reactive power
$(+)h_t$	instantaneous harmonic power
	[Inverting mode]
$(-)i_c$	instantaneous compensating current
$(-)i_{ct}$	instantaneous(i_c- i_o)compensating current
$(-)i_0$	instantaneous compensating loss current
$(-)i_r$	instantaneous reactive current
$(-)i_h$	instantaneous harmonic current
$(-)n$	instantaneous compensating power
$(-)n_0$	instantaneous compensating loss power
$(-)n_t$	instantaneous(n- n_o)compensating power
$(-)q_t$	instantaneous reactive power
$(-)h_t$	instantaneous harmonic power