Analysis of Control Strategy for Hybrid Active Power Filter

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Abstract—**The hybrid active power filter is very efficient in filtering harmonics and power factor correction. But its efficiency depends on many factors; including control strategy plays a very important role. Therefore, this paper aims to analyze mathematical model of the hybrid active power filter. On that basis, a comparison between the control strategy according to the load harmonic current and source harmonic current have done. The simulation results have proven to be that: control strategy according to the load harmonic current is more effective the control strategy according to the source harmonic current. This analysis will be the basis of the researches in control of the hybrid active power filter.**

Keywords-hybrid active powe filter; control strategy; harmonics; active power filter; reactive power filter

I. INTRODUCTION

In power systems, power quality issues have always been concerned and have been the countries in the world are always looking to improve further. One of the main reasons making the power quality is deteriorated because the harmonics are generated from the non-linear loads. The presence of harmonics in the system will be the cause of the problem: the loss of power, distortion of voltage, overheating ... Therefore, to improve power quality, the active filter circuits (Active Power Filter-APF) [1-2] was born in the late 1970s. The most basic structure of APF is a parallel connection with non-linear load to filter the harmonic components of load and correct power factor. The biggest advantage of the APF is the ability to flexibly compensate, does not occur resonance with the grid impedance. However the APF also exists many disadvantages such as high cost, low capacity and difficult to use in the high-voltage grid. To improve the above defects, the hybrid active power filter circuits (HAPF) [3-4] birth is a necessary. Its structure is a combination of the PPFs and APF, so it has all the advantages of both the PPF and the APF. The most prominent advantage of HAPF is it capable of working in the high-voltage grid and large capacity with a capacity of the APF is relatively small.

Currently, also has many research about HAPF, especially about its control strategy and often the researches are based on the load harmonic current [5-8] and the source harmonic current [9-10]. However, do not yet have a paper would give a general analysis of the control strategy for HAPF. With the parameters are known, the selection of control strategy would be most effective? By the way, this paper is based on mathematical model of the HAPF to perform an analysis of the control strategies of HAPF, the influence of each parameter up control effectiveness of HAPF.

II. MATHEMATICAL MODEL AND CONTROL STRATEGY FOR HAPF

Structure of HAPF is shown as in Figure I.

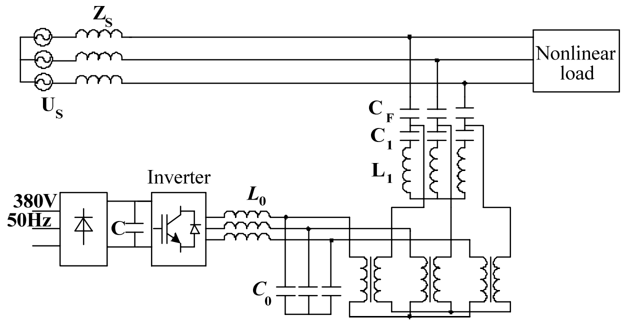


FIGURE I. STRUCTURE OF HAPF

The structure of a HAPF consists of four parts: the rectifier - inverter, output filter, ideal transformer and added circuit C_1-L_1-C_F. An ideal transformer has transformer ratio is n:1 placed between the output circuit and the added circuit. To reduce the capacity of the APF, a resonant circuit at basic frequency L_1-C_1 is connected with a capacitance C_F.

The single-phase equivalent circuit of HAPF is shown in Figure II.

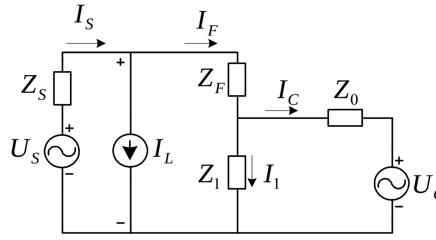


FIGURE II. SINGLE-PHASE EQUIVALENT OF HAPF

$$\text{Where:}\begin{cases} Z_S = R_S + j\omega L_S;\ Z_1 = 1/j\omega C_1 + j\omega L_1; \\ Z_0 = [j\omega L_0 // (1/j\omega C_0)]/n^2;\ Z_F = 1/j\omega C_F \end{cases}$$

From Figure II, I_s calculated as follows:

$$I_S = \frac{U_S - K_1 U_C + (K_2 + Z_F) I_L}{K_2 + Z_F + Z_S} \quad (1)$$

$$\text{with } K_1 = \frac{Z_1}{Z_0 + Z_1}; \; K_2 = \frac{Z_0 Z_1}{Z_0 + Z_1}$$

Based on (1) the following cases are considered with different frequencies: 100Hz, 150Hz, 250Hz and 350 Hz. The parameters of the HAPF are listed as in Table I.

TABLE I. TABLE I. PARAMETERS OF HAPF

$C_F \mu F$	$C_1 \mu F$	$L_1 mH$	$L_0 mH$	$C_0 \mu F$	$L_s mH$	R_s Ω	*n*
100	*338*	*30*	*1*	*60*	*0.2*	*0.01*	*1*

The effectiveness of control strategies are analyzed as follows:

A. Control Srategy Based on the Source Harmonic Current: $U_c = KI_s$(K is controlled gain)

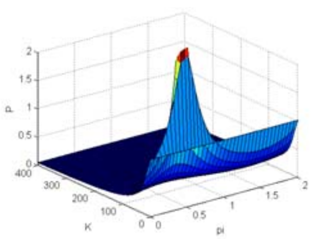
Substitute$U_c = KI_s$ into (1) we calculated out:

$$I_S = \frac{(K_2 + Z_F) I_L + U_S}{K_2 + Z_F + Z_S + KK_1} \quad (2)$$

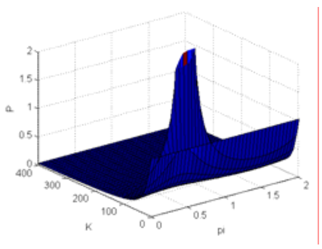
Case 1: The influence of I_L on I_s will be considered as in Eq. (3)

$$\eta_1 \% = \frac{\partial I_S}{\partial I_L}.100 = \frac{K_2 + Z_F}{K_2 + Z_F + Z_S + KK_1}.100 \quad (3)$$

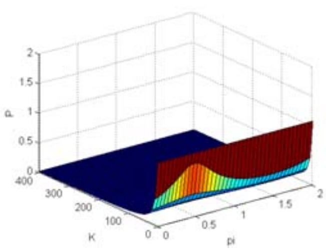
Based on (3), the influence of I_L on I_s be demonstrated as in Figure III



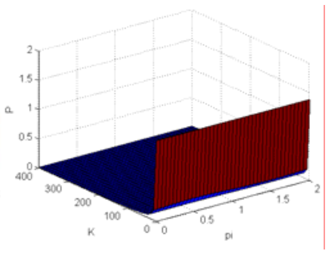
(a) f =100Hz



(b) f =150Hz



(c) f =250Hz



(d) f =350Hz

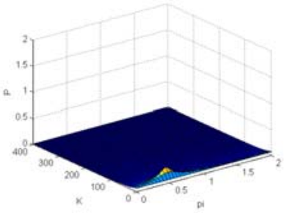
FIGURE III. INFLUENCE OF I_L ON I_S

Case 2: The influence of U_s on I_s

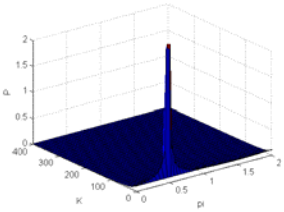
The influence of U_s on I_s will be considered as in Eq. (4)

$$\eta_2 \% = \frac{\partial I_S}{\partial U_S}.100 = \frac{1}{K_2 + Z_F + Z_S + KK_1}.100 \quad (4)$$

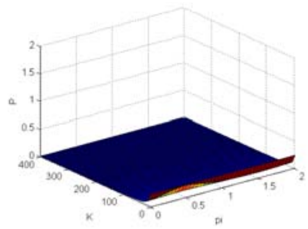
Based on (4), the influence of U_s on I_s be demonstrated as in Figure IV



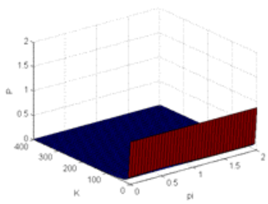
(a) f =100Hz



(b) f =150Hz



(c) f =250Hz



(d) f =350Hz

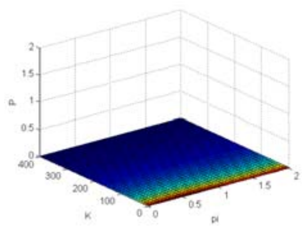
FIGURE IV. INFLUENCE OF U_S ON I_S

Case 3: The influence of Z_s on I_s

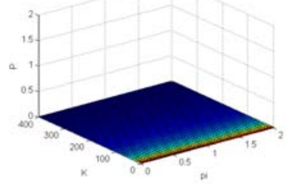
The influence of Z_s on I_s will be considered as in Eq. (5)

Based on (5), the influence of Z_s on I_s be demonstrated as in Figure V.

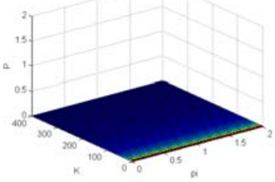
$$\eta_3 \% = \frac{\partial^2 I_S}{\partial Z_S \partial I_L}.100 = -\frac{K_2 + Z_F}{(K_2 + Z_F + Z_S + KK_1)^2}.100 \quad (5)$$



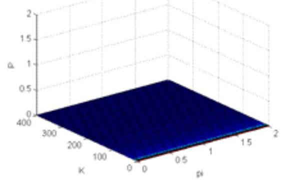
(a) f =100Hz



(b) f =150Hz



(c) f =250Hz



(d) f =350Hz

FIGURE V. INFLUENCE Z_S ON I_S

B. Control Strategy Based on the Load Harmonic Current I_L:

Substitute U_c=KI_L into (1) we calculated out:

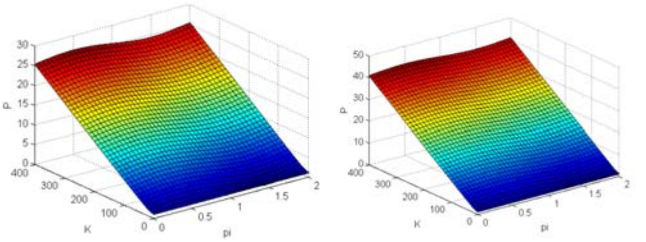
$$I_S = \frac{U_S + (K_2 + Z_F - K.K_1)I_L}{K_2 + Z_F + Z_S} \quad (6)$$

Case 1: The influence of I_L on I_s

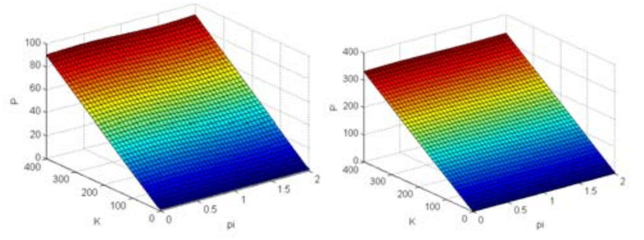
The influence of I_L on $I_s$will be considered as in Eq. (7)

$$\eta_1\% = \frac{\partial I_S}{\partial I_L}.100 = \frac{K_2 - KK_1 + Z_F}{Z_S + Z_F + K_2}.100 \quad (7)$$

Based on (7), the influence of I_L on I_s be demonstrated as in Figure VI.



(a) f =100Hz (b) f =150Hz



(c) f =250Hz (d) f =350Hz

FIGURE VI. FIGURE 6. INFLUENCE OF I_L ON I_S

Case 2: The influence of U_s on I_s

The influence of U_s on $I_s$will be considered as in Eq. (8)

$$\eta_2\% = \frac{\partial I_S}{\partial U_S}.100 = \frac{1}{K_2 + Z_F + Z_S}.100 \quad (8)$$

Based on (8), the influence of U_s on I_s be demonstrated as in Figure VII

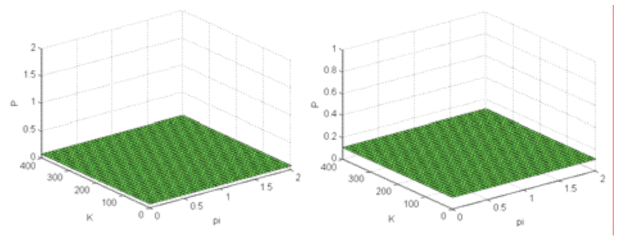
Case 3: The influence of Zs on Is

The influence of Z_s on $I_s$will be considered as in Eq. (9)

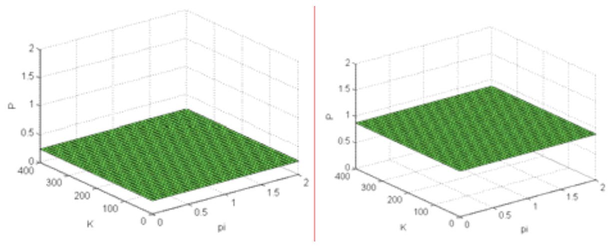
$$\eta_3\% = \frac{\partial^2 I_S}{\partial Z_S \partial I_L}.100 = -\frac{K_2 - KK_1 + Z_F}{(K_2 + Z_F + Z_S)^2}.100 \quad (9)$$

Based on (9), the influence of Z_s on I_s be demonstrated as in Figure VIII.

In summary, from the results of the graphs from Figure 3 to Figure 8, we can notice that: the control strategies U_c=KI_L is more effective the control strategies U_c=KI_s. In Figure 6 and Figure 8: when K increase then P also increased, the relationship between K and P is almost linear, the waveform does not exist the extremes, not been modified unexpectedly. Therefore, the control strategy U_c=KI_L will be very efficient.

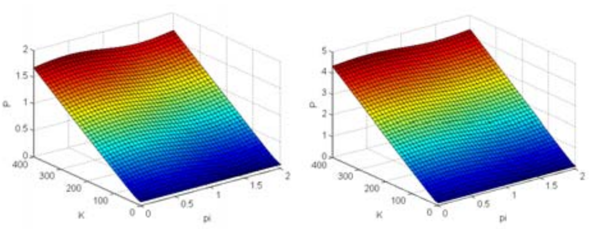


(a) f =100Hz (b) f =150Hz

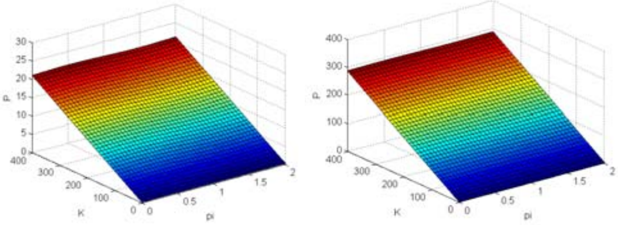


(c) f =250Hz (d) f =350Hz

FIGURE VII. INFLUENCE U_S ON I_S



(a) f =100Hz (b) f =150Hz



(c) f =250Hz (d) f =350Hz

FIGURE VIII. INFLUENCE OF ZS ON IS (η_3)

III. SIMULATION RESULTS

To demonstrate the effectiveness of control strategies U_c=KI_s andU_c=KI_L. The simulation results are made for a system HAPF 380V-50 Hz. The parameters of the HAPF model are given in table I.

Before Kincreased the simulation results of the control strategy$U_c=KI_s$ and$U_c=KI_L$ are represented as in Figure IX and FigureX.

When K increased, simulation results of the control strategy $U_c=KI_s$ and $U_c=KI_L$ are demonstrated as in Figure XI and FigureXII.

From the simulation results we can see that: when K increase, the control strategy $U_c = KI_s$ less effective the control strategy $U_c = KI_L$. However, when K increases also needs to notice to the conditions of the system stability.

The summary table the effectiveness of these strategies in steady-state is shown as in Table II.

TABLE II. SUMMARY TABLE THE EFFECTIVENESS OF THESE STRATEGIES IN STEADY-STATE

Strategies	**Before K increasing**	**After K increasing**
	THD I_s%	THD I_s%
$U_C=KI_S$	8.85%	7.0%
$U_C=KI_L$	5.78%	1.64%

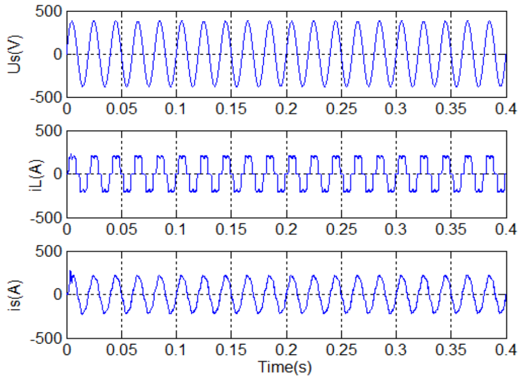


FIGURE IX. SIMULATION RESULT BEFORE INCREASING K WITH $U_C=KI_S$

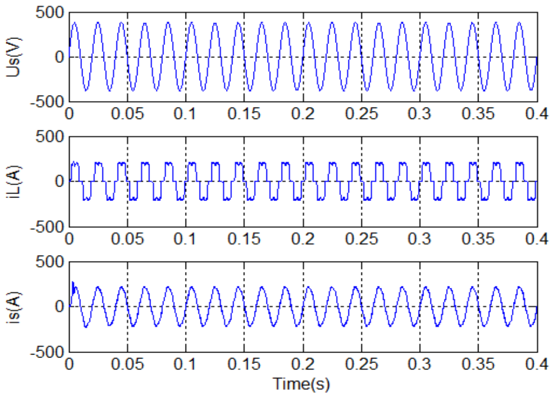


FIGURE X. FIGURE 10. SIMULATION RESULT BEFORE INCREASING K WITH $U_C=KI_L$

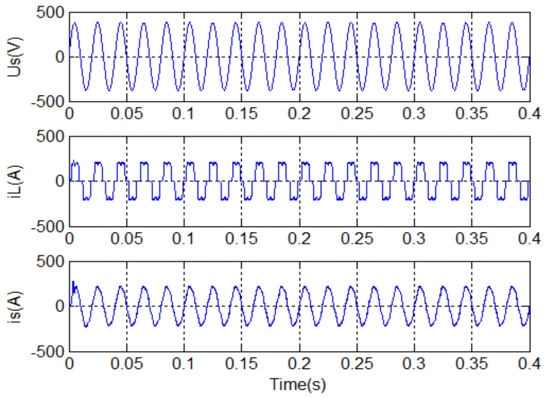


FIGURE XI. SIMULATION RESULT AFTER INCREASING K WITH $U_C=KI_S$

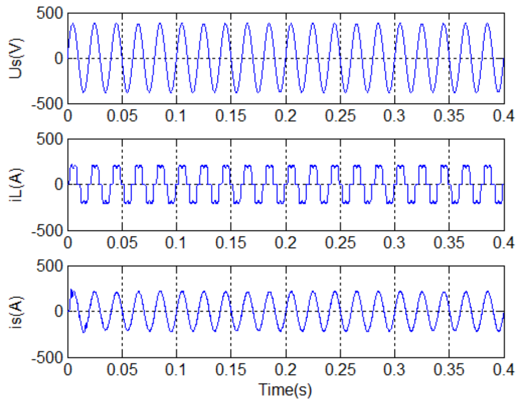


FIGURE XII. SIMULATION RESULT AFTER INCREASING K WITH $U_C=KI_L$

IV. CONCLUSION

The paper has been analysis mathematical model for a form HAPF, demonstrated the influence of each parameter to operate of HAPF. The simulation results show the efficiency of each control strategy. This analysis will be the basis for the decision to choose control method, improve work efficiency for HAPF.

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