An Active Tuning Function of Hybrid Power Filter for Suppression of Harmonics

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Abstract: In order to reduce the harmonic pollution caused due to power electronics devices such as diode, rectifiers and adjustable speed drives etc., it is necessary to install power filter in the power system. The proposed method uses hybrid power filter. The active tuning function is applied on active power filter which continuously carry out filtering performance caused due to nonlinear load.

Keywords: Active tuning function, Harmonics, Hybrid power filter.

I. INTRODUCTION

The nonlinear loads such as renewable power generations systems and a power electronic devices injects current and voltage harmonics in the power system [1] - [2]. Harmonics detoriate the power quality. Therefore it is necessary to carry out Harmonics reduction methods [3].
Passive power filters can be used for harmonic suppression as well as to provide reactive power compensation. By proper selection of L & C, they are tuned for a particular harmonics frequency [4]. Active power filter can be used for harmonic suppression as it provides better performance than passive filter. It is used at the load end as current harmonics are injected by nonlinear load. Active power filter injects equal and opposite in phase compensating current to cancel out effect of harmonics [5] - [6]. But Active power filter cannot be applied to high voltage system due to its small capacity and high cost. A combination of passive power filter and active power filter (APF) is preferred to get the better performance in harmonic reduction [7].
For hybrid power filter, control strategy plays important role to get excellent performance. A synchronous reference frame theory can be utilized so that zero impedance is offered for harmonic currents passing through passive power filters [7]- [8]. Zhikang shuai and others proposed double closed loop control method for hybrid power filter the outer loop is designed to eliminate load harmonic current and inner loop is used to ensure secure operation of hybrid active power filter [9].
The proposed method uses hybrid power filter (HPF) which continuously alters the filter inductive reactance so the harmonic frequency components are suppressed [10].

II. SYSTEM DESCRIPTION

The filter consists of LC passive power filter and active power filter to form hybrid power filter. The filter is connected in parallel with the nonlinear load. The active tuning function is applied to get the pulses from the PWM generator. The active tuning function is carried out to perform the harmonic elimination created due to nonlinear load.

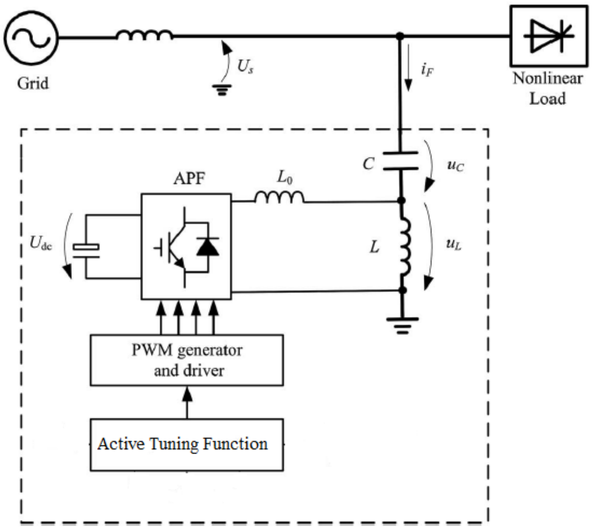

Fig. 1. Single phase system of hybrid power filter

III. OPERATING PRINCIPLE of APF

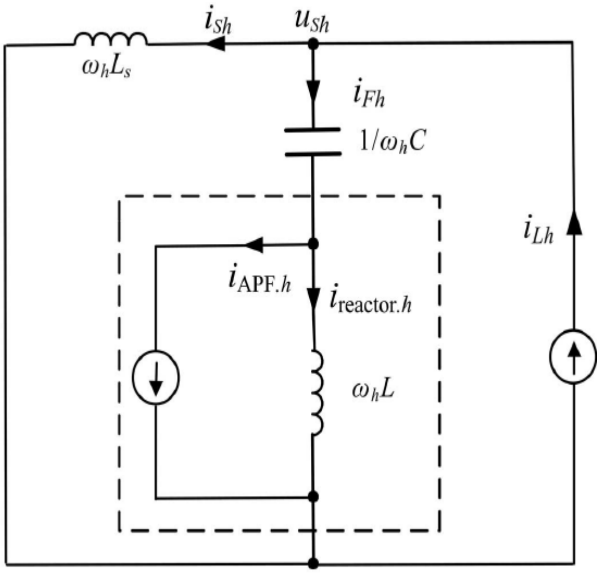

Fig2. Equivalent circuit of hybrid power filter

Fig. 2 represents the equivalent circuit of hybrid power filter.

System Parameters:-
$\omega_h L_s$ = h-order harmonic system reactance
$1/\omega_h C$ = h-order harmonic capacitive filter reactance
$\omega_h L$ = h-order harmonic inductive filter reactance
The nonlinear load and APF is assumed as current sources i_{Lh} and $i_{APF.h}$ respectively.
Applying KVL and KCL to fig 2, we get following relations

$$\left.\begin{aligned} u_{Sh} &= u_{Ch} + u_{Lh} \\ u_{Lh} &= L\,\frac{\text{direactor.h}}{dt} \\ u_{Ch} &= \frac{1}{C}\int i_{Fh}\,dt \\ i_{Fh} &= i_{reactor\ .h} + i_{APF.h} \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

where u_{Lh} & u_{Ch} shows the h-order harmonics voltage across filter inductive reactance and filter capacitive reactance respectively. Let the h-order harmonic current is injected into the HPF and is given as:

$$i_{Fh} = i_{Fh}\sin(\omega_h t + \dot{\varphi}_h)\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

where $\dot{\varphi}_h$ is phase difference with respect to source voltage.
The output current of APF is given by

$$i_{APF.h} = K_h . i_{Fh}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

where K_h represent the control gain of h-order harmonic.
Solving eqn. (1)-(3) we get,

$$u_{Sh} = L\,\frac{\text{director}\ .h}{dt} + \frac{1}{C}\int i_{Fh}\,dt$$
$$u_{Sh} = L\frac{d}{dt}[i_{Fh} - i_{APF.h}] + \frac{1}{C} i_{Fh}\int \sin(\omega_{ht} + \dot{\varphi}_h)\,dt$$
$$u_{Sh} = \frac{LC^2\omega_h^2}{C\omega_h} I_{Fh}\cos(\omega_{ht} + \dot{\varphi}_h)\frac{K_h LC\omega_h^2}{C\omega_h} I_{Fh}\cos(\omega_{ht} + \dot{\varphi}_h) - \frac{I_{Fh}}{C\omega_h}\cos(\omega_{ht} + \dot{\varphi}_h)$$
$$u_{Sh} = \left[\frac{(1-K_h)LC\omega_h^2 - 1}{C\omega_h}\right]\left[I_{Fh}\cos\left(\omega_{ht} + \dot{\varphi}_h\right)\ \ldots\ldots\ldots\ldots\ldots\ (4)$$

The impedance of HPF at h-order harmonic frequency can be obtained as

$$i_{Fh} Z_{ATHPF} = \omega_h L\, i_{reactor\ .h} + \frac{1}{\omega_h C} i_{Fh}\ \ldots\ldots\ldots\ldots\ldots\ (5)$$

$$Z_{ATHPF} = \frac{1}{\omega_h C} + \omega_h L(1 - K_h)\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6)$$

The h-order equivalent reactance of the system is

$$L_{eq.h} = (1 - K_h)\,L\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (7)$$

Equation (7) indicates that if the value of control gain K_h is increased the equivalent inductive reactance decreases and vice versa. The attenuation factors can be obtained by applying current divider rule to fig 2 and we obtain,

$$\frac{I_{sh}}{I_{Fh}} = \frac{\omega_h L_s}{\omega_h L_s + (1-K_h)\omega_h L - 1/\omega_h c}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (8)$$

$$\frac{I_{sh}}{I_{Fh}} = \frac{[(1-K_h)\omega_h L - 1/\omega_h c]}{[(1-K_h)\omega_h L - 1/\omega_h c] + \omega_h L_s}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (9)$$

If control gain K_h meets the following equation,

$$(1 - K_h)\omega_h L - \frac{1}{\omega_h C} = 0\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (10)$$

then
$I_{Sh} = 0, I_{Sh} = I_{Lh}$
Then we can write equation for control gain K_h as

$$K_h = \begin{cases} 1 - \frac{1}{LC{\omega_h}^2} & h \in G \\ = 0 & h \notin G \end{cases}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

where G is the set of selective harmonic frequencies which need to be suppressed.We can write the eqn. (11) as

$$K_h = \begin{cases} 1 - \frac{1}{LC{\omega_h}^2} = 1 - \frac{{\omega_r}^2}{{\omega_h}^2} & h \in G \\ = 0 & h \notin G \end{cases}\ \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

Where ω_r is the resonant angular frequency and is given as

$$\omega_r = \frac{1}{\sqrt{LC}}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (13)$$

IV. REALIZATION OF ACTIVE TUNING FUNCTION

A. Adjusting Method for K_h

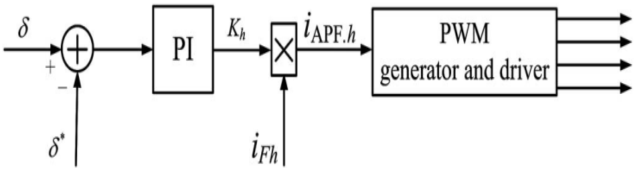

Fig.3.Schematic diagram of active tuning function

Active tuning function can be realized by adjusting the values of K_h. For active tuning function the K_h value is obtained from eqn. (12). Sometimes equation (12) does not give correct results, so it is necessary to adjust K_h according to practical condition to get satisfactory results.
Active tuning function can be implemented using degree of detuning. The degree of detuning can be chosen as the control basis of hybrid power filter. For h-order harmonics the difference between practical detuning δ and its reference δ^* is obtained. The K_h with h-order harmonic current flowing into ATHPF; the h-order reference current $i_{APF.h}$ is generated. The reference current $i_{APF.h}$ is sent to the PWM generator and driver to produce pulses of the switching devices. The δ is assumed as

$$\delta = \frac{U_{Lh} - U_{Ch}}{U_{Lh} + U_{Ch}}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (14)$$

Where U_{Lh} and U_{Ch} are RMS values of h-order harmonic content of voltage across the filter reactor and capacitor.

The analysis given below shows that measured degree of detuning δ gives good performance to indicate the theoretical detuning δ_o.

$$\delta = \frac{U_{Lh}-U_{Ch}}{U_{Lh}+U_{Ch}} = \frac{X_{Lh}-X_{Ch}}{X_{Lh}+X_{Ch}} = \frac{\omega_h^2 L-1}{\omega_h^2 L+1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

According to definition theoretical value δ_o can be given as

$$\delta_o = \frac{\omega_h-\omega_r}{\omega_h} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Using equation (13) and (16) we get,

$$\delta_o \omega_h = \omega_h - \omega_r$$

$$\omega_r = \omega_h - \delta_o \omega_h$$

$$\omega_r = \omega_h (1-\delta_o)$$

$$\omega_h = \frac{1}{\sqrt{LC}(1-\delta_o)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

Using equation (17) in equation (15) we get,

$$\delta = \frac{1-(1-\delta_o)^2}{1+(1-\delta_o)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

$$\delta = \frac{2\delta_o-{\delta_o}^2}{2+{\delta_o}^2-2\delta_o} = \frac{2\delta_o}{2-2\delta_o} \cong \delta_o \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

From equation (19) we can say that practical value of filter δ can be obtained from equation (12)

B. Realization of Active Tuning Function.

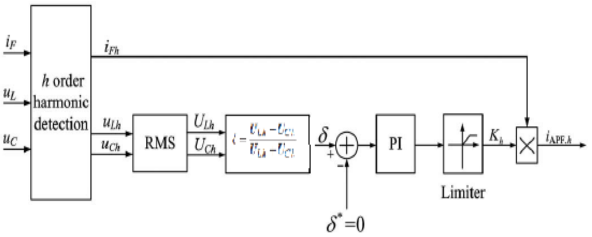

Fig.4.Active tuning function realization of h-order harmonics

Fig 4 shows the realization of active tuning function. The h-order harmonic components i_{Fh}, u_{Lh}, and u_{Ch} are obtained using Fourier series. Then equation (14) is employed to get the degree of detuning factor δ. The reference δ^* is set as zero. The PI regulators adjust the value of K_h in such ay so as to make δ equal to δ^*. As a result the hybrid power filter resonates at the occurrence of h-order harmonics. We can use the active tuning function for suppression of h-order selective harmonic frequency.

V. SIMULATION MODEL AND RESULTS

Simulation results can be obtained from MATLAB Simulink software. The system parameters are given in table I and the simulation results are summarized in table II.

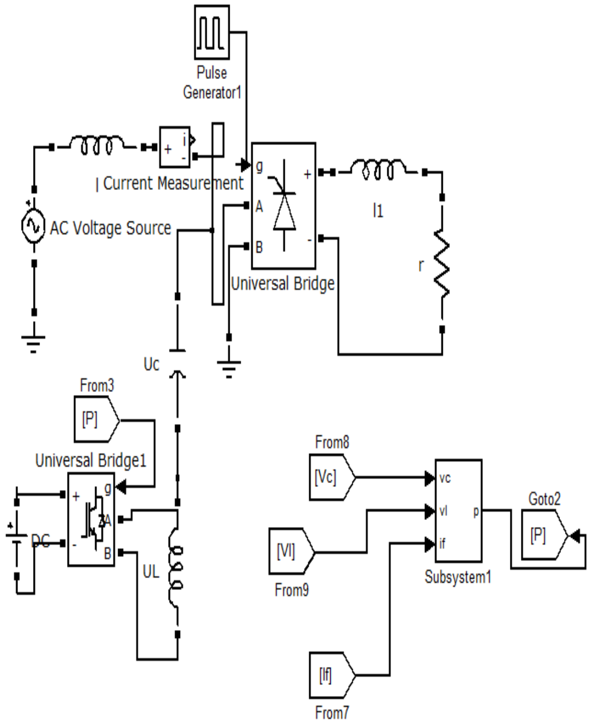

Fig.5.simulink model with active tuning function

TABLE I SYSTEM PARAMETERS

Variable	Quantity
U_s	230 V
f	50Hz
R_{load}	10Ω
L_{load}	200 mH
L_{filter}	17mH
C_{filter}	75µF
U_{dc}	125 V

TABLE II SIMULATION RESULTS

	Source current without filter	**Source current with active tuning function**
Fundamental (%)	100	100
3rd (%)	13.18	0.94
5th (%)	5.66	0.74
7th (%)	6.15	0.40
9th (%)	5.13	0.12
11th (%)	3.05	0.07
THD (%)	26.03	1.37

VI. CONCLUSION

The therotical explanation of active tuning function is verified using the MATLAB Simulink software. Simulation results shows that using active tuning function of hybrid power filter gives the relief from harmonics caused due to nonlinear loads. Further we can extend this method to active detuning function which provides protection against overcurrent.

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