HYBRID ACTIVE POWER FILTER USING FUZZY DIVIDING FREQUENCY CONTROL METHOD

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ABSTRACT

This paper deals with a hybrid active power filter with injection circuit (IHAPF). It shows great promise in reducing harmonics and improving the power factor with a relatively low capacity active power filter. This paper concluded that the stability of the IHAPF based on detection supply current is superior to that of others. To minimize the capacity of IHAPF, an adaptive fuzzy dividing frequency-control method is proposed by analyzing the bode diagram, which consists of two control units: a generalized integrator control unit and fuzzy adjustor unit. The generalized integrator is used for dividing frequency integral control, while fuzzy arithmetic is used for adjusting proportional-integral coefficients timely. And the control method is generally useful and applicable to any other active filters. Compared to other IHAPF control methods, the adaptive fuzzy dividing frequency control shows the advantages of shorter response time and higher control precision. It is implemented in an IHAPF with a 100-kVA APF installed in a copper mill in Northern China. The simulation and experimental results show that the new control method is not only easy to be calculated and implemented, but also very effective in reducing harmonics.

KEYWORDS: *Hybrid Active Power Filter (HAPF), Fuzzy-control method, Integral controller.*

I. INTRODUCTION

Harmonic filters are used to eliminate the harmonic distortion caused by nonlinear loads. Specifically, harmonic filters are designed to attenuate or in some filters eliminate the potentially dangerous effects of harmonic currents active within the power distribution system. Filters can be designed to trap these currents and, through the use of a series of capacitors, coils, and resistors, shunt them to ground. A filter may contain several of these elements, each designed to compensate a particular frequency or an array of frequencies.

A passive filter is composed of only passive elements such as inductors, capacitors and resistors thus not requiring any operational amplifiers. Passive filters are inexpensive compared with most other mitigating devices. Its structure may be either of the series or parallel type. The structure chosen for implementation depends on the type of harmonic source present. Internally, they cause the harmonic current to resonate at its frequency. Through this approach, the harmonic currents are attenuated in the LC circuits tuned to the harmonic orders requiring filtering. This prevents the severe harmonic currents traveling upstream to the power source causing increased widespread problems.

An active filter is implemented when orders of harmonic currents are varying. One case evident of demanding varying harmonics from the power system are variable speed drives. Its structure may be either of the series of parallel type. The structure chosen for implementation depends on the type of harmonic sources present in the power system and the effects that different filter solutions would cause to the overall system performance. Active filters use active components such as IGBT-

transistors to inject negative harmonics into the network effectively replacing a portion of the distorted current wave coming from the load. This is achieved by producing harmonic components of equal amplitude but opposite phase shift, which cancel the harmonic components of the non-linear loads.
Hybrid filters combine an active filter and a passive filter. Its structure may be either of the series or parallel type. The passive filter carries out basic filtering (5th order, for example) and the active filter, through precise control, covers higher harmonics.

II. CLASSIFICATION OF ACTIVE FILTERS ACCORDING TO POWER CIRCUIT, CONFIGURATIONS AND CONNECTIONS

a) Shunt active filters:

Shunt active filters are by far the most widely accept and dominant filter of choice in most industrial processes. The active filter is connected in parallel at the PCC and is fed from the main power circuit. The objective of the shunt active filter is to supply opposing harmonic current to the nonlinear load effectively resulting in a net harmonic current. This means that the supply signals remain purely fundamental.

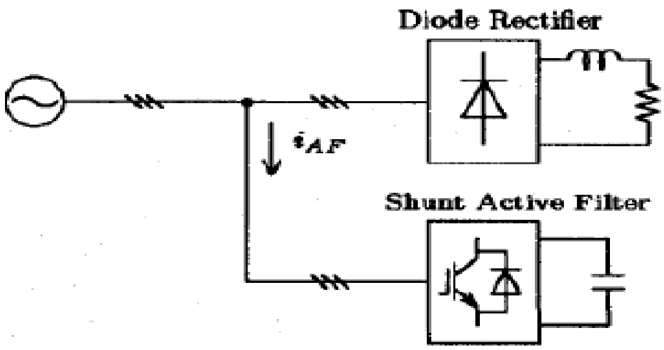


Figure 1 Shunt active filter used alone

Shunt filters also have the additional benefit of contributing to reactive power compensation and balancing of three-phase currents. Since the active filter is connected in parallel to the PCC, only the compensation current plus a small amount of active fundamental current is carried in the unit. For an increased range of power ratings, several shunt active filters can be combined together to withstand higher currents.

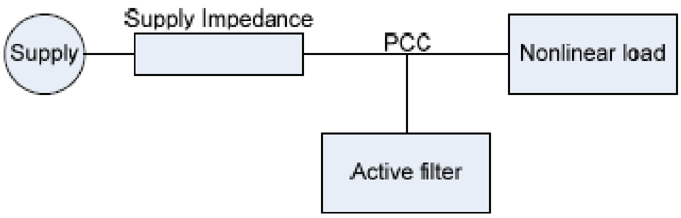


Figure.2 Shunt active filter network configuration

b) Series active filters:

The objective of the series active filter is to maintain a pure sinusoidal voltage waveform across the load. This is achieved by producing a PWM voltage waveform which is added or subtracted against the supply voltage waveform. The choice of power circuit used in most cases is the voltage-fed PWM inverter without a current minor loop. The active filter acts as a voltage source and thus it is often a preferred solution of harmonic producing loads such as large capacity diode rectifiers with capacitive loads. In general, series active filters are less commonly used against the shunt design.
Unlike the shunt filter which carries mainly compensation current, the series circuit has to handle high load currents. This causes an increased rating of the filter suitable to carry the increased current.

Series filters offer the main advantage over the shunt configuration of achieving ac voltage regulation by eliminating voltage-waveform harmonics. This means the load contains a pure sinusoidal waveform.

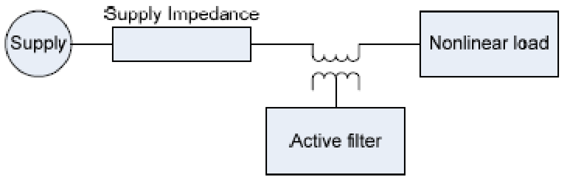


Figure.3 Series active filter configuration

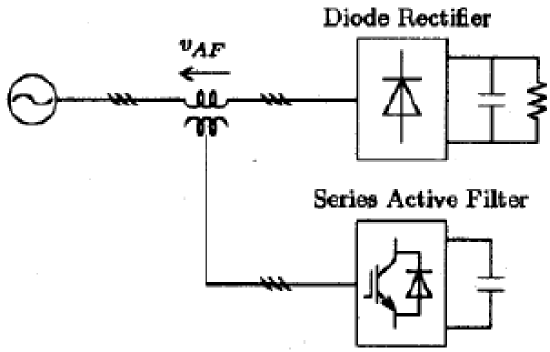


Figure.4 Series active filter used alone

c) Combination of both shunt and series active filters:

The diagram shown in figure below shows the combination of both parallel and series active filters. This system combines both the benefits of the shunt and series and is often used to achieve the demanding power system requirements. The control of active filters can be complex. A combination of the two provides an even greater complexity. The higher cost involved in a more complex design has shown a reduced demand for the combined structure. As a result of the increased cost and complexity, this combination has received less attention than other configurations. Flexible AC transmission systems, commonly abbreviated as FACTS regularly make use of the arrangement.

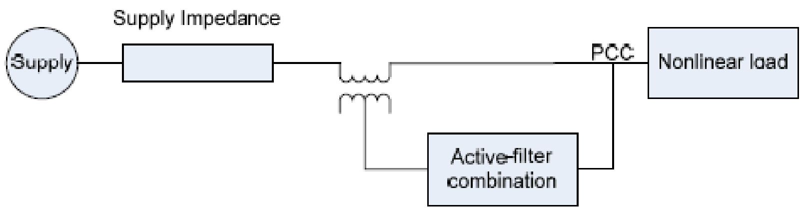


Figure.5 Combination of shunt and series active filters

d) Combination of series active and shunt passive filters :

The combination of the active parallel and active series filters in was seen to be very complex in control yielding a high cost. One method of reducing these problems was to replace the parallel active filter with a passive structure. The series active filter, which constitutes high impedance for high-frequency harmonics, is accompanied by a parallel passive filter to provide a path for the harmonic currents of the load. This combination represented by figure below, permits an improvement over the characteristics of plain series active filters and the extension of their capabilities to include current-harmonic reduction and voltage- harmonic elimination. Passive filters are often easier and simple to implement and do not require any control circuit. This, this deserves to be most beneficial.

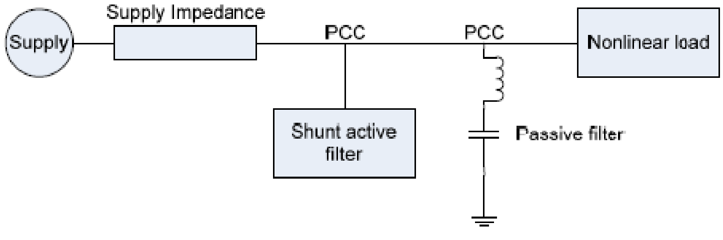


Figure.6 Combination of series active and shunt passive filters

e) Combination of shunt active and passive filter:

As mentioned, shunt active filters are best suitable to compensate for lower order harmonics thus only requiring low power rating which serves most economical. This configuration makes use of a passive filter which serves to compensate for the high order load current harmonics. This combination, represented by figure (shunt active filter network configuration) presents this important configuration.

Combinations such as this can be designed to compensate for higher powers without excessive costs for high-power switching. The major disadvantage of this configuration is the fact that passive filters can only be tuned for a specific predefined harmonic and thus cannot be easily changed for loads which have varying harmonics.

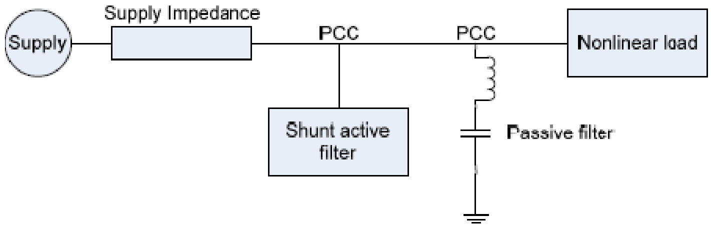


Figure.7 Combination of shunt active and passive filter

f) Active filter in series with shunt passive filter:

The combination of an active filter in series with a shunt passive filter is considered a significant design configuration for medium and high voltage applications. The passive filter is designed to reduce the voltage stress applied to the switches in the active filter. This design is in its infancy of development however, further research is still needed to assess the effectiveness of the configuration.

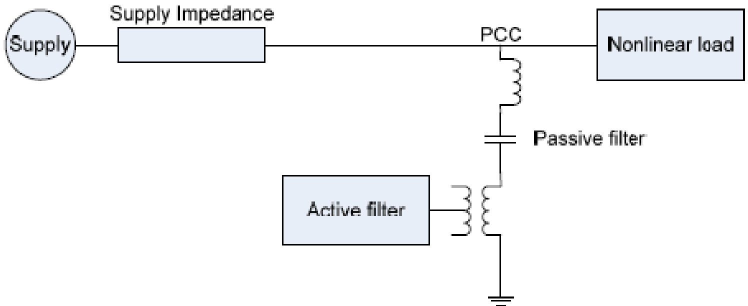


Figure.8 Active filter in series with shunt passive filter

III. SYSTEM CONFIGURATION AND CONTROL STRATEGY

Topology of the Novel HAPF:

The parallel HAPF has the advantages of easy installation and maintenance and can also be made just by transformation on the PPF installed in the grid. Fig.9 shows a PHAPF that is in use now. To reduce the power of APFs, a PPF has been designed for some certain orders of harmonics. As in Fig.9, and make up a PPF to compensate the second, fifth, and seventh harmonic current, while the APF is just used to improve the performance of PPF and get rid of the resonance that may occur.

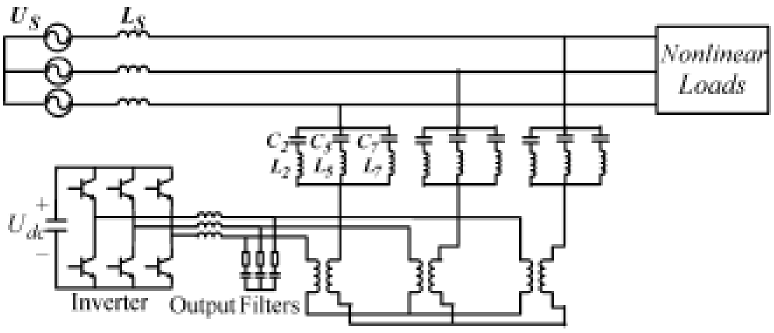


Figure 9. Topology of the Shunt Hybrid APF

So the power of the filter can be reduced sharply, usually one-tenth of the power of the nonlinear load, which enables the APF to be used in a high-power occasion.

HAPF is expected to compensate for reactive power as well as damp harmonics in the grid, and all of the reactive power current will go through APF. To further decrease the power of APF, a novel configuration of the hybrid APF is proposed as shown in Fig. 10 and tune at the fundamental frequency, and then compose the injection branch with the APF, shunted to the fundamental resonance circuit, is directly connected in series with a matching transformer. Therefore, the novel HAPF (IHAPF) is formed. The PPF sustains the main grid voltage and compensates for the constant reactive power, while the fundamental resonance circuit only sustains the harmonic voltage, which greatly reduces the APF power and minimizes the voltage rating of the semiconductor switching device. So it is effective to be used in the 6-kV/10-kV medium-voltage grid.

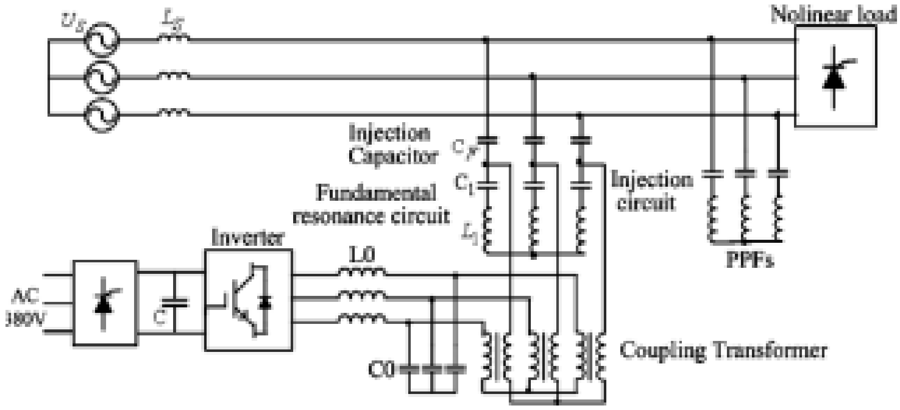


Figure.10 Topology of the Novel HAPF

IV. ADAPTIVE FUZZY DIVIDING FREQUENCY-CONTROL METHOD

The conventional linear feedback controller (PI controller, state feedback control, etc.) is utilized to improve the dynamic Response and/or to increase the stability margin of the closed loop system.

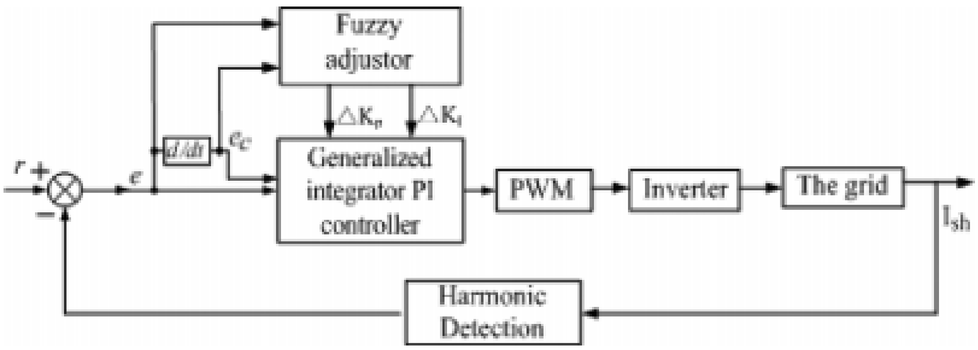


Figure.11 Configuration of the adaptive fuzzy dividing frequency controller

However, these controllers may present a poor steady-state error for the harmonic reference signal. An adaptive fuzzy dividing frequency control method is presented in Fig. 11, which consists of two control units: 1) a generalized integrator control unit and 2) a fuzzy adjustor unit.

The generalized integrator, which can ignore the influence of magnitude and phase, is used for dividing frequency integral control, while fuzzy arithmetic is used to timely adjust the PI coefficients.

Since the purpose of the control scheme is to receive a minimum steady-state error, the harmonic reference signal is set to zero. First, supply harmonic current is detected. Then, the expectation control signal of the inverter is revealed by the adaptive fuzzy dividing frequency controller.

The stability of the system is achieved by a proportional controller, and the perfect dynamic state is received by the generalized integral controller. The fuzzy adjustor is set to adjust the parameters of proportional control and generalized integral control. Therefore, the proposed harmonic current tracking controller can decrease the tracking error of the harmonic compensation current, and have better dynamic response and robustness.

V. SIMULATION RESULTS

Simulation of a 10-kV system has been carried out with software MATLAB shown in the figure 12. The system parameters are listed in Table.1.

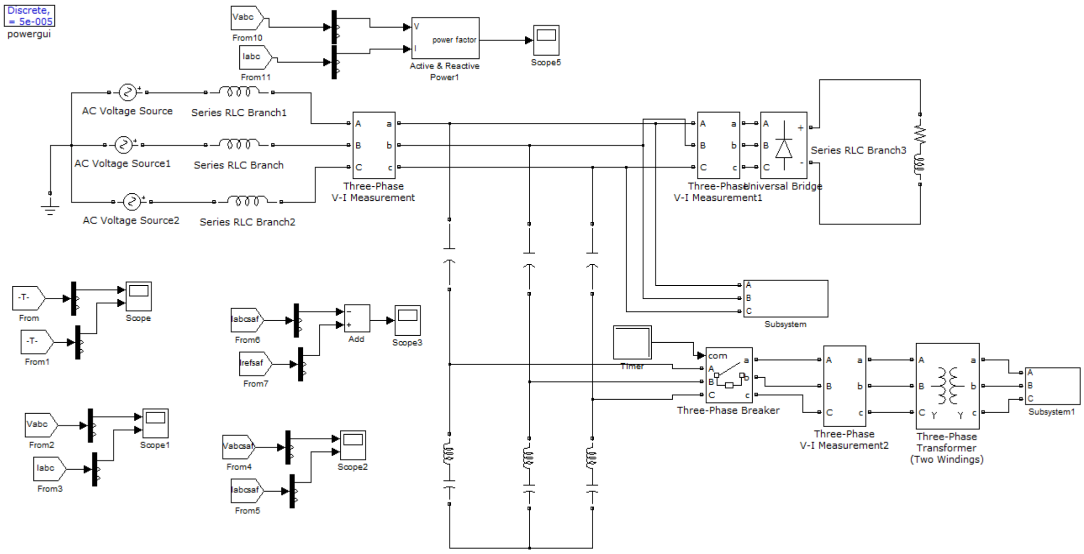
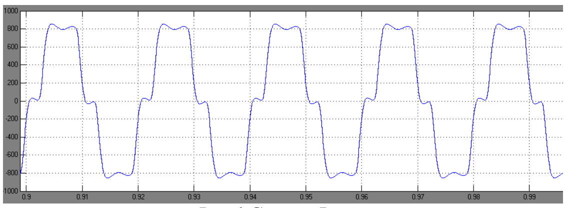


Figure 12: Matlab Simulation Circuit with adaptive fuzzy controller

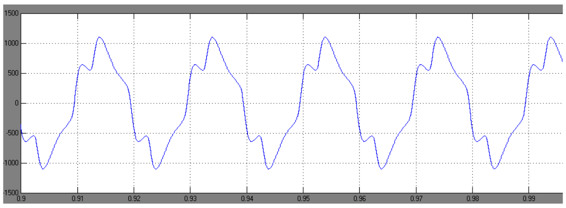
Table.1: System Parameters

	L/mH	C/ μ F	Q
Out put filter	0.2	60	
11^{th} turned filter	1.77	49.75	50
13^{th} turned filter	1.37	44.76	50
6^{th} turned filter	14.75	C_F: 19.65, C_1: 690	

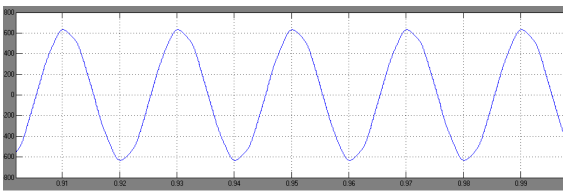
The PPFs are turned at the 11th and 13th, respectively. The injection circuit is turned at the 6th. In this simulation, ideal harmonic current sources are applied. The dc-side voltage is 535 V. Simulation results with the conventional PI controller and the proposed current controller are shown in Fig.13.
I_L, I_S, I_F, I_{apf}, and the error represent the load current, supply current, current though the injection capacitor, current through APF, and error of compensation. When the proposed controller is used, the error can be reduced to 10 A in 0.06 s. It is observed that compared to the conventional PI controller and generalized integral controller, the proposed controller has better dynamic performance.



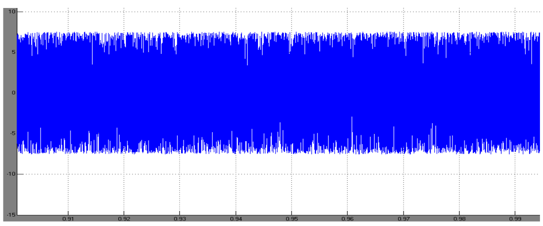
Load Current I_L



Current from APF I_{apf}



Source Current Is



Error

Figure 13 Simulation results of steady state performance with adaptive fuzzy controller

Fig.13 shows the steady-state performance of the IHAPF when fuzzy controller id used. From Fig. 13, it can be seen that after IHAPF with the conventional PI controller runs, the current total harmonic distortion reduces to 3.8% from 21.8%, and the power factor increases to 0.95 from 0.55.

When the conventional generalized integral controller is used, the current THD reduces to 3.3% from 21.8%, while after the IHAPF with the proposed PI controller runs; the current THD reduces to 1.8% from 21.8%. So it can be observed that the proposed current controller exhibits much better performance than the conventional PI controller and the conventional generalized integral controller. Table.2 shows Comparison of supply current THD and Power factor.

Table 2: Comparison without and with IHAPF

	THD	Power Factor
Without IHAPF	21.5%	0.69
With IHAPF	1.9%	0.94

VI. CONCLUSION

A novel hybrid APF with injection circuit was proposed. Its principle and control method was discussed. The proposed adaptive fuzzy-dividing frequency control can decrease the tracking error and increase dynamic response and robustness. The control method is also useful and applicable to any other active filters. It is implemented in an IHAPF with a 100-kVA APF system in a copper mill in Northern China, and demonstrates good performance for harmonic elimination. Simulation and application results proved the feasibility and validity of the IHAPF and the proposed control method.

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