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Fuzzy Logic Control of APF for Harmonic Voltage Suppression in Distribution System

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***Abstract*--Active power filter can prevent harmonic current from injecting into power system, but harmonic propagation cannot damp in distribution system where as voltage detection can do. This paper proposes an APF based on detection load current and harmonic voltage at the point of installation by using fuzzy control method. In addition, based on the relationship between the rated Volt-ampere of APF and the load Volt-ampere, the conductance value could adjust automatically. The objective of the shunt active filter is not only to compensate the harmonic compensation. Fuzzy controller gives the accurate values to pi controller. The input data will be split into the number of membership functions. Through those functions we would develop rules. By that rules it will give the more efficient output than conventional controllers. And the simulation results are performed to verify the validity and effectiveness of the shunt active filter equipped with the Fuzzy control.**

***Index Terms*—Active power filter, active power line conditioner, harmonic distortion, power quality, fuzzy logic**

1. Introduction:

A number of power electronic based appliances such as diode, thyristor, rectifiers & Industrial electric power source generate a large amount of harmonic current in power systems [1]. A parallel active filter is to be placed in parallel with the load to inject a harmonic current with the same amplitude as that of the load [2]. The load impedance, Z_L will become very low for harmonics when a parallel filter is connected on the side of the thyristor rectifier. In case of parallel active filter for a harmonic voltage source, a large series reactor must be placed on the load side to enhance the load impedance [3]. To compensate this minimum of 6% of series Inductance should be placed on the load side. The objective of the APF is not only to compensate the harmonic but also to damp the harmonics using voltage harmonic detection [4]. When the rated volt ampere is limit the harmonic compensation is less considered. Harmonic resonance between the line inductors and shunt capacitors for power factor correction made the harmonic voltage has become a serious problem [5]. When a parallel active filter is installed in a power system network, such as at a point of common coupling, the network impedance and main harmonic sources downstream from the installation point should be placed near the load to get good performance and to minimize the influence to the loads [6]. Installation of active filter at the end of the bus makes the required current rating of the active filter smaller than the installation on the begging bus due to installation at end of the bus it subjected to harmonic propagation [6-7]. Based on the relationship between the rated volt-ampere of the APF and the volt-ampere needed to compensate the non linear load, the conductance value could auto adjustment compared with the fixed gain G is determined by the active filter and mainly dominated by the detection circuit of the harmonics, delay time of the control circuit and current response of the PWM inverter of the active filter [8]. It has two problems mainly due to high capacity non-linear loads and the second is load current detection cannot damp voltage harmonic in distribution system using pi controller [9]. This paper proposes a fuzzy logic controller of a compound control method on the detection of load current and harmonic voltage. Computer simulations are performed to verify the validity and effectiveness of the shunt active filter equipped with the compound control.

2. The Principle of Compound Control:

Fig.1 shows the principle of compound control, each harmonic voltage amplifying by a gain G add to the load current amplifying by a gain K2 produces each current reference in Eq.(1).

$$i^*_c = -GV_{Th} + K_2 . i_L \qquad (1)$$

Assume the rated volt-ampere of APF is W_{APF}, the volt ampere needed to compensate the nonlinear load is W_{LOAD}, the volt-ampere needed to damp harmonic voltage in power system is W_{COM}, G is the equivalent harmonic conductance, and K2 is the compensation coefficient of load current detection. In reality practice there are three conditions

$W_{apf} \geq W_{load} + W_{com}$,

$W_{load} < W_{apf} < W_{load} + W_{com}$,

$W_{apf} < W_{load}$

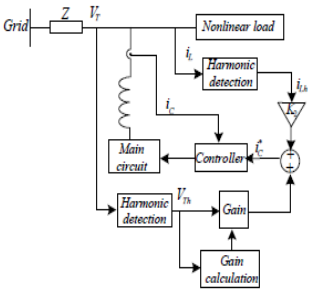

Fig.1: Principle diagram of compound control

Fig.2 shows the principle of auto gain adjustment under constrained volt-ampere with compound control V and V is the ac components of three phase voltages under the synchronization reference frame. The square of harmonic voltage l is calculated in Eq.(2), and the typical value V is defined in Eq.(3), if l is more than V, the counter counts up to Get a bigger G in the auto gain adjustment block[7], adjust G to a stable value until l is lower than V.

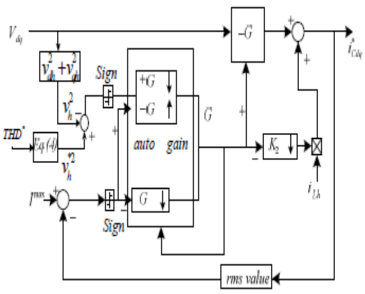

Fig.2: Auto gain adjustment under constrained volt-ampere

$$V_h^2 = v_{dh}^2 + v_{qh}^2 \qquad (2)$$

$$V_H^{*2}=3\ (V_S.THD)^{*2} \qquad (3)$$

In order to promise the volt-ampere of APF operates under rated volt-ampere, it’s necessary to limit G less than a certain value. The volt-ampere of APF relies on the rms value of voltage in the installation bus and the rms value of compensation current, as in Eq. (4).

$$D^h=3VI=3V\ \sqrt{(\ I_5^2\ +I_7^2+\ldots\ldots+I_n^2)} \qquad (4)$$

There are two feasible methods to limit the volt-ampere of APF under rated volt-ampere. The first is cut-off method; the second is scaling-down method. The former is simple but it will draw into new harmonic, we use the latter here. In Fig.2, a current limitation outer loop is added into current reference calculation block. Compared the rms value of current limitation I^m with the compensation current, if is less than I^m, G adjusts normally, otherwise, decrease G until is less than I^m

$$W_{apf}\geq W_{load}+W_{com}$$

In this condition, G is less than I^n, the current limitation outer loop does not work, G adjusts normally.

$$W_{load}< W_{apf}< W_{load} + W_{com}\ ,$$

The current reference scaling-down under the rated volt-ampere can be achieved by reducing G, as shown in Fig.2, the current limitation outer loop work. In this condition, decrease G to a certain value until is less than I^n.

$$W_{apf} < W_{load}$$

Decrease G to zero and keep G zero, and then, decrease K2 from 1 to a certain value until the APF is working on rated volt-ampere, the APF cannot keep the THD at the installation bus within a specified range, there are parts of nonlinear load current injecting into the distribution system.

3. Simulation Result of Traditional Line And Active Power Filter Using PI Controller:

Fig.3 depicts the simulation diagram, Us is pure grid voltage, a seventh harmonic current source of 1.4A (1.4%) is connected downstream of bus 2, a nonlinear load is installed on bus 3. The most serious harmonic propagation occurs around 350Hz. The parameters in the simulation are given as follows:

Grid voltage is 220V (line-to-line), 50Hz. The transmission line parameters are L=0.33mH, C=150uF; a diode rectifier with filter (2mH) inductor and load resistor (10Ω) is installed on bus 3; APF is installed on bus 3, the ac inductor is 0.4mH, DC capacitor is 400uF, switch frequency is 10 kHz.

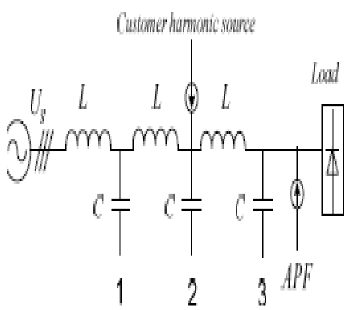

Fig.3: Simulation diagram

A) Results of Traditional Distribution Line:

The output results of traditional distribution line are shown in fig.4, fig.5, fig.6 at $W_{apf} \geq W_{load}+W_{com}$, $W_{load} < W_{apf} < W_{load}+W_{com}$, $W_{apf} < W_{load}$ respectively.

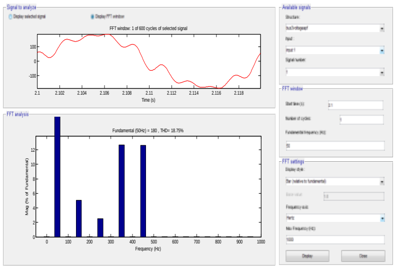

Fig.4: Output of traditional distribution line at time (2.1sec)

Fig.4: Shows the output voltage waveform at $W_{apf} \geq W_{load}+W_{com}$ and total harmonic distortion at time 2.1 sec is 18.75%

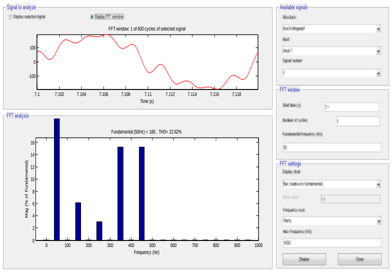

Fig.5: Output of traditional distribution line at (7.1sec)

The output voltage waveform at Wload< Wapf< Wload+Wcom, is shown in the figure 5 and total harmonic distortion at time 7.1 sec is 22.62%

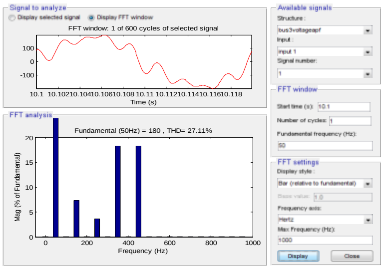

Fig. 6: Output of traditional distribution line (10.1)

The output voltage waveform and total harmonic distortion of the load at $W_{apf} < W_{load}$ is shown in the fig.6 the THD is around 27.11%

B) Active Power Filter Using PI Control Output Results:

The output results of compound controlled apf using PI controller of distribution lines are shown in fig 7 ,fig 8 ,fig 9 at $W_{apf} \geq W_{load}+W_{com}$, $W_{load} < W_{apf} < W_{load}+W_{com}$, $W_{apf} < W_{load}$ respectively.

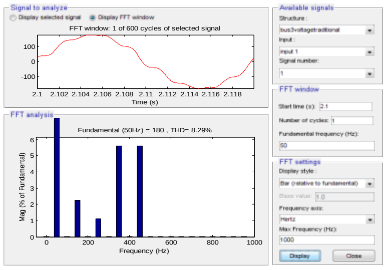

Fig.7: Output of active power filter in distribution line using pi controller (2.1sec)

Fig.7 shows the output voltage waveform at $W_{apf} \geq W_{load}+W_{com}$ and total harmonic distortion at time 2.1sec is 8.29%

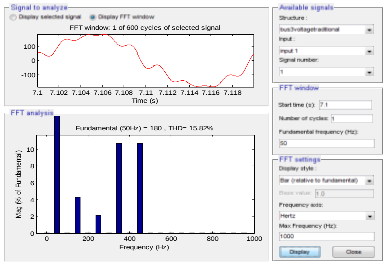

Fig.8: Output of active power filter in distribution line using pi controller (7.1sec)

The output voltage waveform at Wload< Wapf< Wload+Wcom, is shown in the fig.8 and total harmonic distortion is 15.82%

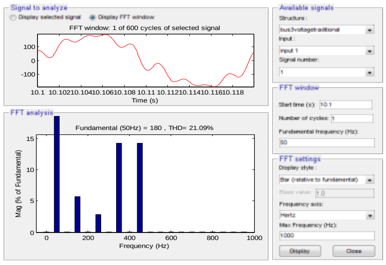

Fig.9: Output of active power filter in distribution line using pi controller (10.1sec)

The output voltage waveform and total harmonic distortion of the load at Wapf < W_{load} is shown in the fig.9 the THD is around 21.09%

Disadvantages of PI Controller

The Convention PI Controller require precise linear mathematical model of the system, which is difficult to obtain under parameter variation and non-linear load disturbances and the Proportional and Integral gains are chosen approximately.

4. Principle of Compound Control Using Fuzzy Logic Controller:

The active power filter is implemented with Pulse Width Modulation current controlled VSI Inverter. The APF consists of an six IGBT's or diode with a freewheeling diode, a d.c. capacitor-L filter, compensation controller(fuzzy logic) and gate signal generator (hysteresis current controller) is shown in figure. The hysteresis current controller is employed to generate switching signals for driving switches in the VSI. The current wave shape is limited by switching frequency of the voltage source Inverter.

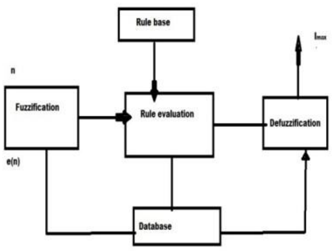

Fig.10: Block diagram of fuzzy logic controller

In a Control system, error between the reference and output can be labeled as Zero (z), positive small (PS), negative small (NS), Positive Medium (PM), negative medium (NM). The process involves converting a numerical variable to a linguistic variable; triangular or sine membership functions are developed for the fuzzufication

Rule Elevator

The basic fuzzy set operations needed for evaluation of fuzzy rules are AND (⋂), OR (⋃) and NOT (-)

AND Intersection : $\mu_{A \cap B} = \min [\mu_A(x), \mu_B(x)]$

OR Intersection : $\mu_{A \cup B} = \max [\mu_A(x), \mu_B(x)]$

NOT Intersection : $\mu_{A} = 1 - \mu_A(x)$

Defuzzification

The rules of FLC generate required output in a linguistic variable format (fuzzy number) according to real world requirements, linguistic variable have to be transformed to crisp output (real number).

Database

It stores the definition of the membership function required by fuzzifier & defuzzifier.

Rule Base

The rule base stores the linguistic control rules required by the rule evaluator. The reference currents (i_{sa}^*, i_{sb}^*, i_{sc}^*) are compare with actual source currents (i_{sa}^*, i_{sb}^*, i_{sc}^*) to generate switching signals for PWM inverter suing hysteresis current controller.

For faster current controllability and easy implementation the hysteresis current control method scores over other current control techniques. In this method, the PWM inverter, hysteresis current controller directly generates the switching signal of the three phases. In the case of Positive input current, if the error current e(t) between the desired reference current $i_{ref}(t)$ and the actual current $i_a(t)$ exceeds the upper hysteresis band limit, the upper switch of the inverter arm is become OFF and the lower is become ON than the current starts to decrease. If the error current e (t) crossed the lower limit of the hysteresis band, the lower switch of the inverter arm is become OFF and the upper switch is become ON. As a result, the current gets back into the hysteresis band and the cycle repeats as shown in fig.10 and the fuzzy logic controller results are shown in below in fig.11,fig12,fig13 at different loads $W_{apf} \geq W_{load} + W_{com}$, $W_{load} < W_{apf} < W_{load} + W_{com}$, $W_{apf} < W_{load}$ respectively.

5. Active Power Filter Using Fuzzy Control Output Results:

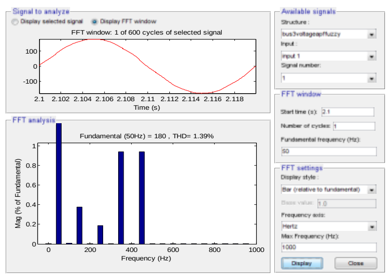

Fig.11: Output of active power filter in distribution line using fuzzy controller (2.1sec)

Fig.11 shows the output voltage waveform at $W_{apf} \geq W_{load}+W_{com}$ and total harmonic distortion is about 1.39%

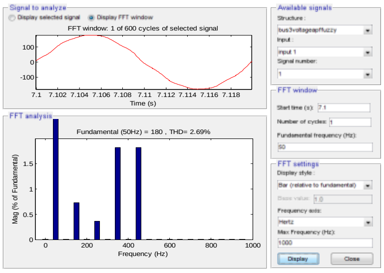

Fig.12: Output of active power filter in distribution line using fuzzy controller (7.1SEC)

The output voltage waveform at Wload< Wapf< Wload+Wcom, shown in the fig.12 and total harmonic distortion is about 2.9%

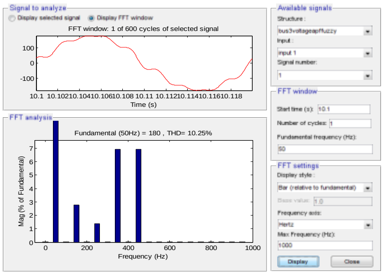

Fig.13: Output of active power filter in distribution line using fuzzy controller (10.1SEC)

The output voltage waveform and total harmonic distortion of the load at Wapf < W_{load} is shown in the fig.13 the THD is around 10.25%

6. Results:

The total harmonic distortion of the distribution line is observed under PI Controller and FUZZY logic controller. By using PI Controller, the total harmonic distortion in the line about 8% and by using Fuzzy logic control, the total harmonic distortion is reduced to 1.98%., which is about 5% less than the PI controller.

TOTAL HARMONIC DISTORTION			
LOAD CONDITION	AT LOAD 1	AT LOAD 2	AT LOAD 3
Without PI Controller	18.75%	22.62%	27.11%
With PI Controller	08.29%	15.82%	21.09%
With FUZZY Controller	01.39%	2.9%	10.25%

By observing the above table it is clear that APF with FUZZY CONTROL will give less total harmonic distortion when compared with and without PI Controller.

7. Conclusion:

In this paper, the fuzzy logic control of active power filter based detection of load current and voltage to solve the problem that the load current detection apf cannot change the harmonic impedance in distribution system. In this the rated volt-ampere and the load volt ampere, the conductance value could be adjusted automatically. computer simulation is constructed to verify the validity and effectiveness of the pi controller and fuzzy logic controller for the functioning of apf. The fuzzy logic controller provides superior performance in harmonic distortion with the PI controller. The fuzzy logic based apf system is expected with the IEEE standard harmonics.

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