FUZZY LOGIC CONTROL OF THE ENERGY STORAGE CAPACITOR OF A THREE PHASE ACTIVE POWER FILTER IN UNBALANCED NETWORK

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Abstract:

This paper deals with a new control scheme for a parallel 3 phases active filter to optimize the energy storage of the dc voltage and to adjust it to its reference. For that purpose, two DC voltage controllers, a proportional integral PI and fuzzy logic controller are developed and compared. To reach this objectives, an adaptive hysteresis band current control technique is employed to derive the switching signals to active filter and a new algorithm based on an extension of the p, q method is used to determine suitable current references . This investigation shows that a trade off must be found between the criterion to limit the DC voltage fluctuations to limit the THD of the mains current and to minimise voltage variation of the DC capacitor and settling time. Simulation results are presented and discussed showing the effectiveness of fuzzy logic control to optimise the energy storage of the DC capacitor of an active power filter.

Key word:
Shunt active power filter, fuzzy logic control, and optimization.

1. INTRODUCTION

The wide use of non-linear loads such as static power converters is at the origin of harmonic pollution problems. These loads draw non-sinusoidal currents that cause harmonic voltage drops across the network impedance, resulting in distorted voltages. This has serious consequences such as increased power system losses, quick ageing of materials, and excessive heating in rotating machinery, significant interference with communication circuits and others [1].

To avoid these undesirable effects, traditional solutions using passive LC filters were used but appeared ineffective due to their inability to adapt to the network characteristics variations. Therefore, recent progress in switching devices has resulted in the formulation of several active filter topologies, not only for currents or voltages compensation but also for voltage dips, flicker, imbalance or other kinds of disturbances [2,5].

Generally, performances of active power filter depend on design of power semiconductor devices, design of coupling elements (L_f, C_f) and on methods used to determine current references and control dc capacitor voltage.

This paper present the general equations that relate the different compensation objectives of a shunt active power filter [1,4,5], for the case of three phases, three-wire systems. Along the various methods used to determine suitable current references, a new algorithm based on an extension of the p, q [9,10] method is used to provide

balanced sinusoidal currents to the source under several means voltages or load asymmetries. Figure.1. show Block diagram of the proposed work.

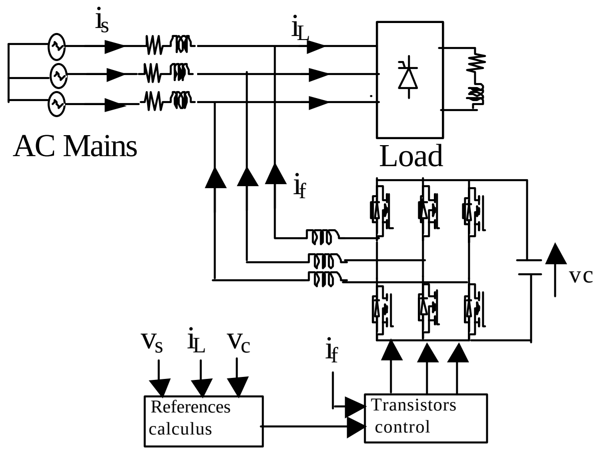

Fig.1: Block diagram of the proposed work

The aim of this paper, in one hand, is to calculate the harmonics current and control of active power filter currents, among various PWM techniques. Hysteresis

band current control PWM method is used because of it simplicity of implementation besides fast response current loop and technique does not need any formation about system parameters, however, the current control with a fixed hysteresis band has the disadvantage that the PWM frequency varies within a band because peak to peak current ripple is required to be controlled at all points of fundamental frequency. As a result, the source current contains excess of harmonics. An adaptive hysteresis current control PWM technique where the band can be programmed as a function of load and supply parameters to optimize the PWM performance has been used. In other hand, to optimize the energy storage, to adjust the DC voltage to its reference and to attenuate harmonic frequencies resulting from power fluctuations, a proportional integral PI and fuzzy logic controller are proposed and compared to prove the effectiveness of the control strategy.
Simulation results are presented and discussed showing the effectiveness of fuzzy logic control to optimize the energy storage of the DC capacitor of an active power filter.

2. ACTIVE POWER FILTER ANALYSIS.

2.1 Nonsinusoidal balanced load currents

For three power system, instantaneous network voltages and lead currents are expressed as: [3]

$$v_{si}(t) = V_s\sqrt{2}\sin(\omega t - \frac{2.\pi}{3}(i-1)) \quad i=(1,2,3) \quad (1)$$

$$i_{Li}(t) = \sum_{n=1}^{\infty} I_{Li}\sqrt{2}\sin[n(\omega t - \frac{2\pi}{3}(i-1)) - \varphi_n] \quad (2)$$

The main currents and instantaneous power supplied from the mains after compensation are:

$$i_s(t) = \sqrt{2}.I_s.\sin(\omega t - \frac{2\pi}{3}(i-1)) \quad i=(1,2,3) \quad (3)$$

$$p_s(t) = \sum_{i=1}^{3} v_{si}(t).i_{si}(t) = P_S = 3V_S I_S$$

P_S is the DC component of ps(t), and represents the real power supplied from the mains.
The power consumed by the non-linear load is:

$$p_L(t) = \sum_{i=1}^{3} v_{si}(t).i_{Li}(t) = P_L + \tilde{p}_L(t).$$
$$P_L = 3V_s I_{L1}\cos\phi_1. \quad (4)$$

Where P_L is a DC component relating to the real power absorbed by the load and $\tilde{p}(t)$ is the AC component due to the load and is represented as:

$$\tilde{p}_L(t) = 3V\sum_{h=1}^{\infty} k_{p6h}\cos(6h\omega t - \varphi_{p6h})$$

$$k_{p6h} = \sqrt{I_{6h+1}^2 + I_{6h-1}^2 - 2I_{6h-1}I_{6h+1}\cos(\varphi_{6h+1} - \varphi_{6h-1})} \quad (5)$$

$$tg\,\varphi_{p6h} = \frac{(I_{6h-1}\sin\varphi_{6h-1} - I_{6h+1}\sin\varphi_{6h+1})}{(I_{6h-1}\cos\varphi_{6h-1} - I_{6h+1}\cos\varphi_{6h+1})}$$

The power that is injected into the converter is represented as:

$$p_f(t) = p_L(t) - P_S = P_L - P_S + \tilde{p}_L(t)$$
$$p_f(t) = P_f + \tilde{p}_f(t). \quad (6)$$
$$P_f = P_L - P_s.$$

Where P_f and $\tilde{p}_f(t)$ are the DC and AC components of pf respectively [1].
Equation.6. gives the power exchange between active filter, non linear load and supply under transients caused by the load step change. The power transfer is give by DC voltage variation, witch reestablished by the DC regulator figure 2.

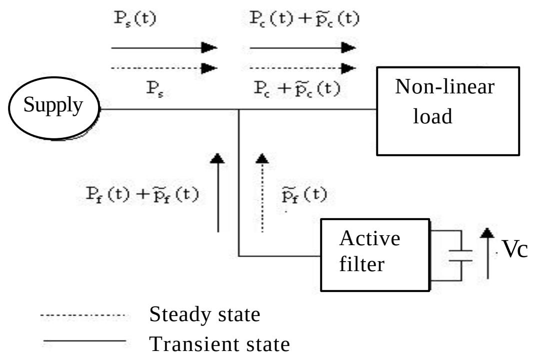

Fig.2. Power exchange between active filters, non- linear load and the supply

The average value of the load power $p_L(t)$ during a mains cycle does not affect the average voltage of DC capacitor. However, the AC components of $p_L(t)$ may result in voltage fluctuation of DC capacitor. Hence, the DC voltage can be represented as:

$$v_c(t) = V_c + \tilde{v}_c(t) \quad (7)$$

Where Vc is the average voltage of DC capacitor, and $\tilde{v}_c(t)$ is the fluctuating voltage which depends on the harmonic order.
In steady state, the input instantaneous power must be equal to that of the output, that is:

$$\tilde{p}_f(t) = \tilde{p}_L(t)$$

The current harmonic supplied from the DC capacitor can be represented by:

$$i_c(t) = \frac{\tilde{p}_f(t)}{V_c} \quad (8)$$

However, the voltage fluctuation of the DC capacitor can be obtained and represented by:

$$\tilde{V}_c = \frac{1}{C_f}\int_0^t i_c(t)dt \quad (9)$$

$$\tilde{v}_c(t) = -\frac{1}{C_f.V_c}\sum_{n=1}^{\infty}\frac{P_{6n}}{6n\omega}\sin(6n\omega t-\varphi_{6n}).$$

The voltage fluctuation of the DC capacitor must be regulated to an acceptable level to obtain a good compensating accuracy and high operation efficiency. From equation.9, the voltage fluctuation of the DC capacitor depends on the order and the magnitude of AC power component $\tilde{p}(t)$ and on the voltage of DC capacitor and its value. However, the lower the frequency, or the larger the magnitude of the AC power component $\tilde{p}(t)$, the larger of the DC capacitor required. Then, the modification of C_f value can have serious consequences on the DC voltage variations. Thus, the capacitor value will be determined by the response of the DC voltage controller under transients caused by load step changes [3,7].

If, a power imbalance occurs, the active filter has to consume (pf<0), then, the DC voltage variation increases, if pf>0 then, the DC voltage variation decreases. In this case.

$$p_f(t)=P_L-P_S=3V_s(I_{L1}\cos\varphi_1-I_s)$$
$$=\pm 3V_s.I_0. \quad (10)$$
$$I_0=\left|I_{L1}\cos\varphi_1-I_s\right|.$$

In steady state, the active power filter do not exchange any real power with network, then, we have:

$$P_f = P_L - P_S \quad (11)$$
$$I_s = I_{L1}\cos\varphi_1$$

If switching losses are neglected the real power absorbed by the active power filter can be expressed as:

$$P_f = -\frac{1}{2}C_f\frac{dV_c^2(t)}{dt} \quad (12)$$

The model for the real power analysis can be represented as shown in figure.3

2.2 Nonsinusoidal unbalanced load currents

In the assumed unbalanced current condition, the instantanoues active and reactive powers can be written:

$$P = \overline{P} + \tilde{P} = P + P_{2\omega} + P_h$$
$$q = \overline{q} + \tilde{q} = q + q_{2\omega} + q_h$$

With:

$$p_{2\omega} = -3V_{s1+}I_{l1-}\cos(2\omega t-\varphi_{1-}) - 3V_{s1-}I_{l1+}\cos(2\omega t-\varphi_{1+})$$
$$q_{2\omega} = 3V_{s1+}I_{l1-}\sin(2\omega t-\varphi_{1-}) + 3V_{s1-}I_{l1+}\sin(2\omega t-\varphi_{1+})$$

Where $\tilde{p}_{2\omega}$ and $\tilde{q}_{2\omega}$ are two components with frequency 2ω, caused by asymmetrical three-phase fundamental components of load currents (negative sequence current), and $\tilde{p}_h$, $\tilde{q}_h$ are other harmoniques.

3. DC VOLTAGE CONTROL.

The aim of the regulator is to adjust vc(t) to its reference and to attenuate harmonic frequencies resulting from power fluctuation.

To realize these objectives, a proportional integral and fuzzy logic controllers will be considered and compared.

3.1 Proportional integral controller PI. [14]

The closed loop transfer function of DC voltage is given by figure3. ki and kp are controllers parameters. The required system natural frequency w_n imposed by the voltage controller must be smaller than the minimum frequency of current compensation to be injected by the converter, to avoid interactions between the voltage controller and harmonics currents injection system [1.3.6.8].

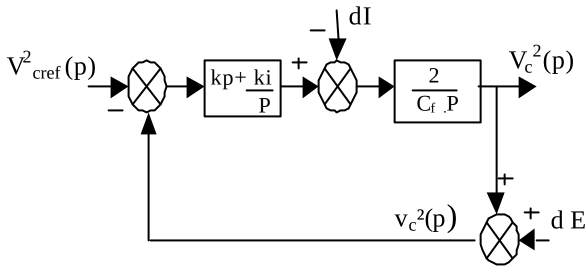

Fig.3. DC voltage control using PI structure

dI is the internal disturbance of the system due to real power P_L and dE is the external one represented by the DC voltage fluctuations due to the alternating power $\tilde{p}(t)$. This system has been simulated and compared to fuzzy logic controller.

3.2. Fuzzy logic controller

Among the various power filter controller, the most promising is the fuzzy logic control. A fuzzy controller consists of stages: fuzzification, knowledge base, inference mechanisms and defuzzification. The knowledge bases designed in order to obtain a good dynamic response under uncertainty in process parameters and external disturbances.

In this application, the fuzzy controller is based on processing voltage error and change error as shown in figure 4.

The determination of the membership functions quite depends on the designer's experiences and experts' knowledge. It is not trivial to choose a particular shape that is better than others. Triangle shaped membership function has advantages of simplicity and easier implementation and is chosen in this application. Fig.5 shows the membership functions of the input and the output linguistic variables [11,12].

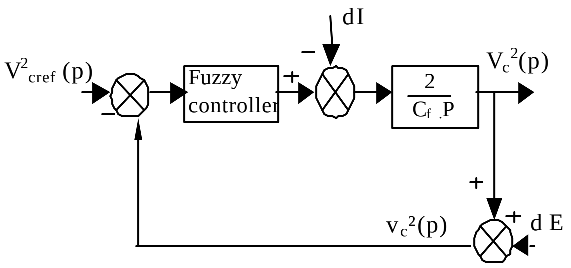

Fig.4. DC voltage control using fuzzy contoller structure

In the design of a fuzzy control system, the formulation of its rule set plays a key role in improvement of system performance. The rule table s constructed to contain the 49 rules as shown in table.1. Where LP, MP, ... are linguistic codes (LP: large positive, MP: medium positive, SP: small positive, ZE: zero, LN: large negative, MN: medium negative, SN: small negative).

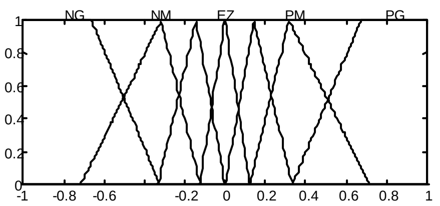

Fig.5. Membership functions for input variables (e, de) and output variable

de/e	NG	NM	NP	EZ	PP	PM	PG
NG	NG	NG	NG	NG	NM	NP	EZ
NM	NG	NG	NG	NM	NP	EZ	PP
NP	NG	NG	NM	NP	EZ	PP	PM
EZ	NG	NM	NP	EZ	PP	PM	PG
PP	NM	NP	EZ	PP	PM	PG	PG
PM	NP	EZ	PS	PM	PG	PG	PG
PG	EZ	PP	PM	PG	PG	PG	PG

Table.1.

Various inference mechanisms have been developed to deffuzzify the fuzzy rules. In this paper, we applied max-min inference method to get implied fuzzy set of the turning rules.

The imprecise fuzzy control action generated from the inference engine must be transform to a precise control action in real applications. The center of mass method was used to deffuzzify the implied fuzzy control variables.

4. CURRENT CONTROL. [13]

Hysteresis band instantaneous current control PWM technique is popular because of its simplicity of implementation, fast current control response and inherent peak current limiting capability. However, the current control with a fixed band has the disadvantage that the modulation frequency is not constant in a band and as result generate non-optimum current ripple.

An adaptive hysteresis band current control PWM technique can be programmed as a function of the load and supply parameters to minimize the influence of current distortions on modulated waveform. Which is given by equation .13.

$$\Delta I=\frac{V_C}{6.f_c.L_{f'}}\left(1-\frac{9L_f^2}{V_c}\left(\frac{v_{s1}(t)}{L_f}+\frac{di^*_{f1}}{dt}\right)^2\right) \qquad (13)$$

fc is modulation frequency, i_f* is the reference current.

Fig.6 show the bloc diagram of the adaptive hysteresis band current control using equation 13.

The reference current is the sum of current compensation of the load and current given by the DC voltage control.

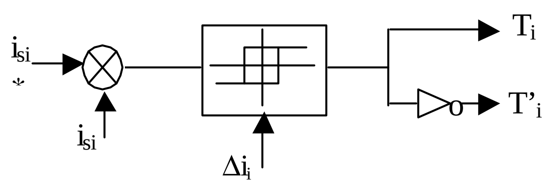

Fig.6 . Simplied model for an adaptative PWM hysterisis -band current control

5. SIMULATION RESULTS

Performance characteristics of the active power filter system with proposed control scheme are given in fig.7 illustrating the steady state and transient behavior at different loads.

Fig.7 show source voltage, load current, active power filter current and the source current. When the load increases, the source current responds very quickly and settle to steady state value within a cycle. The active power filter current increases almost instantaneously to feed the increased load current demand by taking the energy instantaneously from DC capacitor. DC voltage capacitor recovers within a cycle.

The active power filter meets the requirements of harmonic and reactive components of the load current and maintains the source current sinusoidal in transient and steady state conditions.

The performance of the proposed control algorithm of the active power filter is found to be excellent and the source current is practically sinusoidal and in phase with the source voltage.

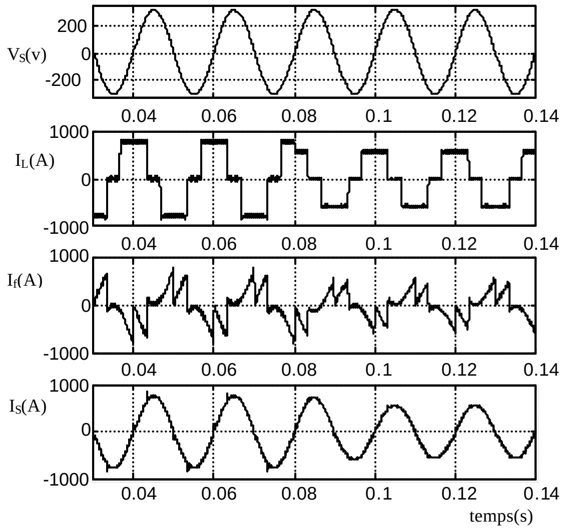

Fig.7 : performance of AF system under load change, with:
V_S(v) :voltage source, i_L: load current, i_f AF current, i_s: source current.

Fig.8 represents performance of PI regulator for different frequencies, it shows that, when the frequency fc increase, the DC voltage variation across the capacitor under the step change of the load current decreases but the DC voltage fluctuations increases. This investigation shows that a trade off must be found between the criterion to limit the DC voltage fluctuation, then to limit the THD of the mains current and to minimize voltage variation ΔVc and settling time.

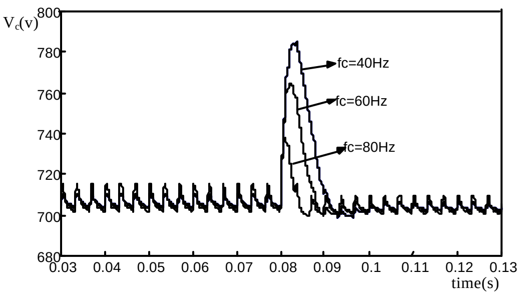

Fig 8. DC voltage variation for different frequencies load under step changes. C_f=1mF

Fig.9 shows the DC voltage variations during transient state using PI controller for different values of capacitor C_f, if C_f value is decreased the DC voltage fluctuations and DC voltage variations increases. But with fuzzy controller fig10, we can reduce the capacity value with minimum DC voltage fluctuations and variation, in this way the design of C_f is optimized.

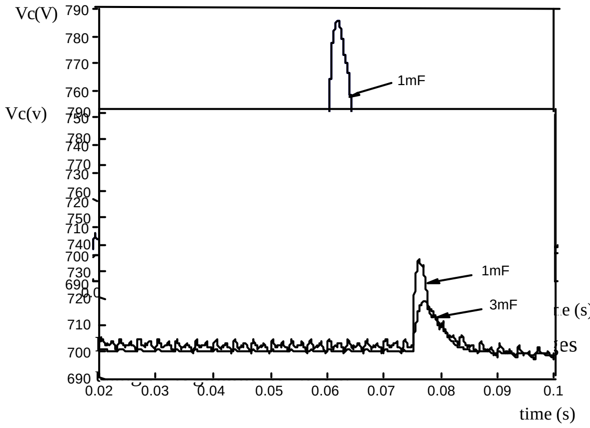

Fig..10 . DC voltage variations under load step changes using fuzzy regulator

Fig.11 presents the system performance for an unbalanced nonlinear load such as asingle phase rectifier connected between phases 1 and 3. The harmonic spectra of the load i_{1R} and grid i_{1L} currents are also presented. All the load harmonic currents are unbalanced systems of odd orders, including the first harmonic one The load harmonic unbalanced current systems and also the first harmonic negative sqequence system are compensated by the converter. Thus the mains currents are a positive sequence first harmonic system.

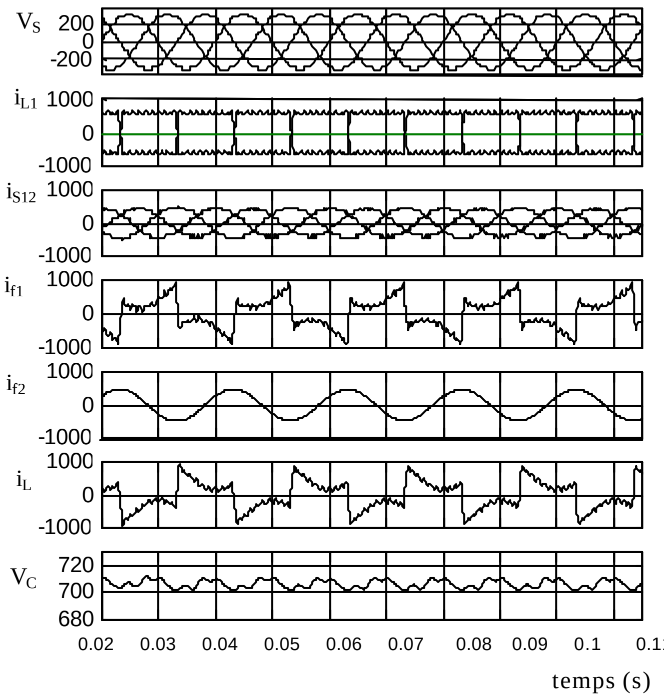

Figure 11.Active power filter steady –state performance for the currents compensation of non sinusoidal (á=30°)

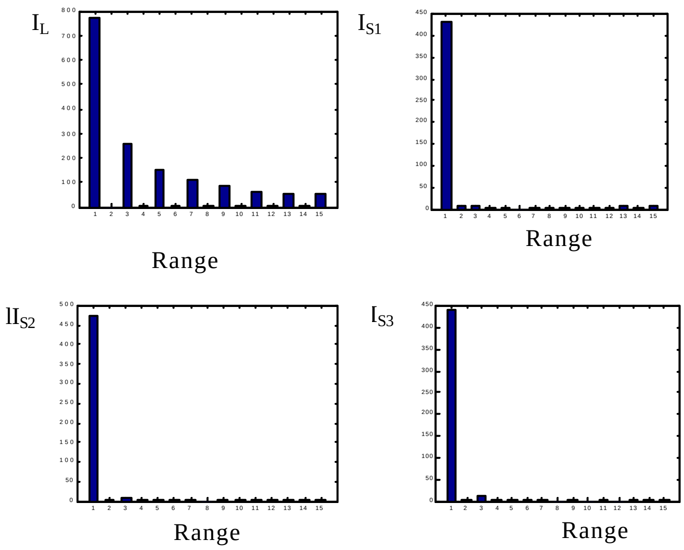

Fig 12 The load and the source spectrum

6. CONCLUSION

This paper demonstrated the validation of simpler control approach for the parallel active power filter. The active power filter is enable to eliminate the harmonic and the reactive components of the load current resulting in sinusoidal and unity power factor source currents. It is observed that the source current remains below the load current even during transient conditions. Two DC capacitor voltage controllers have been studied to improve the active power filter performances and reduce the design of energy storage capacitor. The fuzzy controller can easily be adapted to others more severe constraints.

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