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Model Predictive Current Control of Single Phase Shunt Active Power Filter

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Abstract

A Model Predictive Current Control (MPCC) of single phase Shunt Active Power Filter (SAPF) is introduced in this paper. A single phase Voltage Source Inverter (VSI) is used as a SAPF to compensate the current harmonic and reactive power. A DC link capacitor voltage regulation based Proportional - Integral (PI) control algorithm is adopted for determining the reference current. A bridge rectifier with RL and RC loads are acting as a Non-Linear Loads (NLL). The harmonic compensation performance of SAPF and associated control methods like switch on response and transient responses were verified through a simulation with MATLAB software.

Keywords: Model predictive current control, single phase shunt active power filter, total harmonic distortion

1. Introduction

The shunt active power filter mainly is made up of power electronic components and passive energy storage components which includes capacitors and inductors. The modern power electronic loads behave as NLL to generate the sizable amount of harmonics. Some examples of these loads are variable speed drives, switched mode power supply, electric furnaces, etc. Due to harmonic current presents in the power system which can affect the grid voltage and lead to numerous adverse effects which includes overheating of electrical equipment, interference in communication systems and failures of solid state equipment.

Usually, passive harmonic filters are mainly used in power systems to limit the current harmonics. But, they have many disadvantages such as tuning problems, large size and poor performance for mitigating high order harmonics.

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In order overcome these harms, the SAPF has been developed to compensate the current harmonic distortion. The single phase SAPF is normally used in educational buildings and commercial applications. The single phase SAPF operates at peak frequencies which also leads to attain improved performance condition [1-2].The SAPF performance mainly depends on two factors, first one is reference current extraction and second one is current control scheme. The reference current extraction has to be done by PI control algorithm scheme which is simple in nature to design and implement it for real time purpose.

And various methods have been proposed for current control of single phase SAPF such as PWM based control [3], hysteresis current control [4], double band hysteresis control [1] and predictive PWM control [6] method. From the literature it has been observed that there is a need of simple and accurate current tracking ability technique. Henceforth in this paper a MPCC algorithm is used in single phase SAPF due to its high accuracy, simple concept and easy addition of system nonlinearities. Recently many researchers show their interest towards MPCC for power converters [7-10]. Generally, in SAPF application the MPCC algorithm is used to control the SAPF power switches to generate the opposite harmonics and to inject them at the point of common coupling (PCC) for compensating current harmonic and reactive power. So in this manuscript the MPCC of single phase SAPF is introduced and a performance of SAPF and associated control methods like switch on response and transient responses were verified through a simulation with MATLAB software.

This manuscript is structured as follows. The model of single phase inverter is discussed in section 1. The control strategies of SAPF are presented with clear illustration in section 3. In Section 4, detailed simulation results are given. Finally the paper ends with suitable conclusion.

2. Single Phase Voltage Source Inverter Model

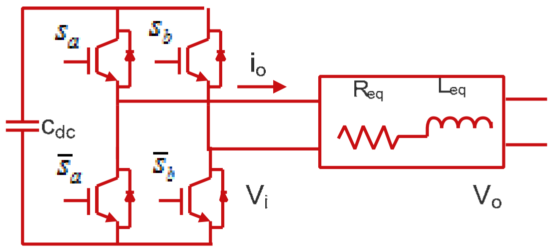

Fig. 1.Single phase VSI model.

The model of single phase VSI is presented in Fig. 1. The output voltage can be derived from DC link voltage and VSI switching states as follows

$$V_i = V_{dc}(S_a - S_b) \tag{1}$$

Where V_i - output voltage of inverter, V_{dc} - DC link voltage and S_a & S_b - control signal of inverter. The mathematical model of single phase SAPF from the Fig.2 is expressed as

$$V_o = V_i - R_{eq} i_o - L_{eq} \frac{di_o}{dt} \tag{2}$$

Where R_{eq} and L_{eq} are the equivalent resistance and inductance of single phase SAPF system.

3. Control Strategy of SAPF

The control strategy of shunt active filter is the significant portion for its effective performance in order to mitigate the harmonics and which can be mainly implemented over and done with in two steps,

- Extraction of reference compensating current
- Generation of gate signals for power switching devices of VSI

The single phase SAPF model is shown in Fig. 2.

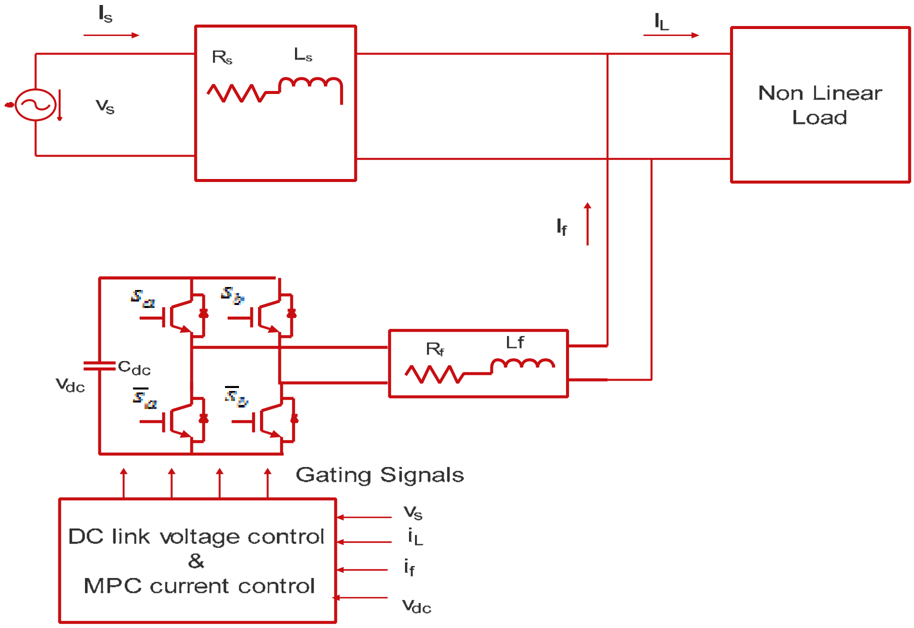

Fig. 2. Single phase SAPF model.

3.1. Extraction of reference compensating current

PI control algorithm is employed to extract the reference compensating current for harmonic compensation. Initially by comparing voltage across the capacitor with a reference value, which is fed to a PI controller. Then the PI controller output is multiplied by a unit amplitude of sine wave to obtain the reference source current (Is, ref). The signal of the supply voltage is used to generate the sinewave, with unit amplitude and in phase with the mains voltage. Finally the reference source current is subtracted from the load current which gives reference filter current.

Table 1. Single phase SAPF Parameters.

Description	Variable	Value
Supply voltage	Vs	230 V
Supply frequency	f	50 Hz
DC link capacitor voltage	Vdc	400 V
DC link capacitor	Cdc	4700 µF
source resistance	Rs	0.1 Ω
source inductor	Ls	1 mH
Filter inductor	Lf	5 mH
Filter resistance	Rf	0.01 Ω
Sampling Time	Ts	10 µs

3.2. Model predictive current control

This technique is used to controls switches of an SAPF such that it can force the filter current to track the filter reference current. The block diagram of MPCC scheme is shown in Fig. 3.

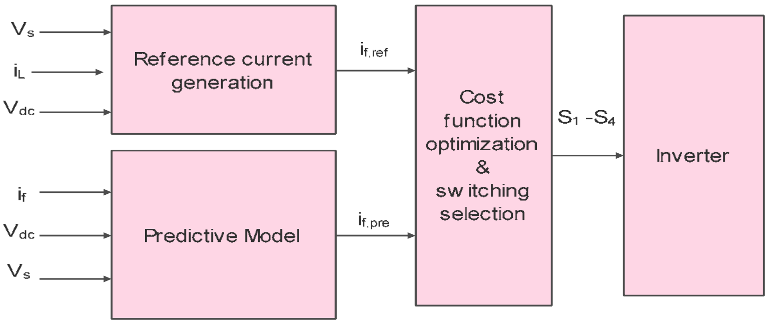

Fig. 3. Model Predictive Current Control of Single phase SAPF

The MPCC technique uses a system model, DC link voltage and inverter switching state for predict the future value of filter current. And based on the information the optimal switching state is selected by the controller, which will apply to the switches of an SAPF. The possible predicted output current can be expressed as follows

$$i_{f,pre}(k+1)=\frac{T_s}{L_{eq}}(V_i(k)-V_s(k))+\left(1-\frac{R_{eq}T_s}{L_{eq}}\right)i_f(k) \tag{3}$$

where Ts is the controller sampling time value.

So as to apply optimal switching signal to the SAPF, the all possible predicted filter currents are compare with filter reference current using cost function ‘g’. It can as represented as

$$g=(i_{f,ref}(k+1)-i_{f,pre}(k+1)) \tag{4}$$

The MPCC algorithm is implemented in MATLAB embedded function block. The functional block operates in the discrete update technique which is based on sampling time defined for the algorithm. The algorithm consists of following steps.

In step 1 the parameters used in this algorithm are initialized with specific values: Set the equivalent resistance and inductance values as 0.01 Ω and 6mH respectively, define the sampling time as 10 µs, and optimal cost function value is infinity.

In step II the estimate the voltage vectors and to predict the filter current at the instant of (k+1) by using Eqs. (1) and (3).

The cost functions are calculated in step III using Eq. (4). Finally the minimum ‘g’ value is selected and corresponding switching signals given to the SAPF for proper compensation.

4. Simulation results

A single phase SAPF model is developed and evaluated in MATLAB/Simulink software. The MPCC technique was programmed using embedded function block and it can operate at a sampling period of 10 µs. The steady and dynamic state conditions are performed to examine performance of single phase SAPF. And it consists of two types of nonlinear loads. The first nonlinear load is made by using a single-phase bridge rectifier with R-L load and the second load is designed using same rectifier with R-C Load. The THD value source current before single phase SAPF connected to the point of common coupling is 40.11 % for RL-load and 77.58 % for RC-load are shown in Fig 8. The parameters of SAPF are represented in Table.1. The performance of SAPF is analyzed with two cases namely switch on response and transient response.

4.1. Switch on Response

In switch on response condition the single phase SAPF is turned on at t = 0.1s for both RL and RC load conditions. The performance indices of SAPF like settling time, over shoot and under shoot of (V_{dc}) and THD of source current are listed in Table 2. In Fig 4 and 5, shows the supply voltage (Vs), DC link voltage (V_{dc}), supply current (I_s), load current (I_L), and SAPF filter current (I_f) for both RL and RC-load.

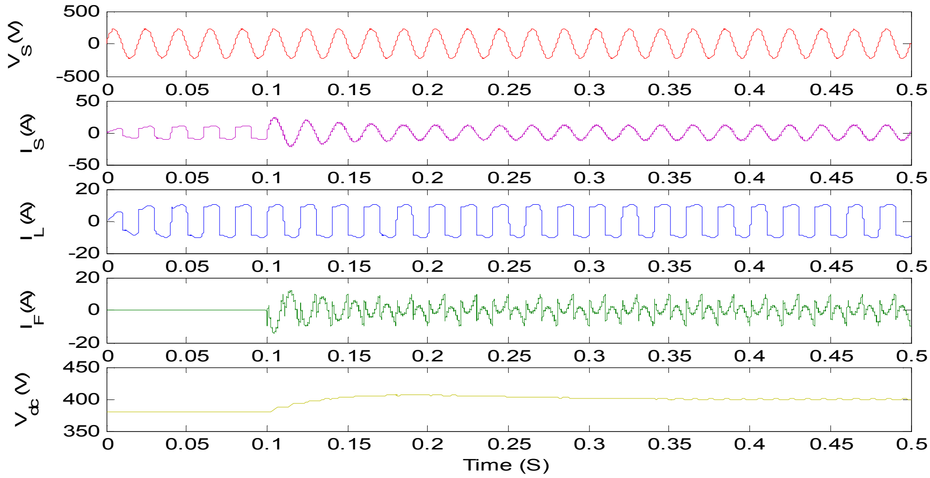

Fig. 4. Switch on response of RL load

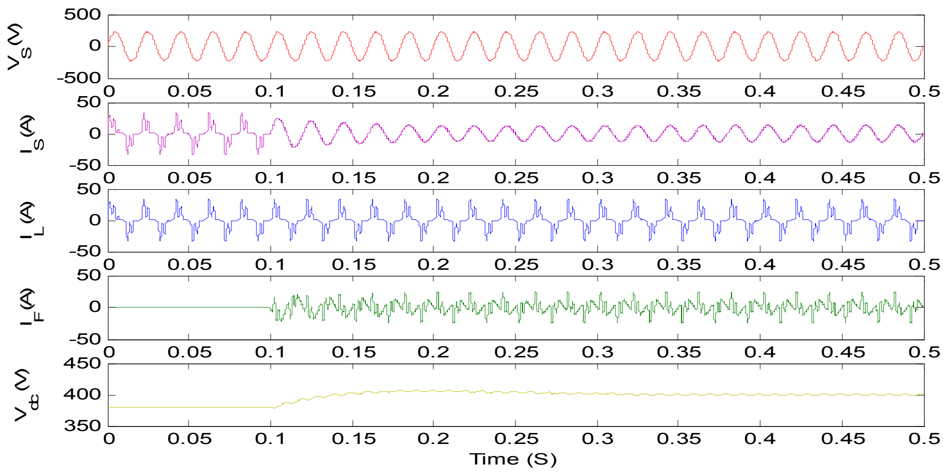

Fig. 5. Switch on response of RC load

The above figures shows that, the supply current becomes sinusoidal in nature and in phase with supply voltage when the single phase SAPF is switched on at 0.1s for both RL and RC load conditions. The DC link voltage is remains constant for whole SAPF operation. The corresponding THD and settling time values are given in Table 2.

4.2. Transient Response

In transient response analysis, two scenarios are considered. In first scenario the load changes from RL-load to RC-load at 0.5s and RC-load to RL-load at 0.5s in second scenario. In Fig 6 and 7 represents the supply voltage (Vs), DC link voltage (V_{dc}), supply current (I_s), load current (I_L), and SAPF filter current (I_f) for both load changes.

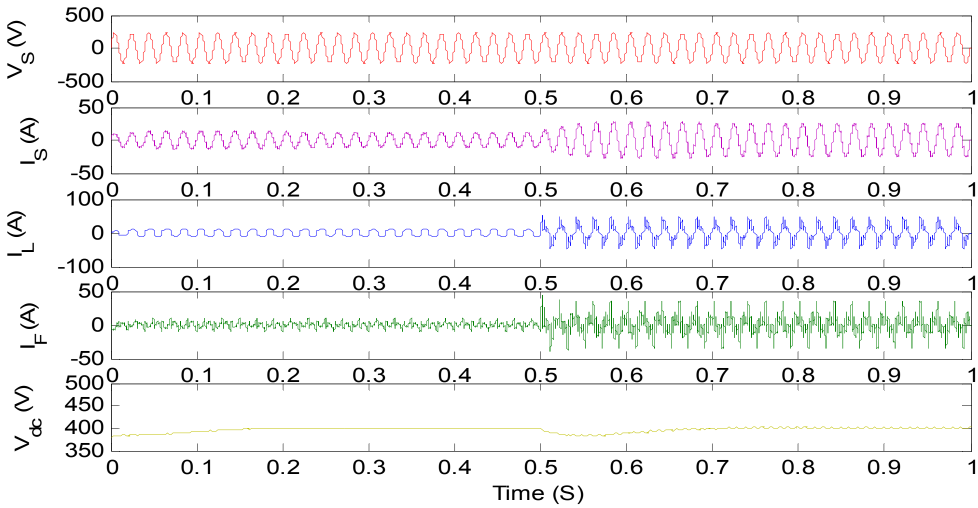

Fig. 6. Transient response of SAPF (load changes from RL to RC load)

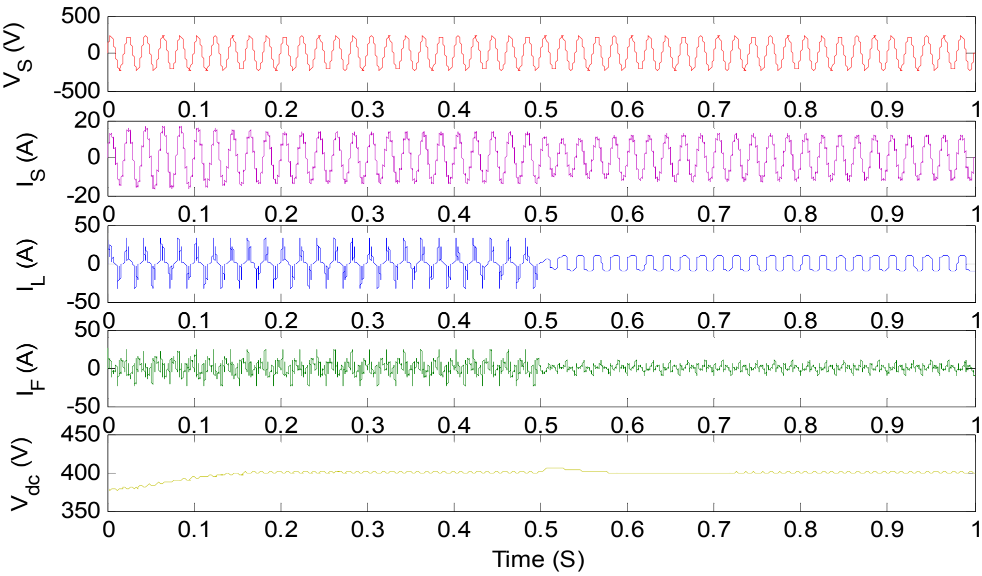

Fig. 7. Transient response of SAPF (load changes from RC to RL load)

In Fig. 6 and 7 shows that the transient response of single phase SAPF under load changes. The source current becomes remains sinusoidal in nature and DC link voltages return to its set value.

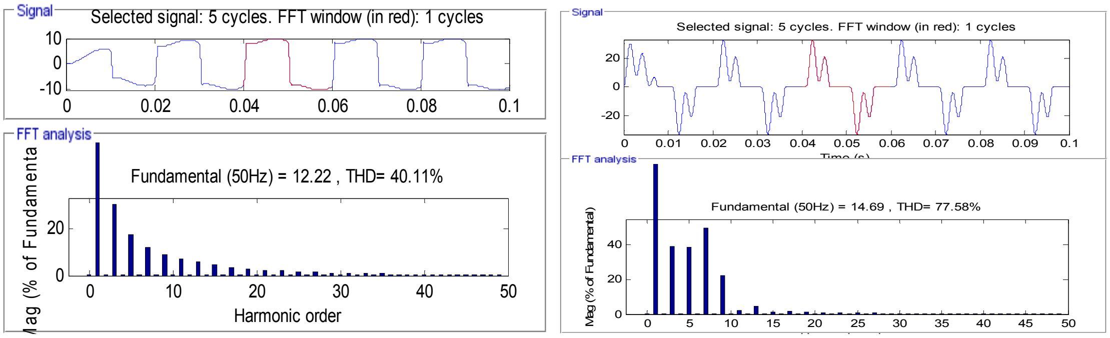

Fig. 8. FFT analysis of source current before compensation a) RL-load and b) RC –load

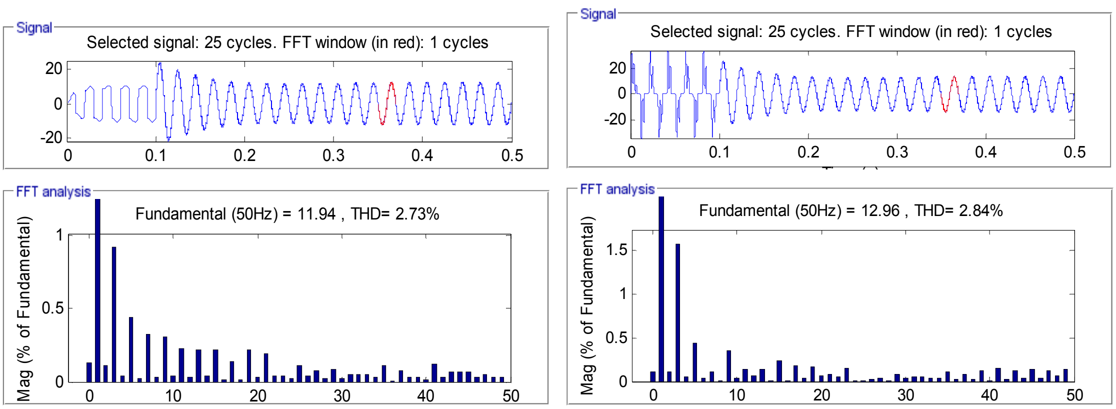

Fig. 9. FFT analysis of source current during compensation a) RL- load and b) RC -load

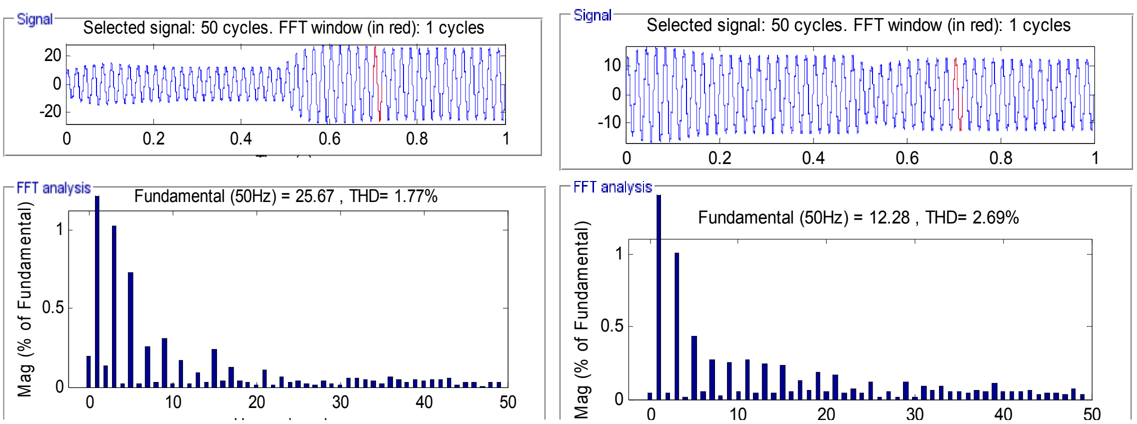

Fig. 10. FFT analysis of source current after load changes a) RL- RC load and b) RC –RL load

Table 2. Performance analysis of single phase SAPF.

Parameters	Switch on response		Transient response	
	RL-Load	RC-Load	RL to RC-load	RC to RL-load
Vdc-Tset (ms)	~250	~250	~200	~200
%THD	2.73	2.84	1.77	2.7
Undershoot (V)	6	6	18	0
Overshoot (V)	0	0	0	5.5

The THD value of source current before and after compensation for both RL and RC loads are illustrated in Figs. 8-10.It seen from the Table 2, the THD value of source current is less than 5% and the settling time of DC link voltage is nearly 250 ms for switch on condition and nearly 200 ms for transient condition. In order to reduce the settling time below 50 ms there is a need of tuning of PI controller with help of optimization technique.

5. Conclusion

A MPCC technique applied to the single phase SAPF is presented and analyzed in this manuscript. The main advantage of this scheme is easy to design and implement. In this proposed method a DC link capacitor voltage regulation based PI control algorithm is employed for determining the filter reference current. This technique effectively compensated the current harmonics and reactive power generated by non-linear loads. And the MPCC technique having good current tracking ability in both switch on and transient response conditions and it is alternative to classical current control methods.

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