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Comparative study of ATSMC and PTMC for a Single Phase SAPF

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Abstract : This paper describes the analysis, design, simulation and comparison of the Precise Total Multivariable Control (PTMC) theory and Adaptive Total Sliding Mode Controller (ATSMC) to a single phase shunt dynamic power filter(SPSDPF) to enhance the power quality by reducing harmonic distortions of electrical system. The aim of this paper is to show the comparison of the PTMC and ATSMC theory and find out which theory is better for the reduction of harmonics. These controllers are implemented and designed in MATLAB 2012a. MATLAB/SIMULINK Results are provided in MATLAB 2012a.

Keywords:- Precise Total Multivariable Control, Adaptive Total Sliding Mode Controller, Shunt dynamic power filter, Harmonic Elimination.

I. INTRODUCTION

Nowadays the use of non-linear load is increased rapidly in industry and in electronic equipment. All the power electronic devices are considered as nonlinear load. Television, Refrigerator, Air Conditioner, Inverters, Printers, Fax machines are some example of non-linear load[1]. Increased use of non-linear load has increased the amount of distorted currents on electrical system.Therefore, interest has been shown as to the effect of power factor and the extent of harmonics currents being generated and injected in power lines.

Traditionally, passive filters have been used to compensate voltage and current harmonics generated by constant non-linear loads. Passive power filters provide low impedance path for distorting harmonics in voltage and current, resulting in improvement of power quality. Passive filters can be easily designed and have low cost. However, there are some drawbacks of passive filters such as mistuning, resonance, bulky implementation, no possibility of using same power filter for different load.[2]-[3].

These drawbacks of passive filters can be overcome by use of active power filters.

Several control topologies functioning with power semiconductor switches have been developed for high-quality requirement. These topologies are designed to call off the original voltage and current harmonics deformation by injecting the same detected deformation, but with reverse polarity, thereby recuperating the power quality. Active power filters are connected between source and load. Depending upon the type of connection it can be classified as series dynamic power filter, shunt dynamic power filter and hybrid dynamic power filter.

Shunt active power filters are most widely used solution to reduce current harmonics, while series active power filters are used to reduce voltage harmonics. Universal active power filters are used current harmonics as well as voltage harmonics. Shunt active power filters are usually applied to three phase systems whereas single phase active filters can be applied in adjustable speed motor drive.

Different control methods have been reported to control shunt active power filters. These can be classified as:

1. Time-Domain Control Techniques
2. Frequency-Domain Control TechniquesBoth time-domain and frequency-domain control techniques have well-known disadvantages as these provide non-linear dynamics of the closed loop system.

Also, some advance control methods have been reported, such as sliding mode control, artificial neural networks, and optimization[4]- [9]. Of the above-mentioned control methods, the sliding mode control have been extensively applied to the power converters because it has natural tendency to control time varying topologies. Sliding mode control is the non-linear control strategy.

The principle for applying sliding mode control strategy is to propose a sliding surface or switching function. Sliding mode control has inherent characteristics such as insensitivity to system parameters variation, robustness and simple control implementation. In this study, sliding mode control(SMC) is proposed which leads to sliding surface which is linear combination of system state variables and the generated references. This control design results in sliding mode controller, which makes the system robust, insensitive to system parameter variation and simple implementation.

Further, PTMC is proposed using sliding mode controller which simplifies the procedure to convert non-linear system to normal system. The comparison of ATSMC with PTMC is shown in this work.

II. STUDY OF ADAPTIVE TOTAL SLIDING MODE CONTROLLER

The main aim of this part of paper is to present an efficient design, mathematical analysis of shunt dynamic power filter and design of Adaptive Total Sliding Mode Controller

A. Active Mathematical Modelling of shunt dynamic power filter

To analyze the operational mode of shunt dynamic power filter, we define a switching function represented as:

$$U_i = \begin{cases} 1 \text{ if } T_i \text{ is ON} \\ 0 \text{ if } T_i \text{ is OFF} \end{cases}$$

Here ‘i’ can be given values from (1 to 4) each representing the switch number. The two switches from the similar segment of the dynamic power filter must operate harmonizing. Therefore, we can write:

$U_1 + U_2 = 1$ and $U_3 + U_4 = 1$ (1)

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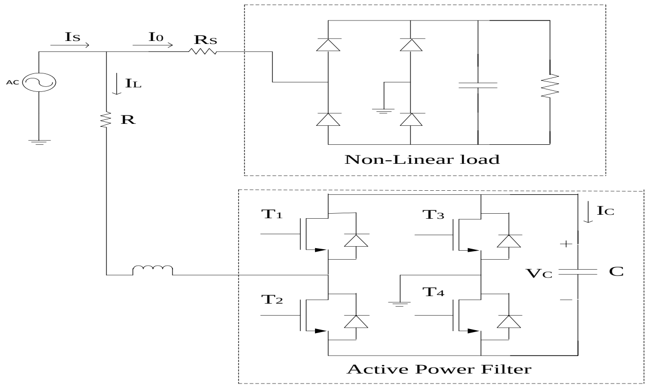

Fig.1. Shunt dynamic power filter

$$v_x = (U_1U_4 - U_2U_3)V_C \quad (2)$$

From equation (1) and (2) we get

$$v_x = (U_1 + U_4 - 1)V_C \quad (3)$$

The current curving through filter capacitor (I_C) can be written as:

$$I_C = (U_1 + U_4 - 1) \times I_L \quad (4)$$

From expressions of v_x (3) and I_C (4), the dynamic state equations for the inductor current and capacitor voltage are as given below:

$$L\frac{dI_L}{dt} = V_S - I_L R - (U_1 + U_4 - 1)V_C \quad (5)$$

$$C\frac{dV_C}{dt} = (U_1 + U_4 - 1)I_L \quad (6)$$

Here V_S is the source voltage.

Let$U_1 + U_2 - 1 = U$, the dynamic state model of shunt active power filter becomes:

$$\frac{dI_L}{dt} = \frac{1}{L}(V_S - I_L R - UV_C) \quad (7)$$

$$\frac{dV_C}{dt} = \frac{1}{C}UI_L \quad (8)$$

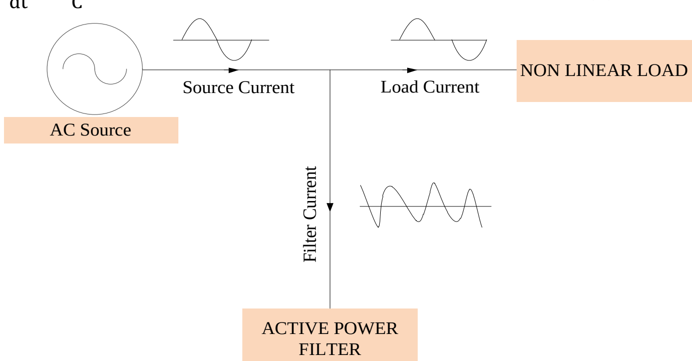

Fig.2. Block Diagram of Shunt dynamic power filter

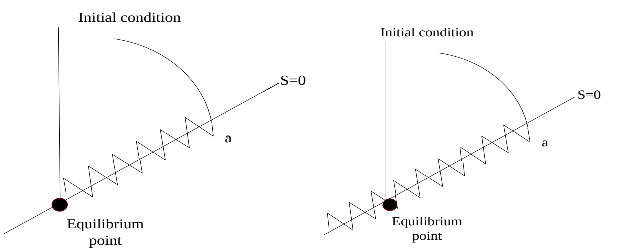

Fig.3. Sliding surface (a) Stable system (b) Unstable system

B. Adaptive Total Sliding Mode Control Strategy

The controller consists of two control loops. Outer voltage loop regulates the capacitor voltage and inner current loop tracks the reference current signal. To control the DC capacitor voltage PI controller is used and inductor current is controlled by the use of Sliding Mode control strategy.

The performance of the controller is improved by proposing a control algorithm based on sliding surface which depends on source current (I_S). Assume (V_{DC}, I_S) be the reference values of filter capacitor voltage and source current. The reference values assumed above are also known as equilibrium points of the control system. Now we calculate the error signal or error function $e_1 = I_S - I_S^* = 0$ which represents the sliding surface. Also, it is found that system has steady state current error. So as to minimize the steady state error an integral term is introduced given by $e_2 = \int e_1 . dt$.

The proposed sliding surface or sliding function is given by:

$S = e_1 + \lambda e_2$ Or $S = e_1 + \lambda \int e_1$(9)

Where λ is a control parameter also known as sliding coefficient? Positive values of sliding surface coefficient (λ) ensures stability of active power filter. After deriving the sliding mode surface, now our aim is to define the control law based on three conditions. These conditions are as followsReaching Condition, Existing Condition, Stability Condition.The inequality which satisfies the existing and reaching condition of the system is given by:

$$\lim_{S\to 0} S.\frac{dS}{dt} < 0$$

C. Controller Design and Reference Current Calculation

In SM controller in order to satisfy the existence condition we usually determine as following:

$$U = \begin{cases} 1 \text{if} S > 0 \\ 0 \text{if} S = 0 \\ -1 \text{if} S < 0 \end{cases}$$

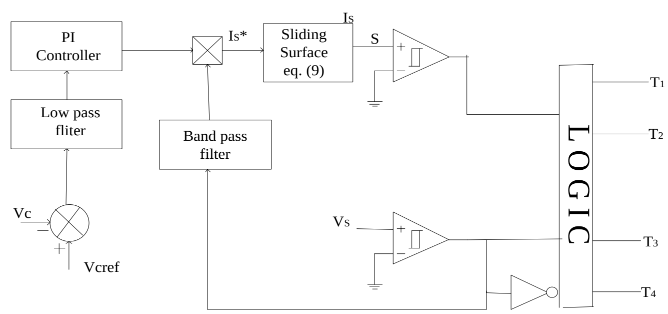

Fig. 4. Adaptive total sliding mode controller for shunt apf

The sign of $\frac{dS}{dt}$ should be controlled to satisfy the existence condition. This can be done by applying the control law given in equation 4. Switches of one leg of APF(T_3,T_4) operates at source voltage frequency and that of other leg(T_1,T_2)operate at high frequency. The control algorithm U makes the state trajectory to reach the sliding surface in finite time and then slides along the surface towards equilibrium point exponentially. The complete analogy SM controller for single phase shunt APF is shown in fig. 4.

Fundamental component of the gate pulses to switch is in same phase to that of source voltage (V_s). So a band pass filter can be used to generate the fundamental component of gate pulse by filtering its harmonics. The characteristics of band pass filter have a significant effect on the active power filter performance. The bandwidth should be small enough to sufficiently attenuate the harmonic components of the reference current.

The capacitor voltage is put through a RC low pass filter which yields the average capacitor voltage. This quantity is compared to the reference capacitor voltage, with the difference driving the PI controller. The output of the PI controller is a slow varying variable which is the peak value of reference source current. This implies that the output of PI controller gives sum of peak value of fundamental load current and the peak value of source current required to compensate the real power loss in filter capacitor. As a result, this slow varying variable is multiplied with the output of band pass filter to generate the desired reference source current.

As band pass filter is used to calculate reference current, small variation in amplitude of source voltage does not affect reference source current. This is why this active filter is applicable for both distorted and nominal source.

III. STUDY OF PRECISE TOTAL MULTIVARAIBLE CONTROL THEORY VIA SLIDING MODE CONTROL

The main motive of this segment is to present an efficient design procedure of precise total multivariable control law by combining it with sliding mode control theory to get better results.

A. *Multivariable linearization:*

In multivariable linearization non-linear characteristics of the electrical system is transformed into a linear characteristics and then linear control techniques are used to control the whole non-linear electrical system.

Taking into consideration a non-linear single-input single-output (SISO) electrical system

$$\dot{x} = f(x)g(x).U$$

□□
□□□

$Y = h(x)$

Where f(x) and g(x) defines smooth vector fields on R^n, h(x) defines smooth function, Y is system output and U is the control input variable. Relative degree is a very important theoretical concept in input-output linearization which is interrelated to the numeral of epoch the system output Y to be differentiated, for the inputtobeappearintheoutput equation

$$\dot{Y} = \nabla h(f + g.U) = L_f h(x) + L_g h(x).U \quad (11)$$

Where $L_f h(x)$ and $L_g h(x)$ are the Lie algebra derivatives of h(x)with reverence to f(x)andg(x). If the virtual degree r of the electrical system coincides with the system order (r=n), we must differentiate r times the system output, i.e.

$$Y^k = L_f^k h(x) for all k < r - 1 \quad (12)$$

$$Y^r = L_f^r h(x) + L_g L_f^{r-1} h(x).U (13)$$

Which shows that $L_g L_f^k h(x) = 0$ for all (k < r-1) and $L_g L_f^{r-1} h(x) \neq 0\ for\ (r = n)$. Hence the system linearization can be done by means of the subsequent input conversion.

$$U = \frac{1}{L_g L_f^{r-1} h(x)}[v - L_f^r h(x)] \quad (14)$$

which provides a linear bond linking the electrical system output Y and the control input v:

$$y^r = v \quad (15)$$

Still, the electrical system cannot be liberalized when the virtual degree of an electrical system is not more than the order of the electrical system. In this case, system is partially liberalized and the part of the system which is set aside of the linearization process should be confirmed [10]. This is the case for reflection of steadiness of internal dynamics of electrical system.

B. *Control Design:*

The stability of the electrical system is conformed if the coefficients K_1 and K_2 of the sliding surface are always positive and greater than zero. The system has following dynamics:

$$\ddot{e} + K_1.\dot{e} + K_2.e = 0 \quad (16)$$

This is exponentially stable if the requirements $K_1, K_2 \geq 0$ are accomplished.

Considering the main function of the shunt active power filter is to shape the line current to be in same phase as the line voltage. Desired behaviour of the line current can be derived as follows

$$i_{sref} = k.v_s \quad (17)$$

where k is output of PI controller and sluggish time varying factor based on power demand.

By the correlation between line current, filter current and load currents, we can derive the current reference expression as

$$i_F^* = k.v_s - i_L \quad (18)$$

Hence, we can write the expression of error function as:

$$e_1 = \int v_s(i_s - kv_s)\partial r \quad (19)$$

and from the above equation the sliding surface can be derived as:

$$s = v_s(i_s - kv_s) + K_1 \int v_s(i_s - kv_s)\partial\tau + K_2 \int\int v_s(i_s - kv_s)\partial\tau \ (20)$$

The key aim in derivation of sliding mode controller is to fulfil the reaching surface condition which ensures the existence of the sliding regime on a sliding surface. The reaching surface condition can be given by:

$$s.\dot{s} < 0$$

The control law is obtained as

$$U = \begin{cases} 1, \text{for } s > 0 \\ 0, \text{for } s < 0 \end{cases}$$

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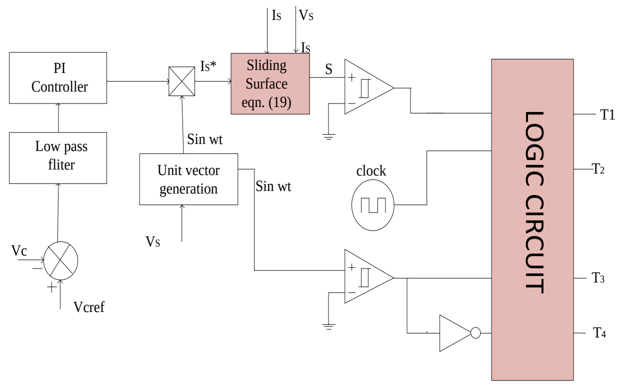

Fig.5 Multivariable Controller Design

IV. SIMULATION RESULTS

To check the robustness and efficiency of the proposed analog SM controller, the complete shunt APF system is simulated using MATLAB/SIMULINK. The diode bridge rectifier having 500-μF capacitor is the non-linear load used in parallel with a 45-Ω resistor at its output side. The system parameters used in the simulation are given in Table1. Cut-off frequency of RC low pass filter has been set as 80 Hz. Cut-off frequency and bandwidth of band pass filter have been set as 50 Hz and 6 Hz respectively.

Table 1. SYSTEM PARAMETERS

L= 5mH	$V_S^{RMS} = 110\ V$	$\lambda = 2000S^{-1}$
V_{ref} = 200V	$f_{V_S} = 50Hz$	$K_p = 0.5$
C = 1100μF	$f_{Clock} = 40kHz$	$K_i = 10$

The THD of the source voltage under ideal condition is found to be 0.11%. Similarly, the THD of the load current considering up to 30th harmonics is calculated as 68.77%. Simulated load current and source voltage waveforms are shown in Fig.6. It is cleared by application of proposed controller, the source current THD is reduced to 4.6%. Fig.7 shows source current and source voltage waveforms of the proposed analog SM controller.

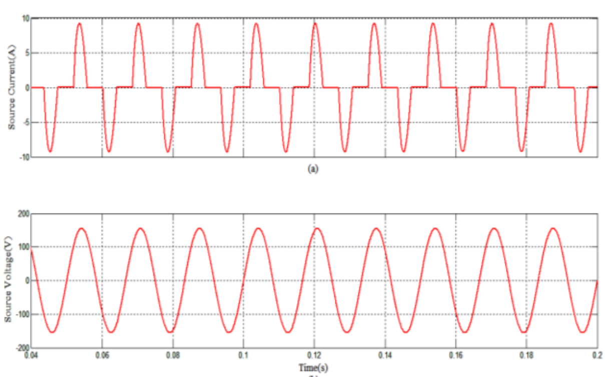

Figure 6. load Current and Source Voltage

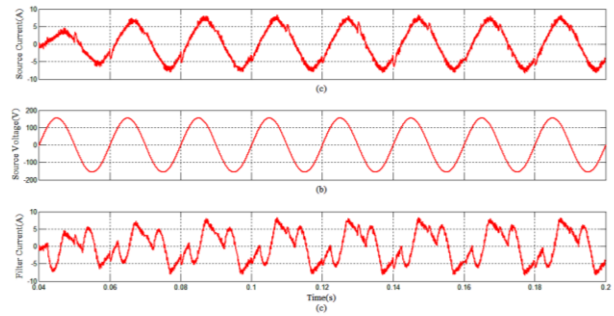

Fig- 7. Source current, Source voltage and Filter current with proposed adaptive sliding mode control

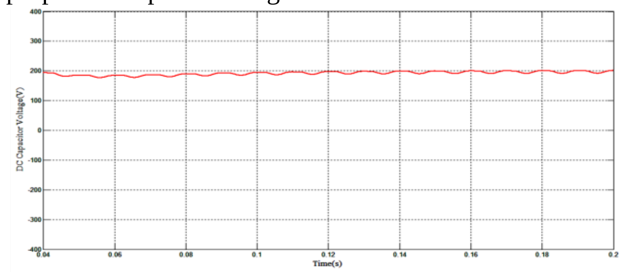

Fig. 8.Dc linkcapacitor voltage

Finally, this part of paper provides simulation results to validate the proposed multivariable control theory. All the results are validated using MATLAB/SIMULINK 2012a.The various parameters used in designing of shunt dynamic power filter are shown in Table II given below:

Table II PARAMETERS OF THE DYNAMIC POWER FILTER

Parameter	Value
V_S	110 V_{RMS}
f_S	50Hz
L	6mH
C	1500μF
R_O	50Ω
C_O	500 μF
R_S	5Ω
K_1	5000
K_2	16650
K_P	0.50
K_I	10
V_C^*	200
$f_{sampling}$	40KHz

The cut-off frequency used in low pass filter is 78 Hz. The proposed multivariable controller reduces the harmonics by less than 5%. The total harmonic distortion in source current after use of this controller is 2.78%.These results are verified for time period from 0.12seconds and up to 4 cycles. The simulation results of proposed controller are verified in MATLAB/SIMULINK 2012a. These are given below:

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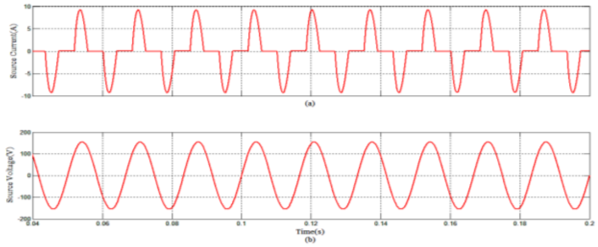

Fig.9. Load current and Source voltage

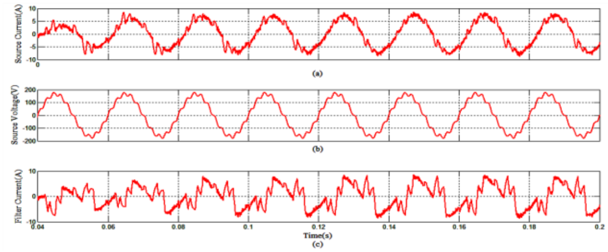

Fig.10.Simulation results of proposed controller (a) Source Current, (b) Source voltage(c) filter current

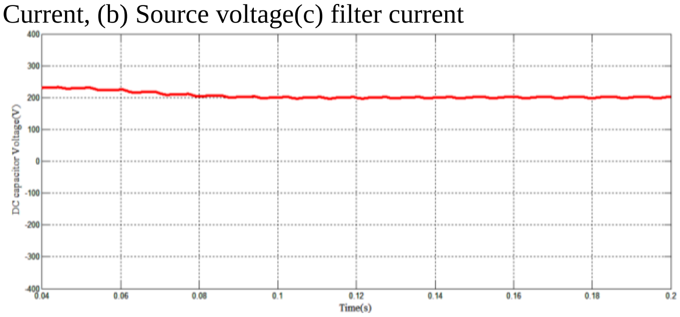

Fig.11 Dc link Voltage

The table given below shows the comparison of the proposed control scheme:

Harmonic (A rms)	THD%
i_L	67%
I_s(proposed controller)	2.78%

V. CONCLUSION

This paper investigates the ATSMC and PTMC to a single-phase shunt dynamic filter by implementing the sliding mode control theory. The comparison shows that PTMC is better in comparison with ATSMC. Its ability to reduce harmonics is much better.

References

i. P. R. Stratford, "Harmonic pollution on power systems—A change in philosophy," IEEE Trans. Ind. Appl., vol. IA–16, pp. 617–623, 1980.

ii. J. S. Subjak and J. S. McQuilkin, "Harmonics—Causes, effects, measurements, and analysis: An update," IEEE Trans. Ind. Appl., vol. 26, no. 6, pp. 1034–1042, Nov.–Dec. 1990.

iii. M. E. Amoli and T. Florence, "Voltage, current harmonic control of a utility system—A summary of 1120 test measurements," IEEE Trans.Power. Del., vol. 5, no. 3, pp. 1552–1557, Jul. 1990.

iv. E. Emanual, J.A. Orr, D.Cybanki, and E.M Gulchenski., "A survey of harmonic voltages, currents at the customer's bus," IEEETrans. Power. Del., vol. 8, no. 1, pp. 411–421, Jan. 1993.

v. Mansoor, W. M. Grady, P. T. Staats, R. S. Thallam, M. T. Doyle, and M. J. Samotyj, "Predicting the net harmonic currents produced by large numbers of distributed single-phase computer loads," IEEETrans. Power. Del., vol. 10, no. 4, pp. 2001–2006, Oct. 1994.

vi. M. El-Habrouk, M. K. Darwish, and P. Mehta, "A survey of active filters and reactive power compensation techniques," IEE Power Electron.Variable Speed Drives, pp. 7–12, 2000.

vii. S. Buso, L. Malesani, and P. Mattavelli, "Comparison of current control techniques for active filter applications," IEEE Trans. Ind. Electron., vol. 45, no. 5, pp. 722–729, Oct. 1998.

viii. Seemant Chourasiya, Seema Agrawal, "A REVIEW: ControlTechniques for Shunt Active Power Filter for Power Quality Improvement from Non-Linear Loads", International Journal Electrical Engineering, 2015, Vol. 6, No.10, pp. 2028-2032.

ix. Seema Agrawal, Prakash Kumar, D.K Palwalia, "Artificial neural network based active power filter ", IEEE 7th international conference PIICON 2016, pp. 1-6 .