Performance Enhancement of Shunt Active Power Filter Using Sliding-Mode And Proportional-Resonance Control Strategy

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Abstract- *The prime focus of this topic is to regulate the DC-Link voltage by a hybrid control technique using a standard SM-PR-SVPWM control strategy to improve the performance of shunt Active Power Filter (APF). Basically, Sliding Mode (SM) control strategy and PI control strategy have been applied considering their ease of implementation and robustness under external disturbances. Low cost analog SM controller is presented to reduce the steady state current error. In this method a band pass filter is used for calculating the reference source current which makes source current Total Harmonic Distortion independent of source voltage THD. To overcome the drawbacks caused by varying switching frequency, a fixed switching frequency SM controller is presented. In this control strategy, a proper combination of fixed frequency sliding mode current control and unipolar PWM increases the dynamic response of APF system and makes it adaptive under variable load and source conditions. The SM scheme continuously determines the gains of the PI controller based on the control loop error and its derivative. The proposed control strategy ensures zero steady-state error and improves the performance under hard transients such as load variation. Generally the Space vector modulation (SVM) is an algorithm for the control of pulse width modulation (PWM). It is used for the creation of alternating current (AC) waveforms; most commonly to drive 3 phase AC powered motors at varying speeds from DC using multiple class-D amplifiers. In this paper the SVPWM technique is used to generate the gate pulse of inverter*

Keywords- Active Shunt Filter, Control strategy, SVPWM Technique.

I. INTRODUCTION

Now a day’s people are extremely dependent on use of nonlinear loads. All the power electronic devices can be considered as nonlinear loads. Controlled/uncontrolled rectifiers, inverters, uninterruptable power supplies, switched mode power supplies, televisions, refrigerators, printers, fax ,machines, fluorescent lamps, adjustable speed drives, air conditioners are some examples of nonlinear loads. The use of nonlinear loads causes harmonic distortion. Harmonics of a sinusoidal waveform are sinusoidal waveforms having frequency integral multiple of frequency of the original sinusoidal waveform. In electrical engineering, voltage and current waveforms plays an important role in the reliability of electrical devices. In India the fundamental frequency of voltage waveform is 50Hz, while in some of the foreign countries fundamental frequency of voltage signal is 60 Hz.

This control strategy is design to maintain the stability of the system when the system is having nonlinear load we introduce SM-PR control strategy which reduces this steady state error and improve the system stability. PI controller with voltage feed-forward suffered from a steady state error when following the reference current, resulting in a difference of approximately 3% between the reference current and the inverter current. The steady state error is less for the PR current controller, practically negligible. Regarding the 3^{rd}, 5^{th} and 7^{th} harmonics in the system, from the results obtained with both controllers the 3^{rd} and 5^{th} harmonics were outside the permissible limits. Therefore in further model the SM-PI is replaced by SM-PR control strategy for controlling the DC-Link voltage to improve the performance of shunt active power filter.

Now further the Pulse Width Modulation variable speed drives are increasingly applied in many new industrial applications that require superior performance. Recently, developments in power electronics and semiconductor technology have lead improvements in power electronic systems. Hence, different circuit configurations namely multilevel inverters have become popular and considerable interest by researcher are given on them.

Variable voltage and frequency supply to ac drives is invariably obtained from a three-phase voltage source inverter. A number of Pulse width modulation (PWM) schemes are used to obtain variable voltage and frequency supply. The most widely used PWM schemes for three-phase voltage source inverters are carrier-based space vector PWM (SVPWM). There is an increasing trend of using space vector PWM (SVPWM) because of the Modulation Index is higher for SVPWM and current, torque harmonics produced are much less, their easier digital realization and better dc bus utilization.

NOMENCLATURE

SM	Sliding mode control
PI	proportional integral
PR	proportional resonant
SM-PR	Sliding mode control- proportional resonant
SM-PI	Sliding mode control- proportional integral
SVPWM	space vector pulse width modulation
PLL	phase-locked loop
PCC	point of common coupling
VSI	voltage source inverter
CSI	current source inverter
SAPF	Shunt active power filter

II. SYSTEM DESCRIPTION AND MODELING

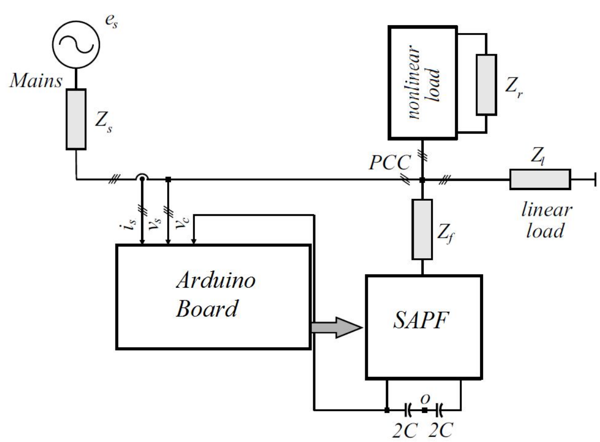

Figure. 1. Basic block diagram for the proposed shunt active power filter system.

Figure.1 presents the topology of shunt active power filter used in the laboratory prototype. The three-phase grid source with its internal impedance (Zs) feeds a three-phase load bank consisting of parallel connected non-controlled rectifier and a linear load (Zl). At the point of common coupling (PCC) the SAPF is implemented a voltage source inverter connected through inductors lf filter impedance, where in r_f is the intrinsic resistance of l_f .

Table A: Simulation Parameters

Parameters	Values
Es	210sq.3
r_s	0.2 ohm
r_f	0.1 ohm
r_l	12.218 ohm
C	500 µF
f_s	50 Hz
l_s	0.1 mH
l_f	3 mH
l_l	38 mH
f_{sw}	25 kHz

In this model proposed a standard control strategy for improving the stability of system by reducing the steady state error using active shunt power filter control strategy. The proposed three-phase active power filter consists of a power converter, DC-link capacitor and filter inductor. For eliminate current harmonic components which is generated by nonlinear loads, the APF produces equal but opposite harmonic currents to the connection point with the nonlinear load. Therefore the results comes in a reduction of the original distortion and achieving zero steady state error and improving stability of the system and if the system is stable then the power quality is also improved.

Nonlinear load is main key point for create instability in the power system. So for reducing this effect or mitigating this effects which is come from nonlinear load SAPF is places in shunt with the line. The SAPF control techniques are used based on p-q theory. SVPWM control scheme is used for IGBT switching control and PWM generation.

Figure.1 represent the Basic block diagram for the conventional system which contain basic voltage and current measurement blocks, Active power filter which is connected with the non-linear load and for improving the performance of this active power filter we used SM-PR-SVPWM control strategy which is modelled in the Simulink MATLAB.

III. CONTROL SCHEME

The proposed control scheme based on the shunt active power filter methodology. Figure.1 consist a Arduino board which contains SM-PR-SVPWM control strategy which help to improve the performance of the SAPF. The control model consist the SM-PR controller for stabilizing steady state errors using some transfer function and calculation:

a) SM-PR controller

SM: SM control is one of the nonlinear control strategies. It is mostly applied to variable structure system. The basic principle for applying SM control strategy is to design a sliding surface or switching function. Then the switches of power electronic device are controlled in such a way that the system trajectory will be directed towards the sliding surface, slides along the surface and eventually reach the equilibrium point. The system performance depends on the design of sliding surface. The sliding surface taken is given by,

Where α_1, α_2, α_3 are positive constant and p1, p2, p3 are state variable of the DC-DC converter. The sliding surface is given by,

$$S = \left(\frac{d}{dt} + \quad \rho \right) (X X_d)$$

Where is a positive constant and x, xd is the error between state variable to be controlled and desired reference variable. After designing of the sliding surface, the next step is to de ne a control law based on three conditions. These conditions are given as follows: (1) Reaching condition or hitting condition (2) Existence condition (3) Stability condition.

The aim of reaching condition is that regard less of initial position, the trajectory of the system will be directed toward the sliding surface. Once it reaches the sliding surface, to maintain the trajectory on the surface is the objective of existence condition. The existence condition can be treated as local reachability condition.

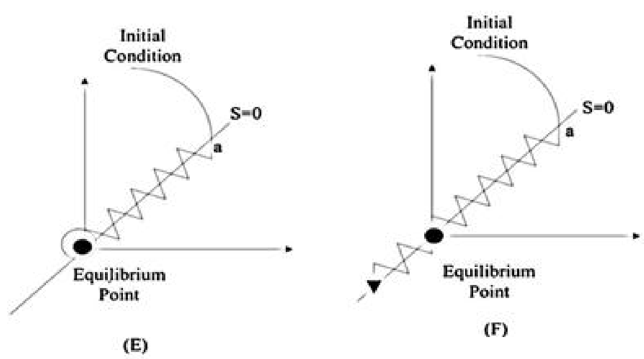

Figure.2 Sliding Condition (E) Stable Systems (F) Unstable systems

The trajectory reaches the sliding regime at point (a), slides along the surface (existence condition) and finally settles at the equilibrium point. The inequality which makes the system satisfy the reaching and existence condition is given as follows:

$$\lim_{s \to 0} s \frac{ds}{dt} < 0$$

The above inequality is based on lyapunov stability theorem, of which the lyapunov energy like function is, The stability condition is for ensuring system trajectory to reach the equilibrium point and to settle there for the rest of the time. The sliding coefficients must be chosen carefully to ensure the stability of the system. A stable system the system trajectory slides along the surface and finally settles at the equilibrium point. But for an unstable system the trajectory crosses the

$$S = \alpha_1 p_1 + \alpha_2 p_2 + \alpha_3 p_3$$

equilibrium point and move towards infinity.

Compared with other nonlinear control methods, SMC is more insensitive to internal parameter variations and external disturbance once the system trajectory reaches and stays on the sliding surface. However, how to design the SMC controller to reduce chattering is crucial, which motivates our researches for a new reaching law introduced in the next section. A complete study of SMRL theory can be found in [3]. In this section, the basic SMC design method is introduced brie y. In general, SMC design can be divided into two steps, the first step is to choose the sliding-mode surface, and the next step is to design the control input such that the system trajectory is forced toward the sliding-mode surface, which ensures the system to satisfy the sliding-mode reaching condition that is expressed as follows:

$$ss < 0$$

Where s is the sliding-mode surface. The following second-order nonlinear model is generally used to describe the SMC system adopting one reaching law method:

$$x_1 = x_2$$
$$x_2 = f_x + g_x + b_x$$

Design a sliding manifold or sliding surface in state space. Design a controller to reach the sliding surface in finite time. Design a control law to con ne the desired state variables to the sliding manifold,

$$\mu = (\rho + L)\text{sign}(б)$$
$$L \geq |\sin 3t| \; L \geq 1 \text{ Let } L \approx 1{:}5$$
$$\rho \geq |8{:}52| /5 = 17{:}04$$
$$\mu = -18{:}5\text{sign}(\rho)$$

PR: The PR controller is in essence a grouping of a proportional kp and resonant controller discussed earlier, which results in an ideal controller transfer function GAC(s),

$$G_{AC}(S) = K_P + \frac{SK_i}{S^2+\omega^2}$$

Where, ω is the AC frequency and ki is a constant that is carefully selected to shift the controller's magnitude response vertically. The ideal PR controller has an infinite gain at the AC frequency and no phase shift and gain at other frequencies. The simulated module is given in the Figure.A. The controller's infinite gain may cause stability problems and due to practical limitations of signal processing systems that implement it, a non-ideal transfer function G_{AC} (s), with the practical PR transfer function, its gain is infinite, but it is still relatively high for enforcing a small steady-state error.

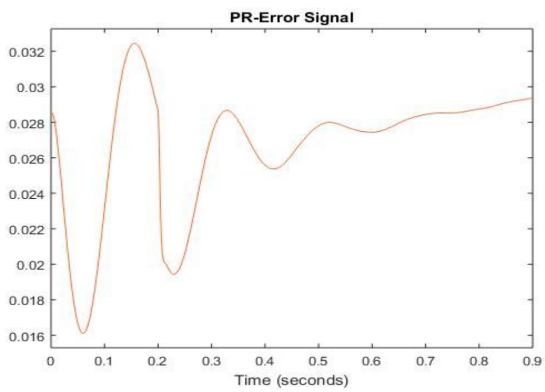

Figure.3 Simulation result for PR-Error Signal

PI controller, develops the Proportional resonant (PR) controller for reference tracking in the stationary frame. Interestingly, the same control structure can also be used for the precise control of a single-phase converter. In brief, the basic functionality of the PR controller is to introduce an infinite gain at a selected resonant frequency for eliminating steady-state error at that frequency, and is therefore

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b) SVPWM Technique

A three-phase 2-level inverter with dc link configuration can have eight possible switching states, which generates output voltage of the inverter. Each inverter switching state generates a voltage Space Vector (V1 to V6 active vectors, V7 and V8 zero voltage vectors) in the Space Vector plane. The magnitude of each active vector (V1 to V6) is 2/3 Vdc (dc bus voltage).

The Space Vector PWM (SVPWM) module inputs modulation index commands (U_α and U_β) which are orthogonal signals (α and β).

Where:

$M = Umag*Mod_{Scl*10-4}$

$Umag = \sqrt{(U_{\alpha 2} + U_{\beta 2})}$

Mod_Scl: Input scaling factor

The inverter fundamental line-to-line rms output voltage (Vline) can be approximated (linear range) by the following equation:

$Vline = Umag*Mod_{Scl}*Vdc/\sqrt{6}/2^{25}$

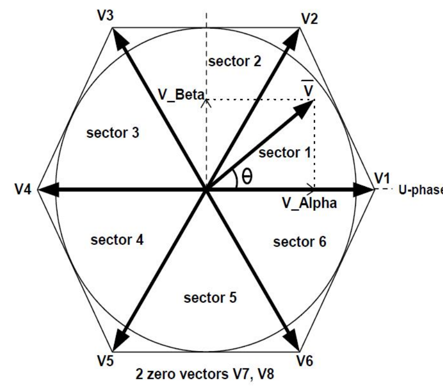

Figure 4.Space Vector Diagram

$$G_{AC}(S) = K_P + \frac{2SK_i\omega_C}{S^2 + 2S\omega_C + 2\omega^2}$$

The maximum achievable modulation(Umag_L)in the linear operating range is given by:
$Umag\_L = 2^{25}*\sqrt{3} /Mod\_Scl$

Over modulation occurs when modulation Umag > $Umag_L$. This corresponds to the condition where the voltage vector increases beyond the hexagon boundary. Under such circumstance, the Space Vector PWM algorithm will rescale the magnitude of the voltage vector to fit within the Hexagon limit. The magnitude of the voltage vector is restricted within the Hexagon; however, the phase angle (θ) is always preserved. The transfer gain of the PWM modulator reduces and becomes non-linear in the over modulation region.

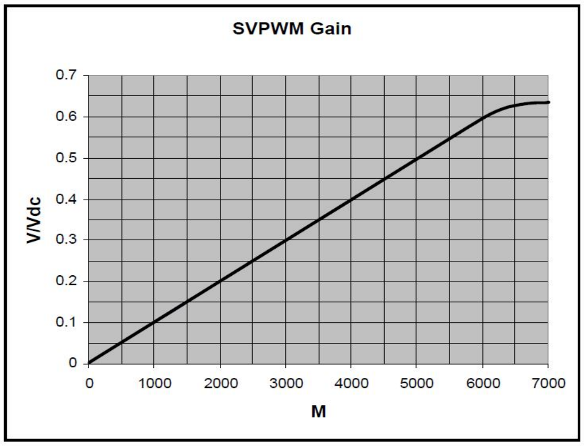

Figure.5 Transfer charactarystics

The inverter fed 3-phase AC motor with three phase windings u, v and w. The three phase voltages are applied by three pairs of semiconductor switches vu+/vu−, vv+/vv− and vw+/vw− with amplitude, frequency and phase angle defined by microcontroller calculated pulse patterns. The inverter is fed by the DC link voltage UDC. In our example, a transistor inverter is used, which is today realized preferably with IGBTs.

The special positions of the standard voltage vectors in stator-fixed αβ coordinates in relation to the three windings u, v and ware illustrated in Simulink model. The vectors divide the vector space into six sectors S1 … S6 and respectively into four quadrants Q1 … Q4. Thus we generate the gate pulse with the help of SVPWM.

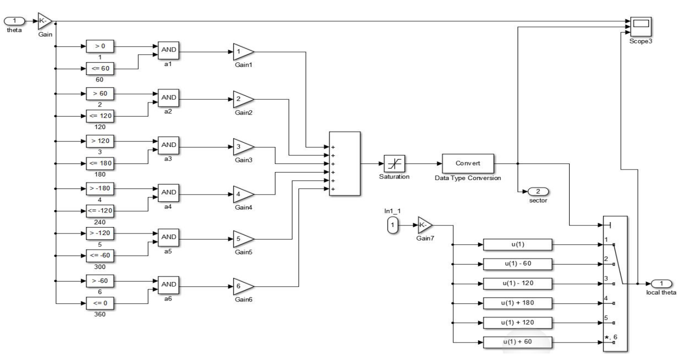

Figure.6 Voltage Vector Scaling and calculation.

IV. SIMULATION, RESULTS AND DISCUSSIONS

The proposed strategy is compared with the conventional hybrid voltage and current mode control by using SM-PI control strategy so when we want to control the stability the system then conventional paper used SM-PI controller but the result which is getting from SM-PI control strategy cannot achive zero steady state error because the PI controller is not able to track a sinusoidal reference with zero steady state error and poor disturbance rejection capability so we used the SM-PR control strategy.

The PI controller is not able to remove the low current harmonics due to their bandwidth limitations and in order to increase the bandwidth of the PI controller then it required high proportional gain but if the high gain is provided to the system then the system is move on unstable mode and that is a very critical issue therefore in this paper we used the SM-PR controller for achieving zero steady state error because the results of SM-PR methods are simulated in MATLAB. In the hybrid voltage and current mode control scheme. The control diagram in the MATLAB Simulink is designs for both the hybrid voltage and current mode control and the proposed control are as shown in the following gures:

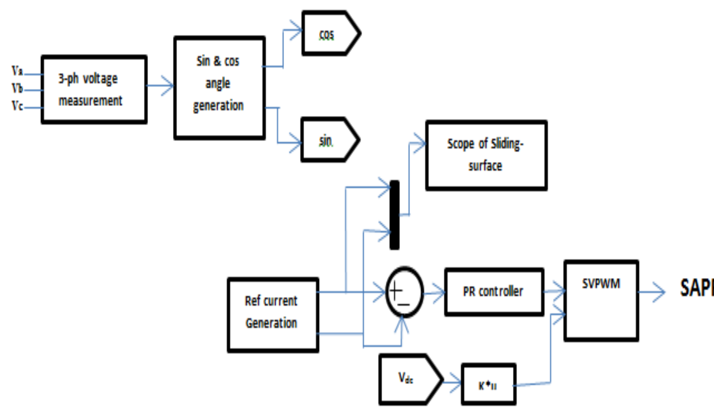

Figure.7 Control diagram for proposed method in MATLAB

All the parameters of the proposed system are summarized in Table-A the parameters remains same for all type of simulation designs in this project

In this project the dynamic response of both the methods for the change in the system input values are validated, for that we connect the nonlinear load to the grid and create unstable conditions for analysed the both scheme. The following figures RESULT1 and RESULT2 shows the simulation results for both the methods.

From the results it is found that after connecting the nonlinear load in the system the phase current is distorted and transients are created in the source current. So when the nonlinear load attached then the phase current is getting distorted to change output response according to the change in the input takes around 0.2sec in the conventional hybrid voltage mode control as shown in the figure 7.

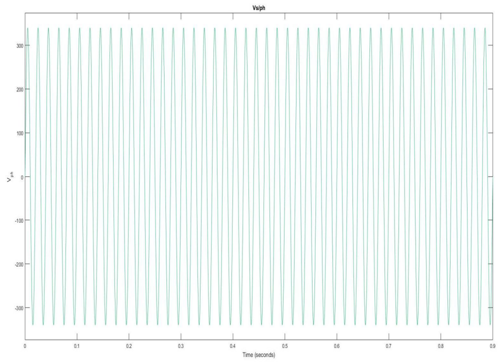

Figure 8 Conventional Hybrid Output Voltage

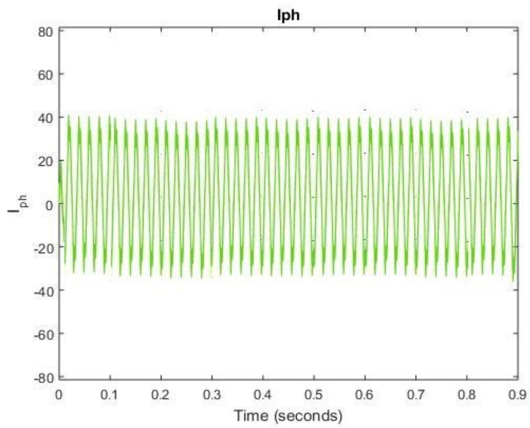

Figure.9 Simulation Results of V_{ph} and I_{ph} in MATLAB

On other hand the figure.8 shows the typical type and ever present transient in APF application it means transitory of load power. There are some variations are displayed between t = 0.5s to 0.15sec as shown in figure.10.

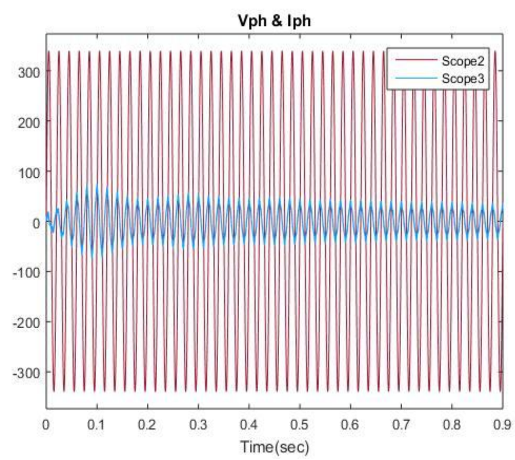

Figure.10 Simulation Results of distorted I_{ph} in MATLAB

According to the proposed control strategy the DC-Link voltage control scheme implemented by proportional resonant controller with high gain calculated by the SM control technique. Due to the sliding function of the sliding-mode technique we achieve the stable system. SM-PR control strategy introduces using theoretical basis and the stability prof was presented.

As shown in Figure.11 the zero steady state error is achieved. Because the PR controller reduced complexity and improved harmonic rejection capacity, it introduce an infinite gain at the fundamental frequency hence can achieve zero steady state error which is given in figure.11.

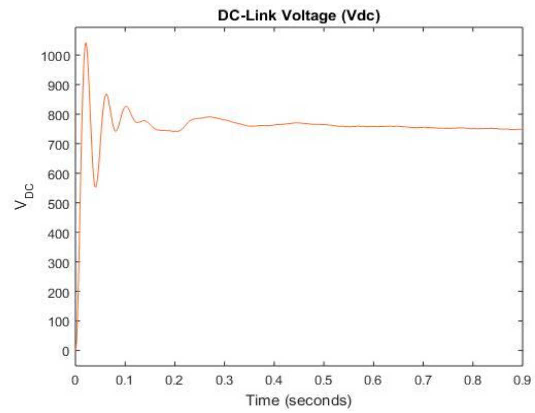

Figure. 11 Simulation Results of proposed method with PR controller in MATLAB

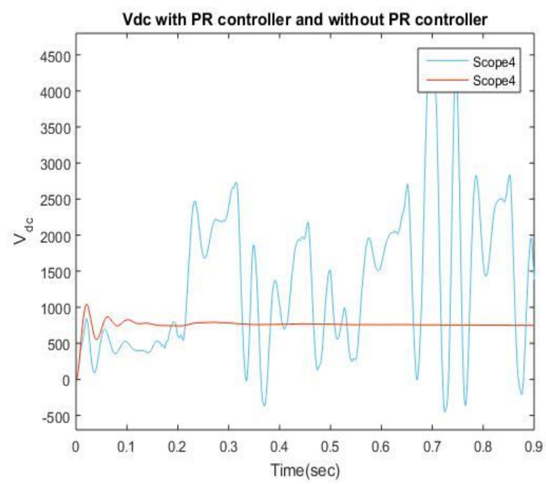

Figure. 12 Simulation Results of proposed method without PR controller in MATLAB

Figure. 12 shows the combine result of proposed strategy with and without PR controller. As we discussed PR controller provide infinite gain in very narrow bandwidth that is centred at resonance frequency. The PR has high gain around resonance frequency to eliminate the steady state error which is shown in fig.12.

If there is Absence of PR then the transitions are occurred. So the stability of the APF is reduces therefore we used PR controller which introduce high gain around the resonance frequency and achive zero steady state error.

V. CONCLUSION

In the proposed work the SM-PR control strategy has been design for improve the stability of the system by achieving zero steady state error. Also it can replace PR controller instead of PI controller for showing better performance in terms of steady state error by regulated the DC-Link voltage.

The active power filter is used here to improve the system performance. Hence the results from SM-PI and SM-PR controller has been analysed and the results shows that SM-PR technique is proved efficient and achieve zero steady error therefore the stability of the system is improved.

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