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A New Strategy of Series-Shunt Power Quality Compensator

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Abstract: Every new technology evolved with minimalism as well as stumbling blocks, as the recent innovations and excessive use of power electronic devices such as, fast switching uncontrolled/controlled converters, invertors and cyclo-converters, high voltage power converters used in HVDC etc. make the system flexible to work but also a complex problem of power quality has evolved, the measure of it was voltage and current harmonics, low power factor, reactive power demand etc. Ideally power system network must be electrically clean, harmonics free, balanced, regulated voltage at point of common coupling and must have a unity power factor. In this paper, the analysis of the Series-Shunt Power Quality Compensator (S-SPQC) is presented for three-phase three wire distorted system conditions, in this topology two types of active filter i.e. Series (SAF) and Parallel (PAF) are integrated to accomplish the goal of improving voltage quality by SAF and current quality by PAF. In combined approach of S-SPQC, SAF part is designed by using Synchronous Reference Frame (SRF) technique while PAF part is designed by using Indirect Current Control (ICC) technique. The MATLAB/ Simulink based simulation results are graphically shown as well as tabulated in detail which reflects the performance of the S-SPQC control method discussed in this paper.

Keywords: Power Quality, Harmonics, Direct and Quadrature Axes, Series-Shunt Power Quality Compensator (S-SPQC), Voltage Reference Generation, Current Reference Generation

I. INTRODUCTION

With day to day advancement in the world, electricity is becoming the primary need to everyone. It is important to provide a clean & good quality power to the consumers as well as to maintain it at the PCC. There is a boom in the development of the power electronic devices which drops the quality of power at the PCC, which has adverse effects on the power system. To avoid such problems there is a vast research on power filters is going on continuously.

Recently advanced active power filtering techniques identifies superiority than passive filters because of the performance, compactness and response to eliminate harmonics and compensate burden of reactive power generated by the nonlinear loads [1]. Now a days, by combining the series and shunt converters having a common capacitive storage device, it is possible to overcome nearly all kind of power quality problems which is known as Series Shunt Power Quality Compensator (S-SPQC) [2]. The function of S-SPQC system is to compensate problems associated with the voltage and current profiles, which ideally have harmonic free Voltage and current waveforms, unity power factor of load, balanced load, stabilized/ regulated voltage across dc link capacitor, negligible reactive power demand and maintain constant voltage at point of common coupling (PCC) under load variation and fault condition. The current related compensation is provided through PAF connected near the loads and the voltage related compensation is provided through SAF connected in series with a line through a series transformer and functions as a controlled voltage source [2-5].

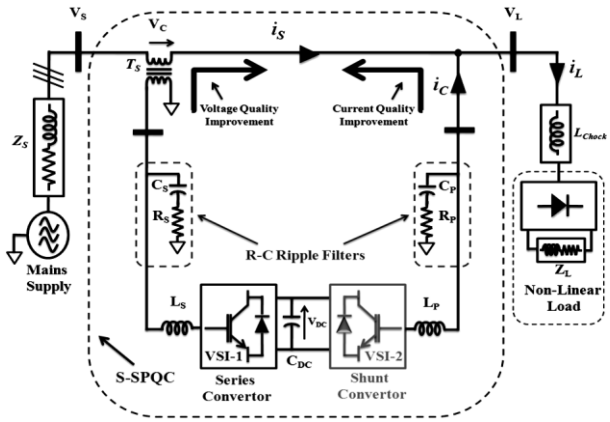

Figure 1. Schematic diagram of S-SPQC

There are so many controlling techniques presented in the various literatures out of that, SRF technique consisting of phase locked loops [5,6,8] and ICC technique consisting of Source Current tracking system [11,12] so there is not much effect of voltage distortion and these techniques found to be very simple to design, requires less number of sensors and fast responding. SRF technique uses Clark's and Park's Transformation for voltage reference generation. ICC technique which need not require load and filter current measurements, works on direct axis and quadrature axis component using unit templates for current reference

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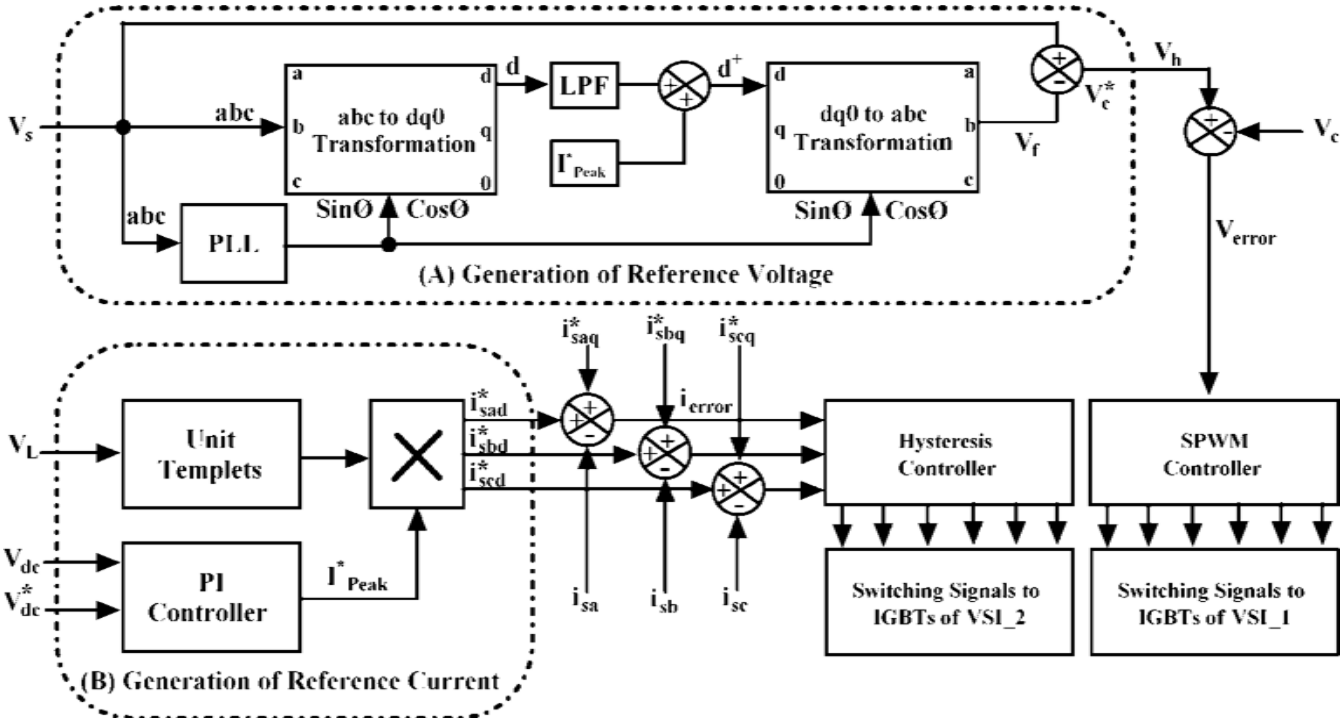

Figure 2. Proposed S-SPQC control algorithm block diagram (A) Generation of reference voltage (B) Generation of reference current

generation. Considering quadrature axis component system provides voltage regulation if required otherwise maintains load unity power factor, due to which system performance is improved.

In this paper a new control algorithm by integrating the SRF and ICC techniques for the Series-Shunt Power Quality Compensator (S-SPQC) is presented. MATLAB/ Simulink software based Simulation is carried out and results are mentioned, which shows the usefulness of the control algorithm.

convertors. S-SPQC has the capability to compensate voltage and current related problems like harmonics compensation, voltage flickers, imbalance, regulation and power factor improvement, neutral current control, reactive power compensation, dc-link voltage stabilization and load unbalance minimization.

A. Series APF

1) Generation of reference voltage by SRF technique: Voltage perturbations like sag, swell, flicker & harmonics in the source side mainly compensated using series APF, caused by the faults in the distribution line or sudden rise in the load at the PCC. The reference voltage value which is nathing but the harmonic componant of the voltage is calculated by SRF technique shown in Fig. 2(A), After comparing the harmonic component V_h with AC side filter component V_c the error signal V_{error} is fed to sinusoidal PWM controller [6-8].

In equation (1), supply voltages V_S are transformed from a-b-c to d-q-0 coordinates [5,6].

In equation (2), the direct axes voltage (V_{Sd}) contains a DC (average$\bar{V}_{Sd}$) and AC (oscillating$\tilde{V}_{Sd}$) components of

II. S-SPQC CONTROL ALGOTIRHM

The S-SPQC is mainly a combination of series and shunt active filters with a commonly shared DC link. In SAF series convertor operates as voltage source inverter, while in PAF inverter operates as a current source. Fig. 1 describes the basic blocks of the S-SPQC consisting of series and shunt

source voltages from that, $\bar{V}_{Sd}$ is separate out by using low pass filter.

The estimated amplitude of the source current I^*_{Peak} added up with the average voltage component $\bar{V}_{Sd}$ in order to maintain the DC link capacitor voltage at specified value. Then, the total average voltage component $\bar{V}^+_{Sd}$ will be as given in equation (3).

The fundamental components of voltages V_f are calculated by transforming d-q-0 axis voltages to a-b-c coordinates, as given in equation (4).

$$\begin{bmatrix} V_{S0} \\ V_{Sd} \\ V_{Sq} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ \sin(\omega t) & \sin(\omega t - 2\frac{\pi}{3}) & \sin(\omega t + 2\frac{\pi}{3}) \\ cos(\omega t) & cos(\omega t - 2\frac{\pi}{3}) & cos(\omega t + 2\frac{\pi}{3}) \end{bmatrix} \begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} \quad (1)$$

$$V_{Sd} = \bar{V}_{Sd} + \tilde{V}_{Sd} \quad (2)$$

$$\bar{V}^+_{Sd} = \bar{V}_{Sd} + I^*_{Peak} \quad (3)$$

$$\begin{bmatrix} V_{fa} \\ V_{fb} \\ V_{fc} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin(\omega t) & cos(\omega t) & 1 \\ \sin(\omega t - 2\frac{\pi}{3}) & cos(\omega t + 2\frac{\pi}{3}) & 1 \\ sin(\omega t + 2\frac{\pi}{3}) & cos(\omega t + 2\frac{\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} \bar{V}^+_{Sd} \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

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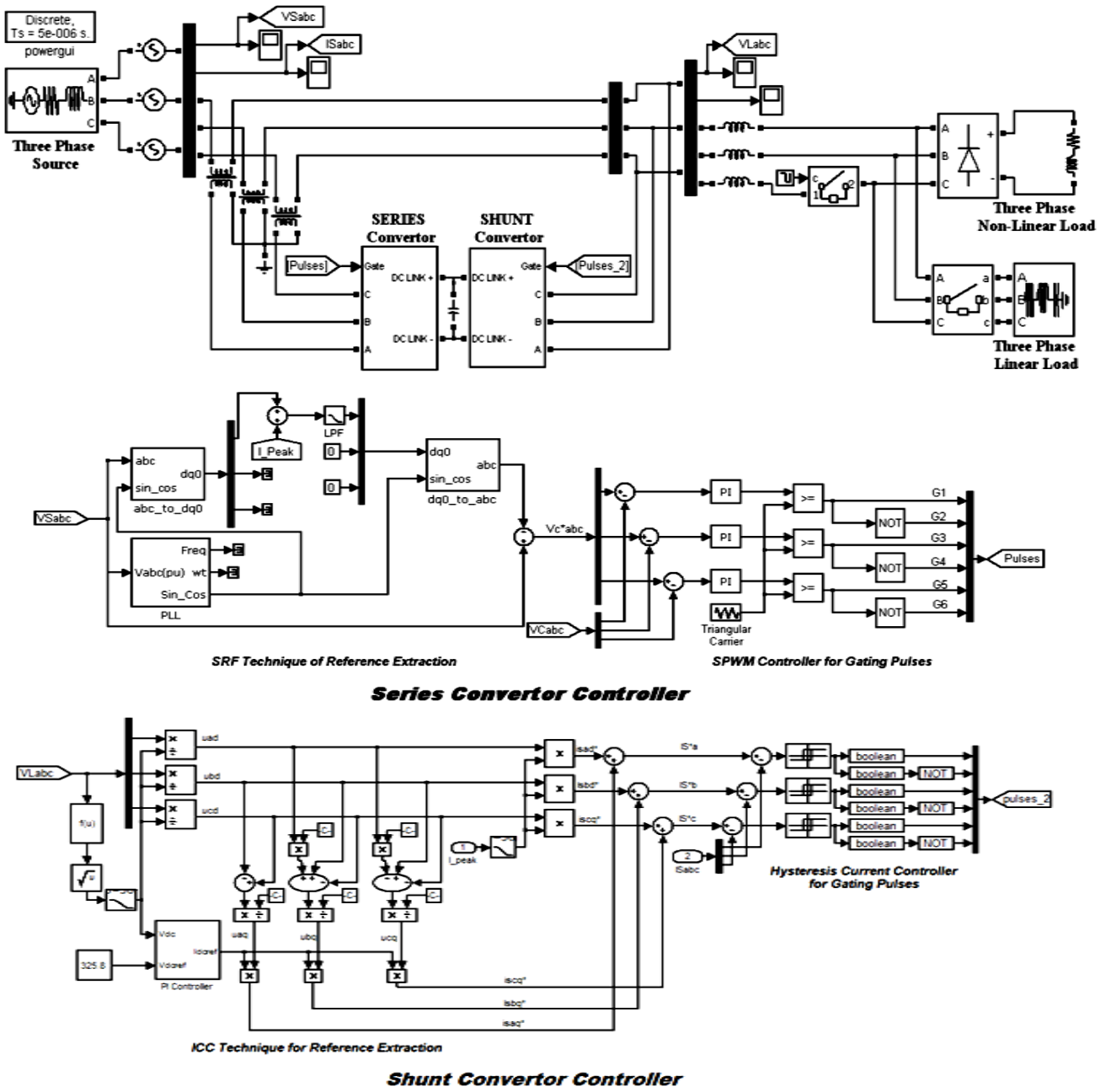

Figure 3. MATLAB Model of Proposed S-SPQC scheme

This fundamental component is then subtracted from source voltage V_S to get harmonic reference compensating componentV_C^*. The switching signals are then generated for series convertor IGBT switches by comparing reference compensating component voltages (V_C^*) and the actual filter voltages (V_C) and processing the error signal V_{error} via sinusoidal PWM controller.

2) SPWM Controller: In this controller high triangular carrier frequency (5 kHz) is compared with low frequency signal shown in Fig. 3. PI controller is used to control the low frequency error signal V_{error} within a given limiter range, then the controlling signal is compared with a carrier signal resulting in the switching signals to the gates.

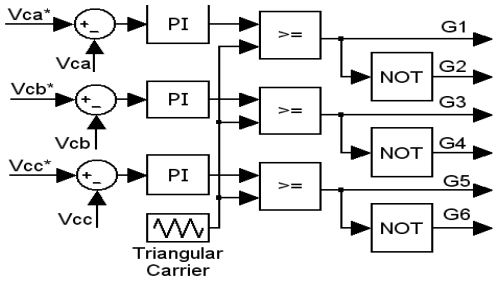

Figure 4. Sinusoidal PWM controller

B. Shunt APF

1) Generation of reference current by ICC technique: Fig. 2(B) shows the ICC Algorithm of the S-SPQC [9]. The control scheme of the S-SPQC requires sensing of

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voltages V_L at PCC and dc bus voltage v_{dc}. A dc bus capacitor balancing is achieved by adjusting the Proportional and Intigral gain of the PI controller having voltage across capacitor (v_{dc}) and reference DC voltage (v_{dc}^*) as an inputs. The PI controller provides the amplitude I_S^* of three-phase reference supply current.

In equation (5), the in-phase current unit templets u_{ad}, u_{bd} and u_{cd} of three-phase currents are derived in-phase with the load voltages.

$$u_{ad} = \frac{V_{La}}{V_{L_{peak}}}; u_{bd} = \frac{V_{Lb}}{V_{L_{peak}}}; u_{cd} = \frac{V_{Lc}}{V_{L_{peak}}} \quad (5)$$

Where $V_{L_{peak}}$ is the peak value of the supply voltage and it is computed as in equation (6).

$$V_{L_{peak}} = \{2/3\,(V_{La}^2 + V_{Lb}^2 + V_{Lc}^2)\}^{1/2} \quad (6)$$

In equation (7), in-phase component of reference supply currents i_{Sad}^*, i_{Sbd}^* and i_{Scd}^* are computed by multiplication of amplitude I_{Sd}^* with unit current vectors u_{ad}, u_{bd} and u_{cd} .

$$i_{Sad}^* = I_{Sd}^* u_{ad}\ ; i_{Sbd}^* = I_{Sd}^* u_{bd}\ ; i_{Scd}^* = I_{Sd}^* u_{cd} \quad (7)$$

In equation (8), the quadrature current unit templets u_{aq}, u_{bq} and u_{cq} of three-phase currents are derived in-phase with the load voltages.

$$u_{aq} = \frac{-u_{bd}+u_{cd}}{\sqrt{3}}; u_{bq} = \frac{u_{ad}\sqrt{3}+u_{bd}-u_{cd}}{2\sqrt{3}}; u_{bq} = \frac{u_{ad}\sqrt{3}+u_{bd}-u_{cd}}{2\sqrt{3}} \quad (8)$$

In equation (9), quadrature component of reference supply currents i_{Saq}^*, i_{Sbq}^* and i_{Scq}^* are computed by multiplication of amplitude I_{Sq}^* with unit current vectors u_{aq}, u_{bq} and u_{cq} .

$$i_{Saq}^* = I_{Sq}^* u_{aq}\ ; i_{Sbq}^* = I_{Sq}^* u_{bq}\ ; i_{Scq}^* = I_{Sq}^* u_{cq} \quad (9)$$

According to the requirement of either power factor improvement, required only in-phase component as a total reference supply current (i_s^*) or voltage regulation, required both in-phase component and quadrature component of currents as a total reference supply current given in equation (10),

$$i_{Sa}^* = i_{Sad}^* + i_{Saq}^*\ ; i_{Sb}^* = i_{Sbd}^* + i_{Sbq}^*\ ; \quad i_{Sc}^* = i_{Scd}^* + i_{Scq}^* \quad (10)$$

The switching signals are then generated for shunt convertor IGBT switches by comparing reference supply currents (i_s^*) and the supply currents (i_s) and processing the error signal i_{error} via hysteresis controller, through which the instantaneous three phase source currents track their estimated reference values.

2) PI Controller: DC and AC PI controllers are used to find out the amplitude of in-phase I_{Sd}^* and quadrature I_{Sq}^* reference supply currents repectively.

The amplitude I_{Sd}^* of in-phase reference supply currents is computed using PI controller over the average value of DC bus voltage (v_{dca}) of the AF and its reference voltage (v_{dc}^*). Comparison of average and reference values of dc bus voltage results in a voltage error, which is expressed as, $v_{dcError\,(n)}$, at n[th] sampling instant:

$$v_{dcError\,(n)} = v_{dc\,(n)}^* - v_{dca\,(n)} \quad (11)$$

The perturbated signal $v_{dcError\,(n)}$ is fed to PI controller and output $y_{0\,(n)}$ at n[th] sampling instant is expressed as:

$$y_{0\,(n)} = y_{0\,(n-1)} + K_{pd}\{v_{dcError\,(n)} - v_{dcError\,(n-1)}\} + K_{id} v_{dcError\,(n)}$$

$$= ISd\ * \quad (12)$$

Where K_{pd} and K_{id} are PI gains. The quantities, $y_{0\,(n-1)}$ and $v_{dcError\,(n-1)}$ are the output of the voltage controller and voltage error, respectively, at $(n-1)th$ sampling instant. The I_{Sd}^* is amplitude of the reference supply currents considered as output $y_{0\,(n)}$ of PI controller.

Similerly, The amplitude I_{Sq}^* of quadrature reference supply currents is computed using AC PI controller, compairing the peak value of the supply voltage ($V_{L_{peak}}$) and its reference voltage (V_{Lpeak}^*) results in a voltage error, which is expressed as, $v_{acError\,(n)}$, at n[th] sampling instant:

$$v_{acError\,(n)} = V_{Lpeak\,(n)}^* - V_{L_{peak}\,(n)} \quad (13)$$

The perturbated signal $v_{acError\,(n)}$ is fed to PI controller and output $x_{0\,(n)}$ at n[th] sampling instant is expressed as:

$$x_{0\,(n)} = x_{0\,(n-1)} + K_{pq}\{v_{acError\,(n)} - v_{acError\,(n-1)}\} + K_{iq} v_{acError\,(n)}$$

$$= ISq\ * \quad (14)$$

Where K_{pq} and K_{iq} are PI gains. The quantities, $x_{0\,(n-1)}$ and $v_{acError\,(n-1)}$ are the output of the voltage controller and voltage error, respectively, at $(n-1)th$ sampling instant. I_{Sq}^* is the amplitude of the reference supply currents considered as output $x_{0\,(n)}$ of PI controller.

3) Hysteresis Controller: The reference supply currents (i_s^*) and the actual supply currents (i_s) is compaired and current error i_{error} signal is pass through the hysteresis band. According to the error position that is at lower and upper limits the transistors are switched to force the current up and down respectivly resulting in the firing pulses at the output.

III. MATLAB MODEL AND SIMULATION RESULTS

A block diagram of MATLAB model of proposed S-SPQC scheme is shown in Fig. 4 with subsystems, the parameters used in the simulations are shown in the table I.

A diode bridge rectifier R-L load represents the system load. The voltage and current waveforms are shown in fig. 5, the Fast Fourier Transform (FFT) analysis of the responses is done to determine the Total Harmonic Distortion (THD) of the waveforms shown in fig. 6 and fig. 7.

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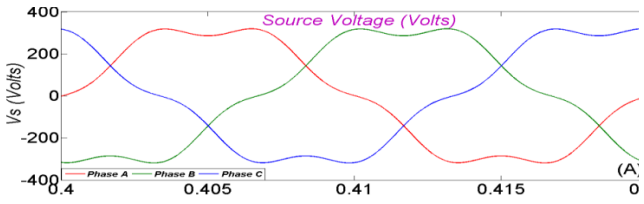
From these results, it can be seen that the source voltage has a distorted waveform (Fig. 5(A)) with a THD value of 12.29% (Fig.6 (A)).It can also be observed that by using SRF technique compensating voltage (Fig. 5(B)) was extracted properly and provides the clean load voltage (Fig. 5(C)) at the point of common coupling with a THD value of 0.57% (Fig. 6 (B)) i.e. 95.36 % voltage harmonics was compensated.

It can be seen that the load current has a distorted waveform (Fig. 5(D)) with a THD value of 25.77% (Fig. 7(A)).It can also be observed that by using ICC technique compensating current (Fig. 5(E)) was extracted properly and supplies the pure source current (Fig. 5(F)) with a THD value of 0.27% (Fig.7 (B)) i.e. 98.95% current harmonics was compensated. It can also be seen that the source current settles to its steady state value within five cycles Furthermore, it can be seen that, for sudden load change (rise) the dc link voltage dips to 695V and settles at its reference value within three cycles (Fig. 5(G))

TABLE I. S-SPQC SYSTEM SIMULATION PARAMETERS

Simulation Blocks	Parameters		Values	
Source	Voltage	V_S	400	V
	Frequency	f	50	Hz
	Source Resistance	R_S	0.03	Ω
	Source Inductance	L_S	0.20	mH
	Total Harmonic Distortion	THD_{Vs}	12.29	%
Non-Linear Load	Line Inductance	L_{chock}	2	mH
	dc Inductance	L_L	10	mH
	dc Resistance	R_L	30	Ω
	Total Harmonic Distortion	THD_{IL}	25.77	%
DC Link	Voltage	V_{DC}	700	V
	Capacitor	C_{DC}	2200	µF
Shunt APF	Line Inductance	L_P	3.5	mH
	Ripple Filter Resistor	R_P	5	Ω
	Ripple Filter Capacitor	C_P	10	µF
Series APF	Line Inductance	L_S	3.5	mH
	Ripple Filter Resistor	R_S	5	Ω
	Ripple Filter Capacitor	C_S	20	µF
ICC block	Proportional Gain	K_{pd}	0.2	--
	Integral gain	K_{id}	3.2	--
	Proportional Gain	K_{pq}	0.32	--
	Integral gain	K_{iq}	3.4	--
SPWM block	Proportional Gain	K_P	1.2	--
	Integral gain	K_i	4.7	--



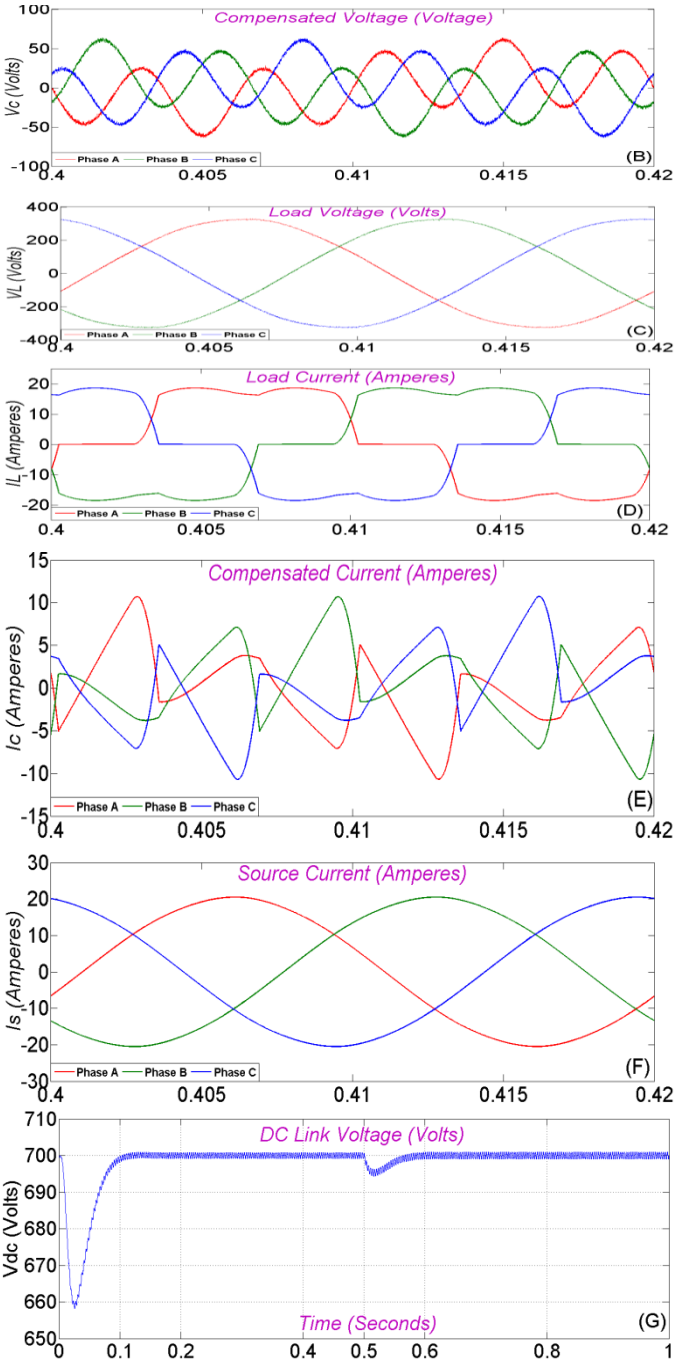


Figure 5. Voltage and current waveforms for distorted mains voltage and harmonically polluted currents

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TABLE II. S-SPQC SIMULATION RESULTS OF VOLTAGE REGULATION FOR VARIOUS CONDITIONS

	Phases	Without Quadrature component of reference current						With Quadrature component of reference current					
		Normal Load		Load Variation (Rise)		One Line open Fault		Normal Load		Load Variation (Rise)		One Line Open Fault	
		RMS Value	% THD	RMS Value	% THD	RMS Value	% THD	RMS Value	% THD	RMS Value	% THD	RMS Value	% THD
Source Voltage (V_S)	A	224	12.64	220.7	12.83	227.9	12.43	223.8	12.65	220.8	12.82	227.3	12.46
	B	224	12.64	220.7	12.83	227.9	12.43	223.9	12.65	220.8	12.82	227.5	12.46
	C	224	12.64	220.7	12.83	227.7	12.43	223.8	12.65	220.8	12.81	227.4	12.45
Voltage At PCC (V_L)	A	231.9	0.34	228.5	0.35	233.8	0.50	**230.6**	0.53	**230.2**	0.43	**230.8**	0.77
	B	231.8	0.36	228.5	0.35	233.4	0.51	**230.7**	0.45	**229.9**	0.39	**230.9**	0.69
	C	231.9	0.34	228.5	0.33	233.5	0.49	**230.5**	0.43	**230.1**	0.40	**231.2**	0.66

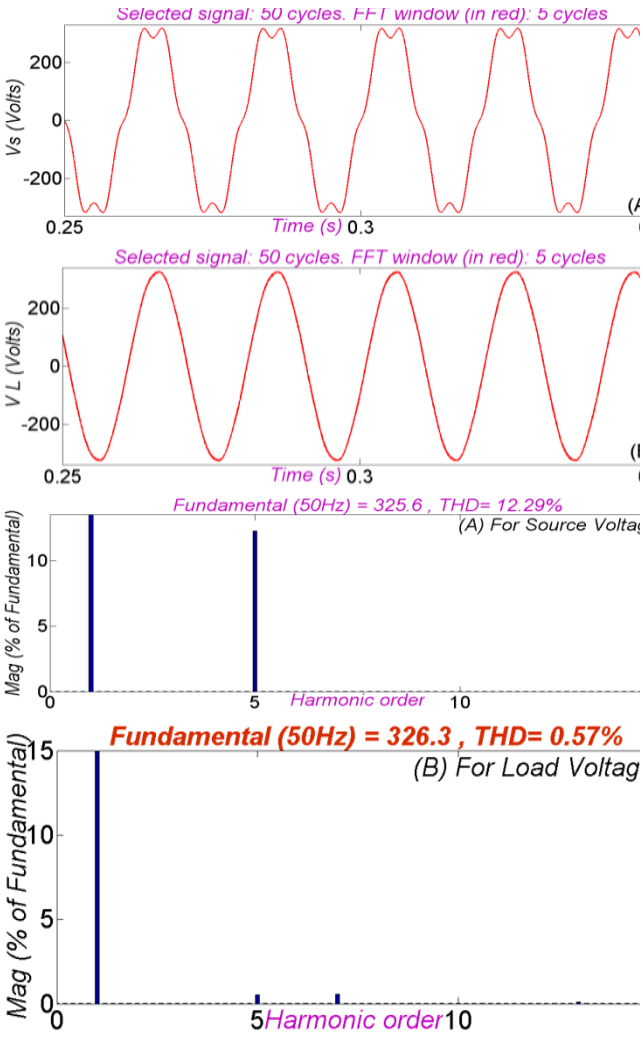

Figure 6. FFT analysis: (A) source voltage (B) load voltage

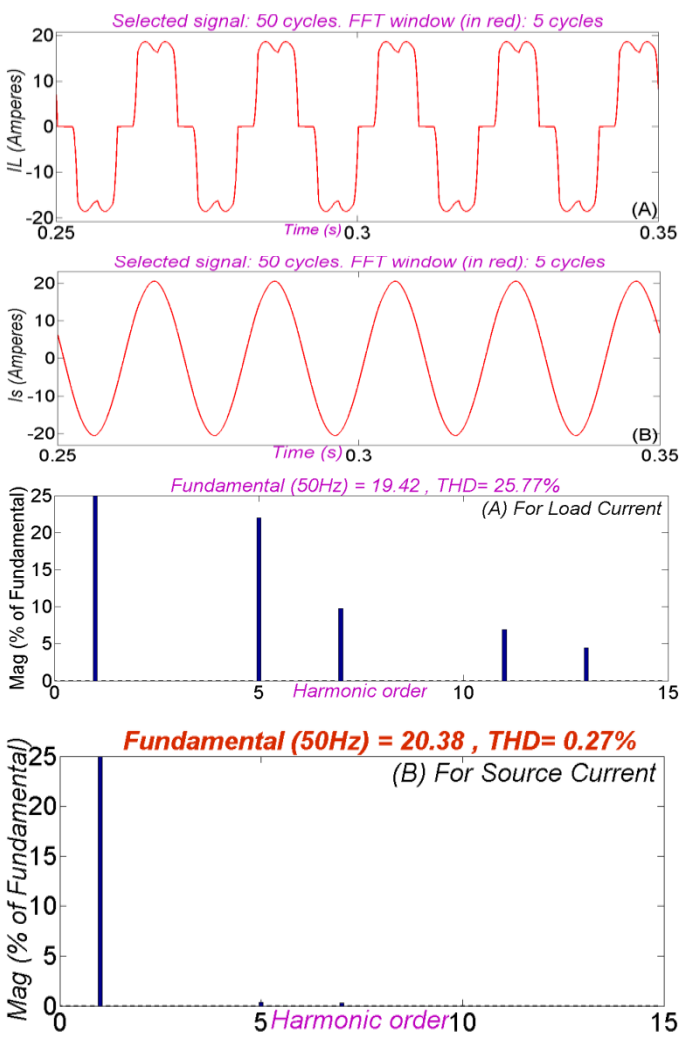

Figure 7. FFT analysis: (A) source current (B) load current

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IV. CONCLUSION

This paper has presented a new control strategy for the S-SPQC system, which mainly compensate reactive power and voltage and current harmonics in the load under distorted mains voltage and load current conditions. The proposed control strategy requires only source current and load voltage measurement for shunt APF based on the indirect current control technique. The synchronous reference frame technique was used by measuring mains voltage and filter voltage for series APF so it reduces the number of measurement sensors. The simulation results highlighted that, the above control algorithms eliminate the impact of distortion of load current on the power line and isolate the loads voltages and source voltage.

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BIOGRAPHIES

Devendra L. Raokhande has obtained his B.E. (Electrical) with first class in 2008 and M.Tech (Electrical, Power System) with first class (distinction) in 2013 both from Walchand College of Engg. Sangli (India). Currently he is working as Junior Engineer at MAHAGENCO. His current research interests include power quality, Active Power Filters, electrical drives and power electronic converters.

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