A NOVEL CONTROL STRATEGY FOR SERIES-SHUNT POWER QUALITY COMPENSATOR

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Abstract- Advancement and extensive use of power electronic devices such as, fast switching uncontrolled/controlled converters, inverters and cycloconverters, high voltage power converters used in HVDC, high voltage drives in traction system, arc furnaces, modern single phase electronic equipments like Compact Fluorescent Lamps (CFLs), Uninterruptible Power Supply (UPS), Personal Computers (PCs), printers, battery chargers, fax machines, photocopiers etc. creates power quality problems, the measure of it was voltage and current harmonics, poor power factor, imbalance, reactive power compensation, voltage regulation etc. Ideally power system network must be electrically clean, harmonics free, balanced, sinusoidal with unity power factor and regulated. This work deals with the performance of Series-Shunt Power Quality Compensator (S-SPQC) under distorted source voltages and load currents. In this work a novel control strategy of Synchronous Reference Frame (SRF) used to extract the fundamental reference voltage component and the ICC based technique used to predict source current which simplifies the computation and amplifies the system performance.

Keywords- Active Power Filter (APF), Harmonics, Power Quality (PQ), Synchronous Reference Frame (SRF), Indirect Current Control (ICC), Series-Shunt Power Quality Compensator (S-SPQC).

1. 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 of power to the consumers as well as to maintain it at the point of common coupling (PCC). There is a rapid growth in the development of the power electronic devices such as, fast switching uncontrolled / controlled converters, inverters and cycloconverters, high voltage power converters used in HVDC, high voltage drives in traction system, arc furnaces, modern single phase electronic equipments like Compact Fluorescent Lamps (CFLs), Uninterruptible Power Supply (UPS), Personal Computers (PCs), printers, battery chargers, fax machines, photocopiers etc. which leads to many undesirable features like inadequacy to maintain unity power factor, low efficiency of the system, disturbance to other consumers, interference with nearby communication network and drops the quality of power at the PCC. To avoid such problems there is a vast research on power filters going on continuously. Classically, for suppression of harmonics, shunt passive filters are used along with shunt capacitor, if required to maintain load Power factor at unity, which have several drawbacks. To overcome limitations of passive filters extensive research is being carried out in the field of harmonics and reactive power compensation. Recently, advanced active power filtering techniques identifies superiority than passive filters due to the performance, compactness and response to eliminate harmonics and compensate burden of reactive power generated by the nonlinear loads [1],[6]. Now a days, by combining the series and shunt converters having a common capacitive storage device which is known as Series Shunt Power Quality Compensator (S-SPQC), it is possible to overcome nearly all kind of power quality problems. Voltage and current events ideally should have harmonic free Voltage and current waveforms, unity power factor, balanced load, zero neutral current flow, stabilized/regulated voltage across dc link capacitor, negligible reactive power demand and maintain constant voltage at PCC under load variation and faulty situations. The function of S-SPQC system is to compensate these problems associated with the voltage and current events. The current related compensation is provided through shunt part, connected near the loads. The voltage related compensation is provided through series part, connected in series with a line, through a series transformer and functions as a controlled voltage source [2-5].

This paper presents a new control algorithm by integrating the SRF and ICC techniques for the Series-Shunt Power Quality Compensator (S-SPQC) which need not require load and filter current measurements. These control algorithms are very simple and requires less computations, due to which system performance is improved. MATLAB/Simulink software based Simulation is carried out and results are mentioned which shows the use of control algorithm of S-SPQC.

II. S-SPQC CONTROL ALGORITHM

The S-SPQC is mainly a combination of series and shunt active power filters with a commonly shared DC link. Series convertor operates as voltage source, while in shunt convertor operates as a current source. Fig. 1 describes the basic blocks of the S-SPQC. Three phase three wire non-linear load is considered for distorted source voltage and load current
conditions and compensation system is located near PCC. It injects compensating currents towards load side for current quality improvement and compensating voltages towards source side for voltage quality improvement. Ripple filters are used to filter out the voltage and current waveform ripples produced due to high switching frequency.

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 [7]. The reference voltage value which is nothing but the harmonic component 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.

In equation (1), supply voltages $V_s$ are transformed from a-b-c to d-q-0 coordinates [4,5].

$$V_s = \begin{bmatrix} \frac{1}{2} \\ \frac{1}{2} \\ \frac{1}{2} \end{bmatrix} \sin (\omega t) \sin (\omega t - \frac{2\pi}{3}) \sin (\omega t + \frac{2\pi}{3}) \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix}$$

$$V_d = V_{sd} + V_{sg}$$

$$V_{d} = \frac{1}{3} \begin{bmatrix} \sin (\omega t) & \cos(\omega t) & 1 \\ \sin (\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) & 1 \\ \sin (\omega t + \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix}$$

This fundamental component is then subtracted from source voltage $V_S$ to get harmonic reference compensating component $V_C$. The switching signals are then generated for series converter IGBT switches by comparing reference compensating component voltages ($V_C$) and the actual filter voltages ($V_f$) 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.

**B. Shunt APF**

Generation of reference current by ICC technique: Fig. 2(B) shows the ICC Algorithm of the S-SPQC [8]. The control scheme of the S-SPQC requires sensing of voltages $V_i$ at PCC and dc bus voltage $V_{dc}$. A dc bus capacitor balancing is achieved by adjusting the Proportional and Integral 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 $I_{dc}$ of three-phase reference supply current.

In equation (5), the unit templates $u_a$, $u_b$, and $u_c$ of three-phase currents are derived in-phase with the load voltages.

$$u_a = \frac{V_{La}}{V_{peak}}; \quad u_b = \frac{V_{Lb}}{V_{peak}}; \quad u_c = \frac{V_{Lc}}{V_{peak}}$$

(5)

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

$$V_{peak} = \left\{ \frac{2}{3} (V_{La}^2 + V_{Lb}^2 + V_{Lc}^2) \right\}^{1/2}$$

(6)

In equation (7), three phase instantaneous reference supply currents $i_{sa}^*$, $i_{sb}^*$ and $i_{sc}^*$ are computed by multiplication of amplitude $I_{dc}$ with unit current vectors $u_a$, $u_b$ and $u_c$.

$$i_{sa}^* = I_{dc}^* u_a; \quad i_{sb}^* = I_{dc}^* u_b; \quad i_{sc}^* = I_{dc}^* u_c$$

(7)

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

1) PI Controller: The amplitude $I_{dc}^*$ of reference supply currents is computed using PI controller over the average value of dc bus voltage ($V_{dc}$) 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:

$$V_{dcError(n)} = V_{dc(n)} - V_{dca(n)}$$

(8)
The perturbated signal $v_{dc\text{Error}}(n)$ is fed to PI controller and output $y_0(n)$ at $n^{th}$ sampling instant is expressed as:

$$y_0(n) = y_0(n-1) + K_p\left(v_{dc\text{Error}}(n) - v_{dc\text{Error}}(n-1)\right) + K_i v_{dc\text{Error}}(n)$$

Where $K_p$ and $K_i$ are Proportional and Integral gains respectively. The quantities, $y_0(n-1)$ and $v_{dc\text{Error}}(n-1)$ are the output of the voltage controller and voltage error, respectively, at $(n-1)^{th}$ sampling instant. The $I_d^*$ is the amplitude of reference supply currents considered as output $y_0(n)$ of PI controller.

3) Hysteresis Controller: The reference supply currents ($I_d^*$) and the actual supply currents ($I_d$) is compared and current error $i_{\text{error}}$ 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 respectively resulting in the firing pulses at the output.

### III. MATLAB MODEL OF S-SPQC SCHEME

A block diagram of MATLAB model of proposed S-SPQC scheme is shown in Fig. 4. A Thyristor bridge rectified three phase R-L non-linear load is taken as a system load. The simulation parameters for different blocks are specified in table I. To filter out the notches and switching ripples in the voltage and current, R-C ripple filters are used. Simulation has been carried out for distorted voltages and current waveform conditions.

### IV. SIMULATION RESULTS

The responses of S-SPQC MATLAB model are shown in fig. 5, then the Fast Fourier Transform (FFT) analysis is done to determine the Total Harmonic Distortion (THD) of the
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Figure 6. FFT analysis: (A) source voltage (B) load voltage

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

Figure 8. S-SPQC System Simulated Performance Under Different Loading Conditions

<table>
<thead>
<tr>
<th>System Condition</th>
<th>Before S-SPQC Connected to system</th>
<th>After S-SPQC connected to system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steady-State</td>
<td>Step-UP</td>
</tr>
<tr>
<td></td>
<td>Current $I_s$ (A)</td>
<td>Voltage $V_s$ (V)</td>
</tr>
<tr>
<td>Distorted load current $I_l$ and</td>
<td>0.7-0.8</td>
<td>0.7-0.8</td>
</tr>
<tr>
<td>source voltage $V_s$, (%THD)</td>
<td>Sec.</td>
<td>Sec.</td>
</tr>
<tr>
<td>A</td>
<td>28.29</td>
<td>11.96</td>
</tr>
<tr>
<td>B</td>
<td>28.23</td>
<td>11.91</td>
</tr>
<tr>
<td>C</td>
<td>28.20</td>
<td>11.91</td>
</tr>
<tr>
<td>Fundamental Component (Peak Values)</td>
<td>19.93</td>
<td>325.8</td>
</tr>
<tr>
<td>A</td>
<td>19.82</td>
<td>325.8</td>
</tr>
<tr>
<td>B</td>
<td>19.81</td>
<td>325.8</td>
</tr>
</tbody>
</table>

waveforms shown in fig. 6 and fig. 7. 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 0.84% (Fig. 6 (B)) i.e. 93.17 % voltage harmonica 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)) i.e. 98.25% current harmonica 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)).

Overall system response can be presented in fig. 8 and summarized in table II under different loading conditions.

V. CONCLUSION

This paper pointed up a new control strategy for the S-SPQC system, which mainly compensate voltage and current harmonics 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 illustrated 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.

REFERENCES


