Comparative Evaluation of Various Control Strategies for Shunt Active Power Filters in Aircraft Power Utility of 400 Hz

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ABSTRACT
Three different conventional control strategies for extracting reference currents for shunt active power filters have been evaluated and their performance has been compared under various non-linear loads. Comparison of the compensation ability of different control strategies based on THD and speed will be done and suggestions will be given for the selection of strategy to be used under different load. Simulation results using MATLAB have been included.


1. INTRODUCTION
Conventional aircraft power systems has started using more electric power to drive aircraft subsystems which was earlier driven by a combination of mechanical, electrical, hydraulic, and pneumatic systems. The latest power electronics devices have given the momentum in the improvement of the performance of the aircraft electrical systems and this leads to advanced aircraft power system [1]-[3]. In aircraft electrical system, different types of loads require power supplies that are different from those provided by the main generators and also used different source frequency i.e. 400 Hz as compare to normal supply of 50Hz. Due to increased application of power electronic devices in the system, the system suffers from the problem of harmonics, reactive power and flow of neutral current. Shunt active power filter has been applied to aircraft system for the compensation and improvement of power quality[4],[7],[9],[10],[12]-[13],[15]. The shunt APF is realized by using one voltage source inverters (VSIs) connected at point of common coupling (PCC) with a common DC link voltage [5]-8.

This paper presents simulation of three different popular control strategies (Constant instantaneous power control strategy, Sinusoidal current control strategy, Synchronous reference frame strategy) for the extraction of the reference currents for a shunt active power filter connected to aircraft power utility. Block diagram of the system using different control strategies has been shown in Figure 1. All three strategies have been simulated using MATLAB/Simulink and their comparative evaluation has been done [1].

The organization of the paper has been done in the following manner. The control strategies have been discussed in Section II, III and IV. Comparative evaluation of their performance using MATLAB/Simulink results has been discussed in Section V and finally Section VI concludes the paper.

Fig. 1: Block diagram of the system using different control strategies
2. CONSTANT INSTANTANEOUS POWER CONTROL STRATEGY (C.I.P.C.)

Figure 2 presents the control diagram of the shunt active filter using constant instantaneous power control strategy. We can observe that four low pass filters have been shown in the control block; in which, three with cut off of 6.4 KHz has been applied to filter the voltages and one for the power $p_0$. Direct application of the phase voltages cannot be used in the control due to instability problem. There may be resonance between source impedance and the small passive filter. Low pass filters have been applied to the system to attenuate the voltage harmonics at the resonance frequency which are higher than 6.4 KHz. $p$, $q$, $p_0$, $v_{\alpha}$, and $v_{\beta}$ are obtained after the calculation from $\alpha$-$\beta$-$0$ transformation and sent to the $\alpha$-$\beta$ current reference block, which calculates $i'_{\alpha}$ and $i'_{\beta}$. Finally, $\alpha$-$\beta$-$0$ inverse transformation block calculates the current references and applied to the PWM current control i.e. hysteresis band controller.

![Fig. 2. Control block diagram of the shunt active filter using constant instantaneous power control strategy](image)

3. SINUSOIDAL CURRENT CONTROL STRATEGY (S.C.C.)

Sinusoidal current control strategy is a modified version of constant instantaneous power control strategy, which can compensate load currents under unbalanced conditions too. The modification includes a positive sequence detector which replaced the 6.4 KHz cutoff frequency low-pass filters and correctly finds the phase angle and frequency of the fundamental positive sequence voltage component and thus shunt active power filter compensates the reactive power of the load. While designing this detector, utmost care should be taken so that shunt active filter produces ac currents orthogonal to the voltage component, otherwise it will produce active power. $i_{\alpha}$, $i_{\beta}$, $p'$ and $q'$ are obtained after the calculation from $\alpha$-$\beta$-$0$ transformation block and send to the $\alpha$-$\beta$ voltage reference block, which calculates $v'_{\alpha}$ and $v'_{\beta}$. Finally, $\alpha$-$\beta$-$0$ inverse transformation block calculates the $V_{sa}$, $V_{sb}$ and $V_{sc}$. In place of the filtered voltages used previously, $V_{sa}$, $V_{sb}$ and $V_{sc}$ are considered as input to the main control circuit of figure 2. Now fundamental negative sequence power, harmonic power, and the fundamental reactive power, are also included in the compensating powers.

![Fig. 3. Block diagram of the fundamental positive-sequence voltage detector for sinusoidal current control strategy](image)

4. SYNCHRONOUS REFERENCE FRAME STRATEGY (S.R.F)

In this strategy, the reference frame d-q is determined by the angle $\theta$ with respect to the $\alpha$-$\beta$ frame applied in the p-q theory. Little modifications are required in the conventional SRF method so that they can be used in aircraft power utility and compensate well the neutral current. For this reasons zero-sequence component of current has not been considered and so, the zero sequence subtract block take away the zero sequence current from the load current and output current comprises of only positive sequence and negative sequence component and after its park transformation, the output current in d-q frame is composed of only instantaneous active and reactive current. A low-pass filter attains the division of the dc and ac component of the active current for compensation of the harmonic and reactive current. This active current passes through a low pass filter and the signal came from dc voltage regulator together though a Park counter-transformation subtracting from the load currents generates the reference current.
5. COMPARATIVE EVALUATION USING SIMULATION RESULTS

Three different control strategies have been simulated using MATLAB/Simulink to evaluate their performance. Three loads has been used i.e. three-phase rectifier parallel with inductive load and an unbalanced load connected a phase with midpoint, the three-phase rectifier connects a pure resistance directly, three-phase inductive load linked with the ground point and combined all three loads connected with system together at different time interval.

The simulation results undoubtedly exhibit that the every one of three schemes are capable to effectively reduce the significant amount of THD in source current and voltage within limits [11]. Simulation has been done for 15 cycles and results have been analyzed on the basis of THD and response time obtained.

A. Uncompensated System

When load has been connected to the system, it has been observed that the system has been polluted and the THD of source current and voltage was well out of limit of international standard and calculated as 2.07% and 28.96% respectively.

B. Performance of APF under load 2(three-phase rectifier connected a pure resistance directly)

Performance of APF under load has been discussed below for Constant instantaneous power control strategy, Sinusoidal Current Control Strategy and Synchronous Reference Frame Strategy

1) For Constant instantaneous power control strategy

From the simulation results shown in figure 5, it has been observed that that the THD of source current & source voltage was 2.30% and 1.48% respectively. The compensation time was 0.016 sec.

2) For Sinusoidal Current Control Strategy

From the simulation results shown in figure 6, it has been observed that that the THD of source current & source voltage was 2.30% and 1.29% respectively. The compensation time was 0.0085 sec.
3) **For Synchronous Reference Frame Strategy**

From the simulation results shown in figure 7, it has been observed that the THD of source current & source voltage was 2.54% and 1.51% respectively. The compensation time was 0.00747 sec. 

![Fig. 7](source.jpg)

*Fig. 7.* Source Voltage, source current, compensation current (phase b), DC link Voltage and load current waveforms of Active power filter using synchronous reference frame strategy with three-phase symmetrical nonlinear and inductive load condition for aircraft power utility

### C. Comparative Analysis of the Simulation Results

Simulation results has been tabulated in Table 1 and from there, Constant instantaneous power control strategy (CIPC) and Sinusoidal current control strategy (SCC) have been found best for least THD of source current, whereas for least THD of source voltage, Sinusoidal current control strategy (SCC) was best. Synchronous reference frame strategy was fastest among all three control strategies for compensation. These conclusions have been also tabulated in Table 2.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>THD-I (%)</th>
<th>THD-V (%)</th>
<th>Response Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIPC Strategy</td>
<td>2.30</td>
<td>1.48</td>
<td>0.016</td>
</tr>
<tr>
<td>SCC Strategy</td>
<td>2.30</td>
<td>1.29</td>
<td>0.0085</td>
</tr>
<tr>
<td>SRF Strategy</td>
<td>2.54</td>
<td>1.51</td>
<td>0.00747</td>
</tr>
</tbody>
</table>

The simulation results shown and the tabulated in table 2 and table 3 undoubtedly explains the choice of different strategy with different load based on THD and response time. The results has also been represented using graphical diagram in figure 8 and 9, which clearly shows the effectiveness of the strategies used for harmonic compensation.

### 6. CONCLUSION

This paper has presented a relative study of three control strategies for shunt APFs installed in aircraft power utility of 400 HZ. The ideas have been given for the optimum selection of strategy for three different
types of loads alone or together. Overall Sinusoidal current control strategy (SCC) has been observed as most fit for all loads discussed and Synchronous reference frame strategy (SRF) found to be fastest among all three control strategies discussed.

APPENDIX
The system parameters used are as follows [1]:
Three-phase source voltage: 115V/400 Hz
Filter inductor=0.25m H
Filter capacitor: 5 uF,
Dc voltage reference: 400 V
Dc capacitor: 4700Uf

REFERENCES