

A NOVEL APPROACH OF CASCADED SHUNT ACTIVE POWER FILTER AIRCRAFT POWER SYSTEM APPLICATION

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Abstract: - In this paper, based on the analysis and modelling of the shunt APF with close-loop control, a feed forward compensation path of load current is proposed to improve the dynamic performance of the APF. The three stage H-bridge cascaded inverter is selected for the aeronautical APF (AAPF). The control levels are increased to improve the performance of APF. The increased control level can increase the aircraft power system power quality and reliability. The global frame work and operation principal of proposed AAPF are presented in detail. Source current direct control strategy and cascaded inverter topology is applied in the proposed AAPF. The power quality characteristics of the conventional system are not up to level. Performance characteristics of EPS with conventional systems are not preferable. The advantage of proposed method is to resolve the power quality issue of aircraft EPS. Overcome stability problems. Total harmonic distortion (THD) of source current is reduced in wide range of system frequency. To verify the compensation performance of the proposed AAPF, The system with control scheme is implemented in Mat lab/Simulink.

Keywords:-Aeronautical active power filter (AAPF), cascaded multilevel inverter, close-loop control, feed forward of fundamental load current.

I. INTRODUCTION

THE increasing use of electrical power in place of hydraulic, pneumatic, and mechanical power is demanding more advanced aircraft power systems. The concept of the “all-electric aircraft” and the “more electric aircraft” (MEA) have been introduced to overcome some of the drawbacks found in conventional architectures and bring more attractive advantages, such as improved fuel consumption and lower maintenance and operation costs. This implies an increase of the electrical load and power electronic equipment, higher consumption of electrical energy, more demand for generated power, power quality, and stability problems.

In the variable-speed variable-frequency (VSF)-based EPS, the “constant speed drive” is moved. Harmonic current compensation by means of active power filter (APF) is a well-known effective solution for the reduction of current distortion and for power quality improvement in electrical systems [4]. The shunt compensator behaves as a controlled current source that can draw any chosen current references which is usually the harmonic components of the load currents. Meanwhile, more and more APFs are applied not only in harmonic current and reactive power compensation but also in the neutral line current compensation, harmonic damping application, and power flow control. In the aircraft EPS, the APF could be installed in the source side (such as the aircraft generator) or near the load side and it could even be integrated into the load-front converter (such as the input stage converter of variable-speed drives). Introducing APF technology to resolve the power quality issues of the aircraft EPS catches increasing attention. Several papers have been published about the APF's application in the aircraft EPS since 2005.

In, a shunt APF using perfect harmonic cancellation is studied. The harmonic filtering performance of the APF in both the conventional and the advanced aircraft EPS is presented with Matlab simulation results. Based on the given structure and modelling of the advanced aircraft EPS, performance characteristics of the EPS without and with APF are compared. The power-quality characteristics of both the conventional and the advanced aircraft EPS with APF are shown to be in compliance with the popular electrical standards.

In this paper, a high-performance aircraft APF is proposed. Differently from traditional open-loop control strategy, the proposed aeronautical APF (AAPF) works in a close-loop way. Good power

quality of the EPS is achieved by using the novel AAPF. Furthermore, in order to improve the dynamic performance of the load response, a feed forward path of the load current is added. Based on the modelling and analysis of the close-loop system, the operation principle of the feed forward compensation path is revealed. Meanwhile, the control method of the cascaded-inverter-based AAPF is proposed.

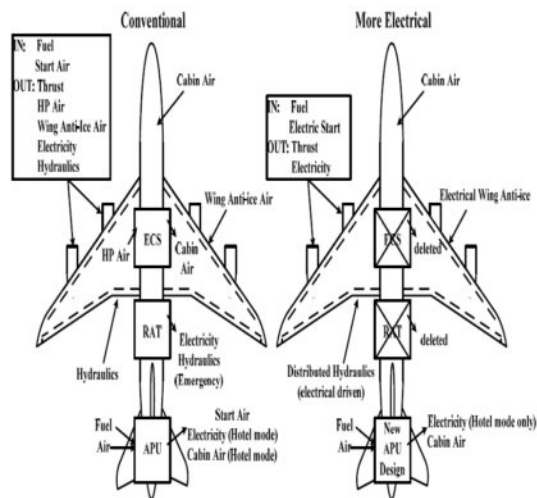


Figure 1: Control strategy

A. Close loop control strategy

In the traditional control of APF, the current reference is usually the harmonic and reactive components of the load currents. However, the approach, essentially based on feed forward open loop control, is sensitive to the parameter mismatches and relies on the ability to accurately predict the voltage-source inverter current reference and its control performance.

In the close-loop control, detection and control target is the source current. In the aircraft EPS, the fundamental frequency is much higher than 50-Hz power system. Furthermore, measure errors, analog to digital conversion time, digital delay, and other non-ideal factors will deteriorate the open-loop compensation effect to a worse degree. As we known, feedback control has the following merits: It could reduce the transfer function from disturbances to the output, and it causes the transfer function from the reference input to the output to be insensitive to variations in the gains in the forward path. Therefore,

compared with open-loop control, close-loop control is more suitable for the aeronautical application.

B. Source current direct control

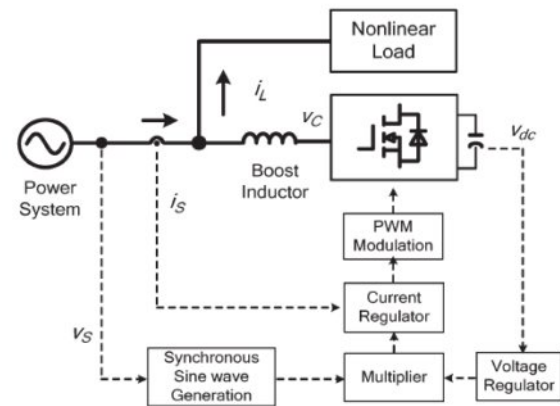


Figure 2: The close loop control scheme

In this paper, the close-loop control named as source current direct control is applied as the main control strategy of the proposed AAPF. The basic system diagram of the close loop control scheme is given in Fig.2. This control strategy operates as follows: The dc-link voltage is sent to the voltage regulator, and the output of the regulator is sent to the multiplier as well as a synchronous sine wave which is detected from the phase voltage. The output of the multiplier is sent to the current regulator, being the source current reference. The output of the current regulator will be sent to the modulator to generate the pulse width modulation waveforms.

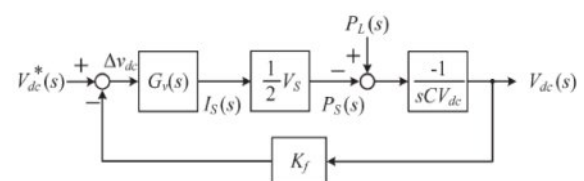


Figure 3: Model for active power analysis

Figure 3 gives the equivalent control model of this compensation strategy. As shown in Fig.3 the source current reference of the source current direct control comes from the variation of the dc-link voltage. Here, $G_v(s)$ corresponds to the transfer function of the voltage controller; K_f is the dc-link voltage detection coefficient.

C. Load current feed forward compensation

As Fig. 4 illustrates, load power $PL(s)$ works as a disturbance factor on the APF system. The transfer function between $PL(s)$ and $\Delta V_{dc}(s)$ is

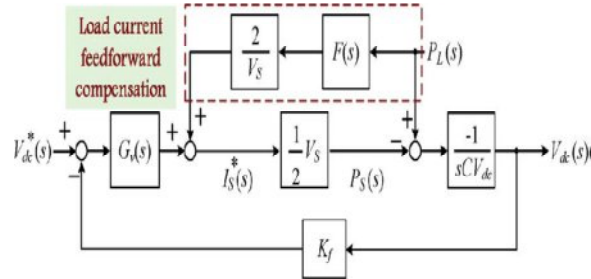


Figure.4.Load current feed forward compensation

$$\Phi_{en}(s) = \frac{\Delta V_{dc}(s)}{P_L(s)} = \frac{\frac{1}{sCV_{dc}} K_f}{1 + G_v(s) \cdot \frac{1}{2} V_s \cdot \frac{1}{sCV_{dc}} \cdot K_f} \quad (1)$$

The transfer function between $IL(s)$ and $I^* S(s)$ is

$$\begin{aligned} H_{iL}(s) &= \frac{I_S^*(s)}{I_L(s)} = \frac{\Delta V_{dc}(s) G_v(s)}{P_L(s) / (\frac{1}{2} V_s)} = \Phi_{en}(s) \cdot \frac{G_v(s)}{\frac{1}{2} V_s} \\ &= \frac{G_v(s) \cdot \frac{1}{2} V_s \cdot \frac{1}{sCV_{dc}} K_f}{s + G_v(s) \cdot \frac{1}{2} V_s \cdot \frac{1}{sCV_{dc}} K_f} = \frac{A \cdot G_v(s)}{s + A \cdot G_v(s)} \quad (2) \end{aligned}$$

Where $A = V_s K_f / (2CV_{dc})$. $HiL(s)|_{f=50}$ shows the dynamic speed of the current reference responding to the load power's change at fundamental frequency. Generally speaking, high dynamic respond is required for an APF system, meaning that a higher value of $HiL(s)|_{f=50}$ is desired. However, $HiL(s)$ is sensitive to many other factors, i.e., voltage controller, line voltage, dc-link voltage, dc-link capacitor, and voltage detection coefficient. Fig. 4 shows the bode diagram of $HiL(s)$ in different voltage controller and coefficient A. For an APF system applied in a 220-V/50-Hz application, coefficient A corresponds to 0.14 when the dc-link voltage is 800 V, dc-link voltage detection coefficient K_f is 0.005, and the dc-link capacitor is 6800 μ F. It is hard to design a voltage controller to derive a high value for $HiL(s)|_{f=50}$ at 50 Hz in such a low value of A. In the aircraft EPS, the phase voltage is only 115 V, leading A to be 0.2 when the dc-link voltage is 600 V, dc-link voltage detection coefficient K_f is 0.005, and the dc-link capacitor is 3300 μ F. It means that poor dynamic respond is derived in both applications. In order to improve the dynamic speed responding to the load's

change, a feed forward compensation path is added to weaken the disturbance effect of the load current, as shown in Fig. 5. Here, $F(s)$ is the transfer function of the low-pass filter (LPF) which extracts the fundamental components of the load currents

$$F(s) = \frac{\omega_0^2}{s^2 + \sqrt{2}\omega_0 s + \omega_0^2} \quad (3)$$

Here, $\omega_0 = 2\pi f_c$ is the cut off angular frequency of the LPF. After the fundamental of the load current is feed forward, the transfer function between $IL(s)$ and $I^* S(s)$ becomes

$$H_{iL}(s) = \frac{A \cdot G_v(s)}{s + A \cdot G_v(s)} + \frac{\omega_0^2}{s^2 + \sqrt{2}\omega_0 s + \omega_0^2} \quad (4)$$

$HiL(s)$ with feed forward compensation and different cut off frequencies. After the load current is feed forward, the magnitude of $HiL(s)|_{f=50}$ gets increased. However, the selection of f_c plays an important role to $HiL(s)$; usually, f_c should be larger than the fundamental frequency.

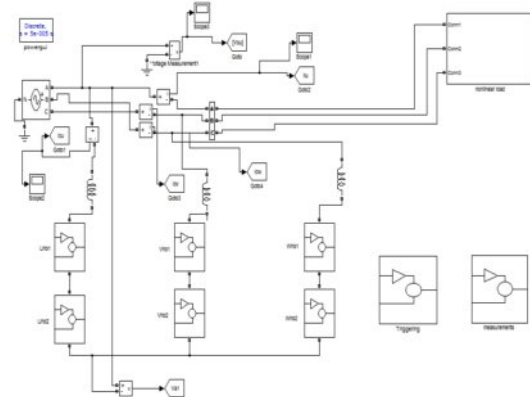


Figure 5: Conventional System

III. PROPOSED SYSTEM

a) Clustered Overall Control

In the cluster overall voltage control loop, sums of the capacitor voltages in each cluster (for example: vub1 vub2 and vub3 for phase-u) are the control target. This cluster overall control yields the u-phase clustered overall voltage signal v_{ou} from the dc capacitor voltage reference v_{dc} , the dc capacitor

voltages of the u-phase cluster v_{ub1} , v_{ub2} , v_{ub3} and the synchronous sine wave e_{su} (as shown in Fig.7). Here v_{ub1} , v_{ub2} and v_{ub3} are given through the $out1$, $out2$ and $out3$. Furthermore, this voltage control scheme could be expanded to the N H-bridge cascaded inverter topology. Here, N corresponds to the number of cascaded converter units. One obvious advantage of this control scheme is that the final compensation performance would not get worse when one or more cascaded units stop working. The remaining cascaded units would share the dc-link voltage of the fault one. This voltage control scheme can increase the fault toleration and reliability of the AAPF system.

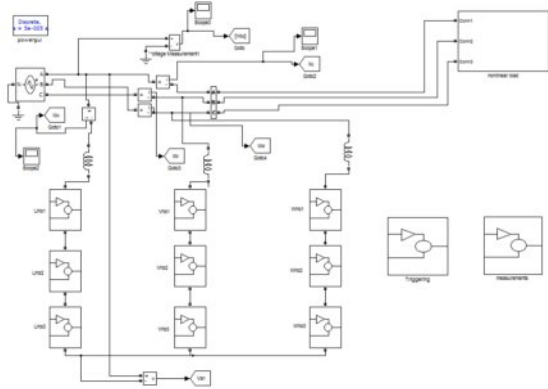


Figure 6: Proposed system Diagram

b) Voltage Balancing Control

As Fig.7 shows, the balancing control yields a balance control signal v_{bn} ($n = u, v, w$) to make the voltage of the capacitors in each cluster balanced. The individual balance control yields two modulation waves' $vmn1, vmn2$ and $vmn3$ from the origin modulation wave vm and the dc capacitor voltages of each cluster $vn1, vn2$. In the CPS PWM modulation, PWM signals for $nb1p1$, $nb1p2$ and $nb1p3$, $nb1p4$ are modulated by $vmn1$, PWM signals for $nb2p1$, $nb2p2$ and $nb2p3$, $nb2p4$ are modulated by $vmn2$, PWM signals for $nb3p1$, $nb3p2$ and $nb3p3$, $nb3p4$ are modulated by $vmn3$. The Current direction and the switch combination define the charging or discharging of the each particular capacitor of the dc link. Depending on the current direction and needed charging or discharging process, the voltage signal v_{bu} should be added or subtracted to/from the modulating signal.

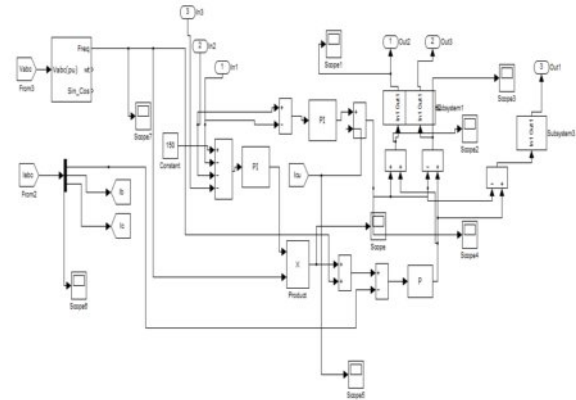


Figure 7: Proposed Control Strategy

For the upper cascaded unit, the input power decreases when the duty cycles of $nb1p1$ and $nb1p4$ decrease, resulting in the dc-link voltage v_{u1} being reduced. Similarly, the dc-link voltage of the lower cascaded unit v_{u2} will get increased. The voltage balance is therefore achieved. Take the phase- u cluster for example to show the regulation procedure of voltage-balance control.

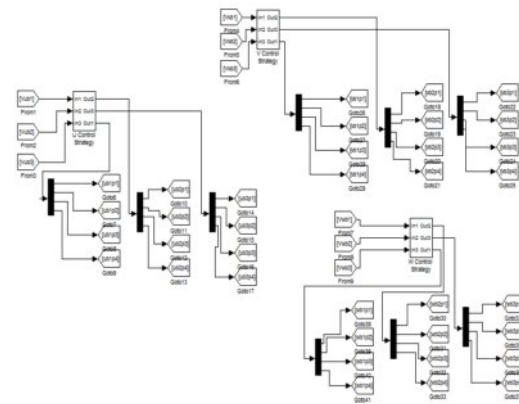
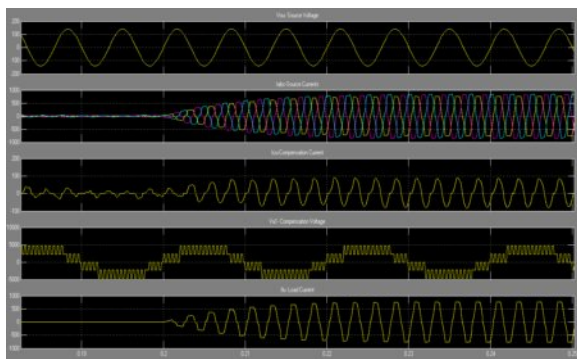


Figure 8: Triggering pulses

In the steady state, the modulation wave of bridge1 (composed of $nb1p1$ and $nb1p1$) is vmu , and the conduct times of $nb1p1$ and $nb1p2$ are $tu1$ and $tu2$, respectively. When the situation $v_{u1} > v_{u2}$ happens, a positive balance control voltage signal v_{bu} is obtained under the regulator's action. As Fig.8 shows, the final modulation signal for $nb1p1$ and $nb1p2$ is the sum of vmu and $-v_{bu}$, which becomes $vmu1$ after regulation.

IV. SIMULATION RESULTS

Conventional system results



Proposed system results

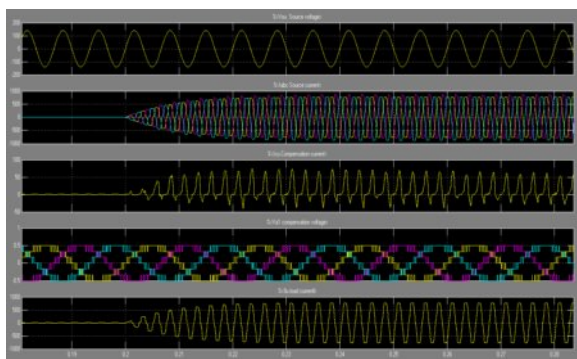


Figure 9: performance analysis for proposed and conventional system

In order to verify the compensation performance of the proposed AAPF, simulated waveforms using the Simulink™ software package of “Matlab” are given. The system power PL is set as $PL=7.2$ kVA, and the dc-link voltage V_{dc} and the switching frequency f_{SW} are set as $V_{dc}=150$ V and $f_{SW}=25$ kHz. Fig.6 shows the simulated waveforms for the 400-Hz EPS with inductive load. Compensation voltage v_{Cu} is a seven-level voltage, and three phase source currents get sinusoidal. The source current becomes nearly sinusoidal, and the total harmonic distortion (THD) of the source current is reduced.

The results show that good compensation performance is achieved by using the proposed AAPF shows the simulated waveforms for a variable frequency EPS application, in which the fundamental frequency 400 Hz. All the waveforms indicate that

the proposed AAPF could improve the source current in a wide range of the system frequency.

V. CONCLUSION

APF technology is a useful method to resolve the power quality of the modern aircraft EPS. In this a load current feed forward compensation method for source current direct control-based AAPF has been proposed. The corresponding system seven level control strategy of the cascaded-inverter based active filter system is shown. The simulation results are shown the good compensation behaviour for various kinds of load condition and the excellent dynamic performance of proposed control method. Compensation performance of the proposed AAPF, simulated waveforms using the “Simulink” software package of “Matlab” is verified.

REFERENCES

- [1] Zhong Chen, Member, IEEE, YingpengLuo, Student Member, IEEE, and Miao Chen”Control and Performance of a Cascaded Shunt Active Power Filter for Aircraft Electric Power System”, IEEE Trans. Ind. Electron., vol. 559, no. 3614-3623, September 2012.
- [2]Zhong Chen, Member, IEEE, YingpengLuo, Student Member, IEEE, and Miao Chen” Design and Implementation of a High PerformanceAeronautical Active Power Filter”, IEEE Trans. Ind. Electron., vol. 232, no.978-1-4244-5226-2, October 2010.
- [3] J. A. Rosero, J. A. Ortega, E. Aldabas, and L. Romeral, “Moving towards a more electric aircraft,” IEEE Aerosp. Electron. Syst. Mag., vol. 22, no. 3, pp. 3–9, Mar. 2007.
- [4] A. Hamadi, S. Rahmani, and K. Al-Haddad, “A hybrid passive filter configuration for VAR control and harmonic compensation,” IEEE Trans.Ind.Electron., vol. 57, no. 7, pp. 2419–2434, Jul. 2010.
- [5] A. Varschavsky, J. Dixon, M. Rotella, and L.Moran, “Cascaded nine-level inverter for hybrid-series active power filter, using industrial controller,” IEEE Trans. Ind. Electron., vol. 57, no. 8, pp. 2761–2767