

A LC-Coupling Hybrid Active Power Filter in Three-Phase Three-Wire Systems

¹T.Athavan, ²J Jayakumar, ³N.V.Ajin
¹PG Scholar, ^{2,3} Assistant Professor, Dept. of EEE,
Annai Vailankanni College Of Engineering

Abstract: This paper proposes a control strategy for a three-phase three-wire thyristor-controlled LC-coupling hybrid active power filter (TCLC-HAPF), which can balance active power and compensate reactive power and harmonic currents under unbalanced loading. Compared with TCLC-HAPF with conventional control strategy, active power filters and hybrid active power filters which either fails to perform satisfactory compensation or require high-rating active inverter part for unbalanced compensation, a control strategy was proposed for TCLC-HAPF to operate with a small rating active inverter part for a variety of loads with satisfactory performance. The control idea is to provide different firing angles for each phase of the thyristor controlled LC-coupling part (TCLC) to balance active power and compensate reactive power, while the active inverter part aims to compensate harmonic currents. First, the required different TCLC impedances are deduced. Then, independent firing angles referenced to the phase angle of voltage across TCLC are calculated. After angle transformations, final firing angles referenced to phase angle of load voltages are obtained. In this paper, a novel controller for TCLC-HAPF under unbalanced loading is proposed. Simulation and experimental results are provided to verify the effectiveness of the proposed controller in comparison with a state-of-the-art controller.

Index Terms—Active power, current harmonics, hybrid active power filter (HAPF), reactive power, thyristor-controlled LC-coupling hybrid active power filter (TCLC-HAPF), unbalanced compensation.

1. INTRODUCTION

When unbalanced nonlinear inductive loads are connected to the three-phase utility distribution system, a number of current quality problems, such as low power factor (PF), harmonic pollution, and unbalanced Currents will rise. If compensation is not provided to the distribution power system, it will cause a series of undesirable consequences, such as additional heating and loss in the stator windings, damage on the overloaded phase power cable, reduction of transmission capability, increase in transmission loss, etc. Implementation of power filters is one of the solutions for power quality problems. In the early days, thyristor-based Static Var Compensators (SVCS) are used. It can inject or absorb reactive power according to different loading situations. However, SVCS have many inherent problems including resonance problem, slow response, lack of harmonic compensation ability, and self-harmonic generation.

Under practical conditions, when unbalanced nonlinear inductive loads are connected to the three-phase utility distribution system, a number of current quality problems, such as low power factor (PF), harmonic pollution, and unbalanced currents will rise. If compensation is not provided to the distribution power system, it will cause a series of undesirable consequences, such as additional heating and loss in the stator windings, damage on the overloaded phase power cable, reduction of transmission capability, increase in transmission loss, etc. Implementation of power filters is one of the solutions for power quality problems. In the early days, thyristor-based static var compensators (SVCs) are used.

It can inject or absorb reactive power according to different loading situations. However, SVCs have many inherent problems including resonance problem, slow response, lack of harmonic compensation ability, and self-harmonic generation. Later on, the remarkably progressive concept of active power filters (APFs) was first proposed in 1976 for dynamically compensating reactive power and current harmonics problems. However, APFs require high dc-link voltage levels ($V_{dc} > \sqrt{2} \cdot V_{L-L}$) to perform compensation, which drives up their initial and operational costs. Afterward, in order to reduce the cost of APFs, an LC-coupling hybrid active power filter (HAPF) with low dc-link operational voltage was.

Unfortunately, HAPF has a narrow compensation range, which may require a high dc-link operation voltage when it is operating outside its compensation range, thus losing its low inverter rating characteristic. Many control techniques have been proposed to improve the performance of the APFs and HAPFs and solve the unbalanced problems. First proposed instantaneous pq control method in order to eliminate the reactive power, harmonic power, and unbalanced power of the loading instantaneously. In order to adapt instantaneous pq control method under different voltage conditions (distorted, unbalanced, etc), many other control techniques were further developed, such as dq control method pqr control method Lyapunov function-based control method, etc.

With all the above control methods, both APFs and HAPFs can effectively compensate the reactive power and harmonic currents under unbalanced loading compensation. However, both APFs and HAPFs probably require high active inverter rating (high initial cost and switching loss) to perform unbalanced current compensation due to the inductive coupling structures of APFs and the narrow compensation range limitations of HAPFs. In the structure of a thyristor-controlled LC-coupling hybrid active power filter (TCLC-HAPF) which can operate with a small rating active inverter part for reactive power and harmonic current compensation in comparison to the conventional solutions.

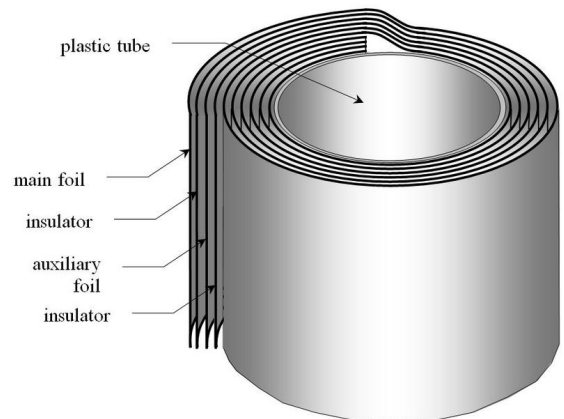
II. Hybrid Active Power Filter

Active power filters (APF) are filters, which can perform the job of harmonic elimination. Active power filters can be used to filter out harmonics in the power system which are significantly below the switching frequency of the filter. The active power filters are used to filter out both higher and lower order harmonics in the power system.

The main difference between active power filters and passive power filters is that APFs mitigate harmonics by injecting active power with the same frequency but with reverse phase to cancel that harmonic, where passive power filters use combinations of resistors (R), inductors (L) and capacitors (C) and does not require an external power source or active components such as transistors. This difference, make it possible for APFs to mitigate a wide range of harmonics.

Hybrid LC filter is a kind of electrical LC filter, which typically contains two conductive foil layers, separated by an insulation material and coiled on a core. Layers are typically made of copper or aluminum. One layer, which is placed between the voltage source, such as inverter, and a load, is called "the main foil"; this layer forms filter inductance. Another foil, called "the auxiliary foil", is connected to a neutral potential (e.g. earth), forming the useful capacitance between

foils. This way the self-capacitance of the main foil is crucially decreased. Filter is characterized by improved high-frequency performance (working frequency range is at least up to tens of MHz).



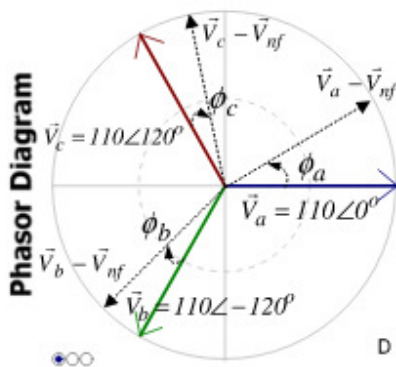
Hybrid LC filter layout

III

PROPOSED UNBALANCED CONTROL STRATEGY FOR TCLC-HAPF

The purposes of the proposed unbalanced control strategy can be described as follows: the TCLC part is controlled to balance active power and compensate reactive power, while the active inverter part aims to compensate harmonic currents. The equivalent fundamental circuit models of the TCLC-HAPF for power analysis are illustrated in Fig. 2, where the subscript "f" denotes the fundamental frequency component. In this paper, V_{sx} and V_{xf} are assumed to be pure sinusoidal without harmonic components ($V_x = V_{sxf} = V_{xf}$) for simplicity. is used to calculate the required impedances and the

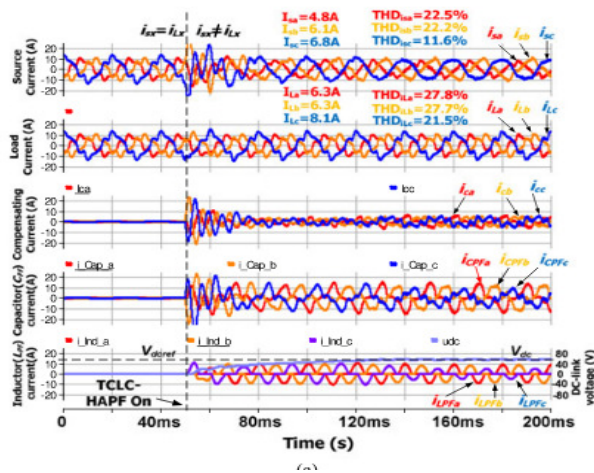
corresponding firing angles for each phase of the TCLC part in order to balance and compensate active and reactive power. In Fig. 2(a), the active inverter can be treated as a controlled voltage source, and the required fundamental inverter voltage (V_{invxf}) depends on the TCLC impedance [24]–[26]. If the TCLC impedance is perfectly matched with the load impedance, then the required V_{invxf} can be equal to zero. In this paper, it is assumed that the TCLC is controlled to be perfectly matched with the loading to simplify the following analysis; thus, $V_{invxf} = 0$, then the required TCLC impedance can be calculated based on Fig. 2(b). In the following, the proposed hybrid control strategy for the TCLC-HAPF under unbalanced loading compensation will be presented and explained in three sections: Section III-A: TCLC part control strategy, which is based on the fundamental model in Fig. 2(b), Section III-B: Active inverter part control strategy, and Section III-C: The overall hybrid controller for TCLC-HAPF.



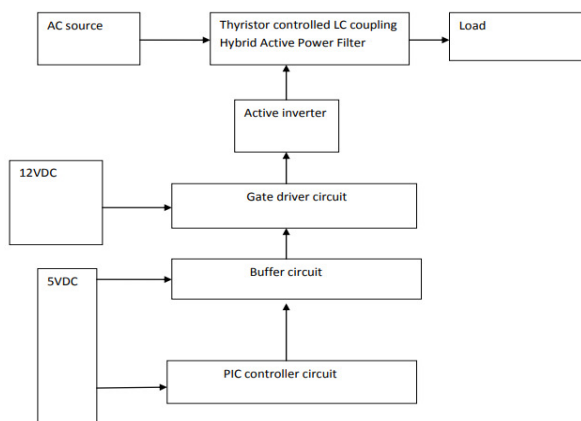
and discussed in comparison with the results of the state-of-the-art control method in [22], in

which the same dc-link voltage is applied to both of them. A 110-V 5-kVA three-phase three-wire TCLC-HAPF experimental prototype is designed and constructed in the laboratory. The details of the TCLC-HAPF experimental setup and its testing environment are provided in Appendix C. The simulations are carried out by using PSCAD/EMTDC, and the system parameters used in simulations are the same as the experiments as shown in Table V of Appendix C. In addition, with reference to the IEEE standard 519-2014 [31], the acceptable total demand distortion (TDD) 15% with ISC/IL is in 100<1000 scale (a small rating 110-V 5-kVA experimental prototype). The nominal rate current is assumed to be equal to the fundamental load current at the worst case analysis, which results in THD=TDD15%. Therefore, this paper evaluates the TCLC-HAPF current harmonics compensating performance by setting an acceptable THD 15%. compensating currents, capacitor (CPF) currents, inductor (LPF) currents, and dc-link voltage, source reactive and active power before and after compensation using the state-of-the-art control method [22] and the proposed control method. Figs. 9 and 10 (simulation results) and Figs. 11 and 12 (experimental results) and Table IV demonstrate the source current spectrums and phasor diagrams of source voltages and currents before and after the state-of-the-art control method [22] and the proposed control method. For each harmonic order of the current spectrum

as in Fig. 11, the three bars from left to right represent phases a, b, and c, respectively.



V BLOCK DIAGRAM

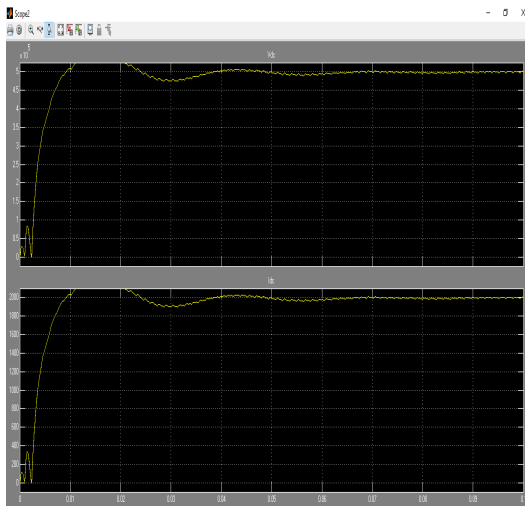
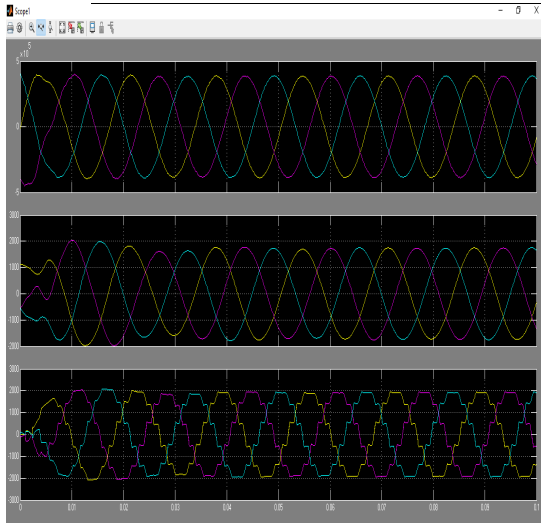


Based on the proposed hybrid control block diagram for the TCLC-HAPF under unbalanced loads compensation. It consists of five main control blocks: the TCLC part control block, the instantaneous power compensation control block, the dc-link control block, and the current PWM control block. The control system plays an important role in the performance of TCLC-HAPF. There are two common types of control

system in TCLC-HAPF. One is based on dq synchronous rotating frame (SRF), and the other is based on stationary frame.

VI BUFFERING CIRCUIT:

Op-amps have a variety of uses. One use is as a so-called buffer. A buffer is something that *isolates* or separates one circuit from another. In order to explain this more precisely, let's take a closer look at our 3-bit DAC. The 3-bit DAC constructed in the previous lab produced a digitally controlled voltage, but it turns out that we can't really use this voltage as a *source* to drive other circuits. The problem is that if we were to attach another circuit to our DAC, then we would be changing the ~~R2R~~ ladder network and hence would change the voltage produced by that network. We refer to this phenomenon as *loading*. The problem with our circuit is that it produces a voltage that is not insensitive to the load on the circuit. We now use our preceding discussion about Thevenin circuits to study the *loading problem*. Our preceding discussion asserted that a simpler circuit known as the Thevenin equivalent can always produce the output voltage of any resistive network with independent sources. The original DAC network (assuming only one of the output pins is high) and its associated Thevenin equivalent.



Current Waveform

VII CONSLUSION

In this paper, a novel control strategy for a three-phase three-wire TCLC-HAPF is proposed, which can maintain itoperating with a small rating active inverter part and at thesame time it can balance the active power and compensatethe reactive power and harmonic currents under unbalancedloading compensation. The design

idea and operation steps of the proposed hybrid controller for the TCLC-HAPF under unbalanced loading is presented and discussed in details. Finally, simulation and experimental results are given to verify the proposed control method in comparison with the state-of-the-art control method, which shows its superior compensating performances under the unbalanced loading condition.

REFERNCES

1. S. Y. Lee and C. J. Wu, "Reactive power compensation and load balancing for unbalanced three-phase four-wire system by a combined system of an SVC and a series active filter," *Proc. IEE Electr. Appl.*, vol. 147, no. 6, 2000.
2. G. Gueth, P. Enstedt, A. Rey, and R. W. Menzies, "Individual phase control of a static compensator for load compensation and voltage balancing and regulation," *IEEE Trans. Power Syst.*, vol. 2, no. 4, pp. 898–905, Nov. 1987
3. G. Tang, K. Zhu, Z. He, and H. Wang, "Study on operational tests for FACTS thyristor valves," *IEEE Trans. Power Del.*, vol. 28, no. 3, pp. 1525–1532, Jul. 2013.
4. E. Ghahremani and I. Kamwa, "Analysing the effects of different types of FACTS devices on the steady-state performance of the Hydro-Québec network," *IET Gener. Transmiss. Distrib.*, vol. 8, no. 2, May 2013.

5. S. Rahmani, K. Al-Haddad, and F. Fnaiech, "A three phase shunt hybrid power filter adopted a general algorithm to compensate harmonics, reactive power and unbalanced load under nonideal mains voltages," in Proc. IEEE Int. Conf. Ind. Technol., 2004, pp. 651–656
6. L. S. Czarnecki and S. E. Pearce, "Compensation objectives and currents' physical components-based generation of reference signals for shunt switching compensator control," IET Power Electron., vol. 2, no. 1, pp. 33–41, Jan. 2009.
7. C.-S. Lam, M.-C. Wong, and Y.-D. Han, "Voltage swell and over voltage compensation with unidirectional power flow controlled dynamic voltage restorer," IEEE Trans. Power Del., vol. 23, no. 4, pp. 2513–2521, Oct. 2008.
8. C.-S. Lam, M.-C. Wong, W.-H. Choi, X.-X. Cui, H.-M. Mei, and J.-Z. Liu, "Design and performance of an adaptive low-dc-voltage-controlled LC-Hybrid active power filter with a neutral inductor in three-phase four-wire power systems," IEEE Trans. Ind. Electron., vol. 61, no. 6, pp. 2635–2647, Jun. 2014
9. F. R. Quintela, J. M. G. Arevalo, and R. C. Redondo, "Power analysis of static var compensators," Electr. Power Syst. Res., vol. 30, no. 6, pp. 376–382, 2008.
10. X. Guo, W. Liu, X. Zhang, X. Sun, Z. Lu, and J. M. Guerrero, "Flexible control strategy for grid-connected inverter under unbalanced grid faults without PLL," IEEE Trans. Power Electron., vol. 30, no. 4, pp. 1773–1778, Apr. 2015.
11. L. Shaohua, W. Xiuli, Y. Zhiqing, L. Tai, and P. Zhong, "Circulating current suppressing strategy for MMC-HVDC based on non ideal proportional resonant controllers under unbalanced grid conditions," IEEE Trans. Power Electron., vol. 30, no. 1, pp. 387–397, Jan. 2015
12. M. Castilla, J. Miret, A. Camacho, L. Garcia de Vicuna, and J. Matas, "Modeling and design of voltage support control schemes for three-phase inverters operating under unbalanced grid conditions," IEEE Trans. Power Electron., vol. 29, no. 11, pp. 6139–6150, Nov. 2014.

