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Hybrid Active Power Filter for Power Quality Improvement

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ABSTRACT- A Deadbeat current controller for an LC-coupling hybrid active power filter is proposed, which can track with the reference compensation current with low steady- state error and fast dynamic response. Moreover, it can lead Hybrid Active power Filter to be operating at a fixed switching frequency with low output current ripples, thus reducing the size of the filtering circuit. The stability issue and parameter design of the proposed deadbeat current controller are analyzed and discussed. Finally, the compensating performance of the deadbeat current controller for the Hybrid Active Power Filter (LC-HAPF) is verified by simulation compared with the conventional hysteresis bandwidth modulation control, the proportional-integral (PI) control, and the proportional multi-resonant control for the LC-HAPF, which shows its effectiveness and superior compensating performances.

KEYWORDS- Power Filter, Power Quality, LC-HAPF, PMR

I. INTRODUCTION

Due to the proliferation and improvement of inductive motor loadings and power electronics loadings (nonlinear hundreds) in energy gadget, those hundreds motive energy pollutants troubles to the energy grid, including the low energy issue and harmonics distortion problems are the biggest concerns. pollutants issues, the early reactive power compensation technique has been implemented capacitor banks (CBs) on the grounds that 1900.However, the CBs can't compensate the contemporary harmonics trouble.

To solve the current harmonics pollution, passive energy filters have been first proposed and hooked up in the mid-1940s. It turned into then extensively implemented to compensate reactive energy and suppress cutting-edge harmonics distortion. Unfortunately, both CBs and PPFs go through many dangers together with static repayment functionality, low dynamic overall performance and resonance troubles Since the concept of an "lively ac strength filter out" turned into first developed by L. Gyugyi in 1976 research studies on energetic energy filters (APFs) for present day satisfactory reimbursement have become an increasing number of interest because of its fast and dynamic compensation traits without resonance troubles as inside the CBs and PPFs from the perspective of APF's manage approach primarily based on desk bound frame, the maximum not unusual and extensively used manage technique is hysteresis band pulse-width modulation (PWM) manage. Although Hysteresis PWM cutting-edge controller is easy and affords a fast-dynamic reaction, it yields a huge and variable switching frequency, consequently producing large output modern ripple. To relax this problem, we usually need to increase the dimensions of the filtering circuit, for that reason growing the machine price. Moreover, every other hassle of the hysteresis PWM controller is yielding a widespread regular-state cutting- edge tracking blunders. For fixing the variable switching frequency trouble, distinct controllers with constant switching frequency modulation approach have been advanced and proposed to suppress the modern ripples proportional-quintessential and proportional-resonant controllers are two famous controllers for the APF. PI controller goals to put off the steady-state errors as a result of the natural proportional controller. However, it does no longer carry out properly on dynamic sign tracking because of phase and time shifting issues. Also, the PI controller requires an countless benefit to assure low regular-country errors, which isn't always feasible Inside the realistic case. The PR manage can acquire infinite gain at resonance frequency, and 0 steady-state monitoring blunders at that resonance frequency ideally. But the endless advantage continues to be not feasible to achieve in practical case. In addition, to cope with the cutting-edge harmonics repayment problem, proportional multi-resonant (PMR) controllers must be designed for the APF to address one-of-a-kind harmonics order; consequently the controller layout is a piece complex. Moreover, the performance of the PR controller is without difficulty affected by the grid frequency. Deadbeat contemporary manage is a sort of predictive manage, which is characterized by fixed switching frequency, high accuracy/small steady-kingdom error, fast dynamic response and comparatively easy manage, as a consequence leading it will become an appealing control approach for the APF in the industry..But this method requires two adaptive predictors, in which each predictor already reasons a huge amount of computation. Another improved deadbeat manipulate turned into proposed in 2011 and 2015, respectively, wherein they stepped forward deadbeat manipulate set of rules to solve the effects of contemporary sampling mistakes and control delays. In 2018, an advanced deadbeat manipulate changed into proposed, it combines two technologies with deadbeat manage that are predictive contemporary era and modern- day-monitoring error repayment generation to in addition improve the overall performance of deadbeat cutting-edge manipulate Hysteresis PWM cutting-edge controller is easy and affords a fast-dynamic reaction, it yields a huge and variable switching frequency, consequently producing large output modern ripple. To relax this problem, we usually need to increase the dimensions of the filtering circuit, for that reason growing the machine price. Moreover, every other hassle of the hysteresis PWM controller is yielding a widespread regular-state cutting- edge tracking blunders. 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These paper pursuits to suggest a deadbeat cutting-edge controller for the LC- HAPF. The primary contribution of this paper is highlighted in beneath:

- To present a deadbeat cutting-edge manipulate strategy for LCHAPF to lessen the steady-state error of the compensating current and output modern ripples primarily based at the deduced mathematical model and manage block diagram.
- To examine the steadiness difficulty and parameter layout of the deadbeat present day controller for the LC-HAPF to make sure its stability.
- To confirm the proposed deadbeat cutting-edge controller for the LC-HAPF with the aid of simulation and experimental consequences in evaluation with the conventional hysteresis modern controller, the PI controller and the PMR controller.

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II. CIRCUIT CONFIGURATION OF LC-HAPF

A.Circuit Configuration of LC-HAPF

Fig. 1 illustrates the system configuration of a three-phase center-split LC-HAPF, where the subscript 'x' denotes phase a, b, c, n. vis the system voltage, vsx is the load voltage, Ls is the system inductance which can be neglected because of its small value. isx, icx and ilx are the system, inverter, load current for each phase respectively. Lcx and Ccx are the coupling inductor and capacitor of the HAPFCdc, VdcU, VdcL are the DC capacitor, upper and lower DC capacitor voltages with VdcU = VdcL = 0.5Vdc. The midpoint of DC-link is assumed as ground reference point g. So that the voltage source inverter (VSI) line-to-ground voltage Vinv-g equals to VSI line-to-neutral voltage Vinv-n.T1xand T2x stand for the trigger signal of the switching device. The loads are inductive nonlinear load which are composed of three single-phase diode bridge rectifiers. It can be considered as harmonics producing loads. Fig. 2 shows the LC- HAPF single-phase equivalent circuit

B.Parameters Design of Passive Part of LC-HAPF

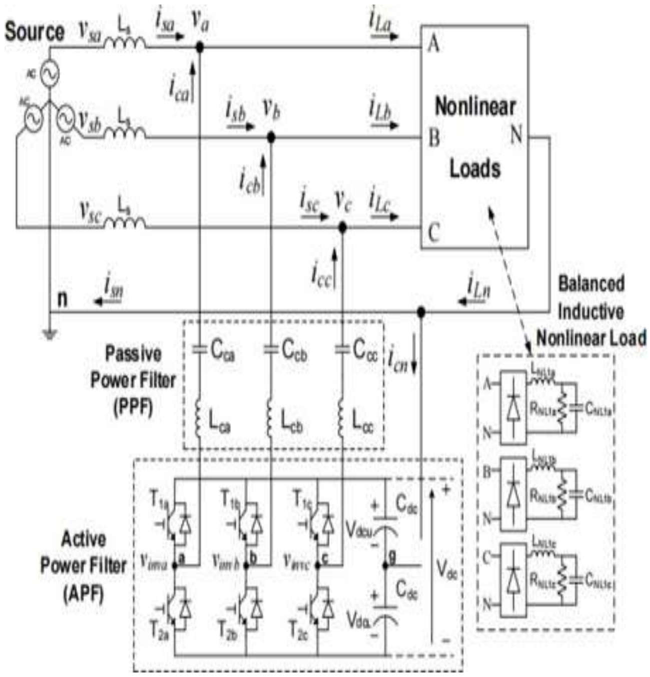

Figure 1: System configuration of a three-phase four-wire center-split LC HAPF

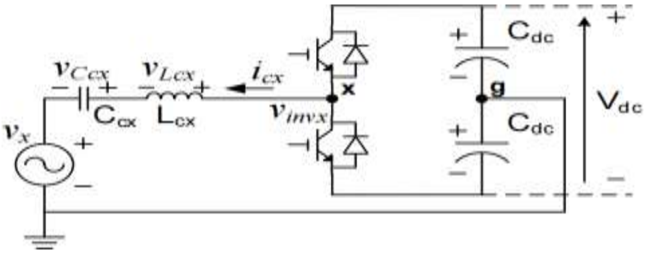

Figure 2: LC-HAPF single-phase equivalent circuit

The coupling Lcx and Ccx the LC-HAPF are designed primarily based on harmonic modern-day of loading and the average fundamental reactive electricity intake. Generally, the dominant harmonic orders in three-section four-wire gadget are ordinary orders (n = 3, 5, 7…) and every LC branch can filter out one unmarried harmonic order. More LC branches may be added to the LC-HAPF to filter greater harmonic present day orders. The design criterion of the Lcx and Ccx is defined inside the following. The relationship among the weight essential reactive energy and reactance and Ccx and Ccx may be expressed in (1), wherein ω1 is the essential angular frequency, Vx represents the basis-suggest-square load voltage, QLxf is the weight reactive electricity below essential frequency, XCcx is reactance of coupling capacitor and XLcx is reactance of coupling inductor. After that, it can resolve the values of XCcx and XLcx with the help of (2). Note that n is the order of filtering harmonic frequency.

$$\frac{V_x^2}{|Q_{Lx_f}|} = X_{Ccx} - X_{Lcx} = \frac{1}{\omega_1 C_{cx}} - \omega_1 L_{cx} \tag{1}$$

$$X_{Lcx} = \frac{1}{n^2} X_{Ccx} \tag{2}$$

III. DEADBEAT CURRENT CONTROLLER OF LC-HAPF

A. Proposed Deadbeat Current Controller of LC-HAPF

The traditional hysteresis modern-day PWM manage for the LC-HAPF will purpose tremendous constant-state errors and additionally the switching frequency is variable, which means complexity in layout of the filtering circuits and the strong comments controller for extensive range operation. Thus, hysteresis PWM control usually generates large ripple and deteriorates the current harmonics reimbursement overall performance of the LC-HAPF. To loosen up the aforementioned problems, a deadbeat modern-day controller many be proposed on this section. Figure 3 suggests a control block diagram of the proposed deadbeat contemporary controller at the same time as Fig 4. Four represents its s-area version, wherein the in-addition evaluation.

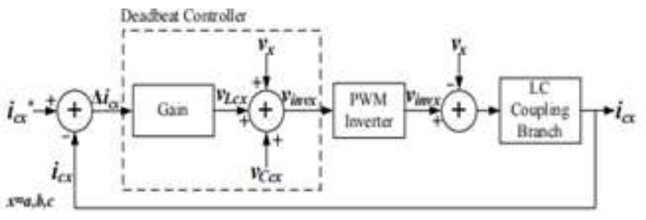

Figure 3: Control Block diagram of deadbeat current controller

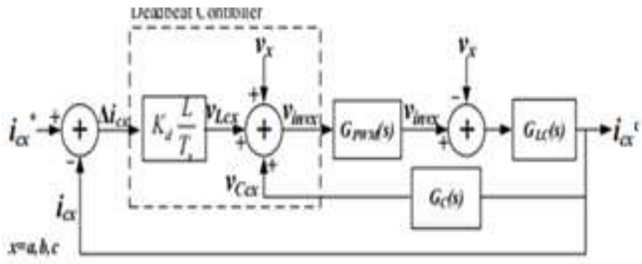

Figure 4: s-domain control block diagram model of deadbeat current controller

Discussion of the design of the controller will be presented in the following. Fig. 5 also shows its working principle waveforms of generating PWM trigger signals. The key concept of this controller is to find out the duty ratio dx of the switching devices in every switching period which is fixed in every single period (TSW = 1/fSW) based on the LC-HAPF system parameters, sampling period Ts and sensed instantaneous load voltage, compensation current and coupling capacitor voltage signals. After that, the trigger PWM signals for the switching devices can be generated by comparing the computed dx with a triangular wave carrier with a fixed switching frequency. In addition, this deadbeat current control strategy can achieve fixed switching frequency, reduce the steady-state error, improve the performance of reference compensating current tracking and compensation performance for the LC-HAPF, which will be verified in the below section. In the following, the mathematical modeling for the deadbeat current controller for the LC-HAPF will be introduced and discussed.

B. Mathematical Modeling

The reference compensating present day icx may be obtained through the use of the on-the-spot p-q concept. From Fig. 2, the feature equation of the LC-HAPF gadget may be expressed as:

$$v_{Lcx}(t) = L_{cx}\frac{di_{cx}(t)}{dt} = v_{invx}(t) - v_x(t) - v_{Ccx}(t) \tag{3}$$

Reforming (3), the averaged model of the LC-HAPF in the stationary coordinate system can be represented as:

$$v_{invx}(t) = d_x(t)\cdot v_{dc} = L_{cx}\frac{di_{cx}(t)}{dt} + v_x(t) + v_{Ccx}(t) \tag{4}$$

Where d_x refers to the duty ratio in one phase of the VSI in each small-time interval. It can be separated by upper and lower switch part as follows:

The summation of them is equal to one for the reason that switching ON and OFF

$$d_{Ux}(t) + d_{Lx}(t) = 1 \tag{5}$$

time of the top and decrease switches of the VSI is same to one manage switching period (TSW=1/fSW). From (five), the
function equation (3) will become:

$$\left[d_{Ux}(t) - d_{Lx}(t)\right]\cdot v_{dc} = L_{cx}\frac{di_{cx}(t)}{dt} + v_x(t) + v_{Ccx}(t) \tag{6}$$

For virtual implementation of the PWM manage set of rules

and the attention approximately the filter out inductance deviation, the immediately averaged model in
(6) may be represented in discrete time with a step size of okay as in (7):

$$\left[d_{Ux}(k)-d_{Lx}(k)\right]\cdot v_{dc}=K_d L_{cx}\frac{i_{cx}(k+1)-i_{cx}(k)}{T_s}+v_x(k)+v_{Ccx}(k) \quad (7)$$

Where Kdis inductance deviation coefficient that may be treated as manage variable, Ts is the sampling duration. icx(ok+1) represents the reference compensating present day icx*. Hence, combining (5) and (7), the duty ratio of 1 phase VSI is now acquired as:

$$\left.\begin{aligned} d_{Ux}(k)&=\frac{1}{2}\left[1+\frac{K_d L_{cx}\frac{i^*_{cx}(k)-i_{cx}(k)}{T_s}+v_x(k)+v_{Ccx}(k)}{v_{dc}}\right]\\ d_{Lx}(k)&=\frac{1}{2}\left[1-\frac{K_d L_{cx}\frac{i^*_{cx}(k)-i_{cx}(k)}{T_s}+v_x(k)+v_{Ccx}(k)}{v_{dc}}\right]\end{aligned}\right\} \quad (8)$$

IV. SIMULATION RESULTS

The basic manipulate precept of the hysteresis in the subsequent, the simulation studies of the traditional hysteresis PW controller, PI controller, MPR controller and deadbeat modern controller for the 3-segment 4-twine center break up LC-HAPF are performed by using PSCAD/EMTDC. The corresponding simulation outcomes earlier than and after the hysteresis PWM managed, the PI managed, the MPR managed and the deadbeat cutting-edge managed LC-HAPF reimbursement might be summarized in Fig. 10 and Table IV. With reference to the IEEE popular 519-2014, the acceptable Total Demand Distortion (TDD) ≤ 15% with ISC/IL is in 100 < one thousand scale (a small score 110V-5kVA experimental prototype). The nominal Fee current is assumed to be same to the essential load cutting-edge on the
worst-case evaluation, which results in THD = TDD≤15%. Therefore, this paper evaluates the LC-HAPF contemporary harmonics compensating overall performance through putting an acceptable THD ≤15%.

PWM control is primarily based on deriving the switching signals from the comparison of the current error Δicx between the reference compensating modern-day icx* and the actual compensating current icx with a set hysteresis band H. The trigger alerts will power the switching devices of the VSI a good way to allow icx tracks with its reference icx*. Every time while the modern-day error Δicx is larger than the advantageous or smaller than the bad hysteresis band's boundary icx*+Hor icx*-H, a nation alternate of the VSI's cause signals takes place. The PI and PMR manage is first of all computing the present day mistakes signal Δicx through subtracting the reference compensating modern-day icx* via the real compensating contemporary Icx and Δicx can be inputted right into a PI / PMR controller. Then its corresponding output could be as compared with a set frequency triangular service wave Vtri to be able to generate the cause alerts for the switching devices of the VSI.

A. Hysteresis PWM Controller

Fig. 10(a) indicates the simulation outcomes of hysteresis PWM controller for the LC-HAPF. From Fig. 10(a), the machine modern ripples after compensation is obvious. From Fig. 10(a) and Table IV, even though it can compensate the system displacement energy issue (DPF) from zero.8 to unity, the device neutral modern-day from 3.08Arms to zero.75Arms, the whole cutting-edge harmonics distortion from 35% to approximately 11%, which satisfies the international widespread of THD ≤15% [47]. The errors percentage of reactive energy injection is 1.9%. Fig.10 (e),actually illustrates the switching frequency of hysteresis contemporary manage isn't always constant. The noise and distortion particularly consciousness on low frequency because the VSI is switching with a low frequency.

B. PI Controller

Fig. 10(b) shows the simulation consequences of PI controller for the LC- HAPF. The device cut in edge ripples after repayment have been decreased notably compared with the hysteresis PW controller. From Fig. 10(b) and Table IV, it could compensate the machine DPF from zero.8 to cohesion, the machine impartial present day from three.08Arms to zero.60Arms, the THD is from 35% to about eight%, which satisfies the global preferred of THD ≤15%.The mistakes percentage of reactive electricity injection is 1.2%, that's decrease than hysteresis PWM controller. Fig. 10(e) and (g) additionally illustrates the section a supply modern-day harmonics spectrum earlier than and after reimbursement. Since the PI controller makes use of service- based totally PWM method to generate trigger alerts for the VSI, the switching frequency is constant at 2 hundredth order (10 kHz), as shown in Fig.11 (b).

C. PMR Controller

Fig. 10(c) indicates the simulation results of PMR controller for the LC-HAPF. The gadget modern ripples were decreased significantly as compared with the hysteresis PWM controller after repayment. From Fig. 10(c) and Table IV, it may compensate the gadget DPF from zero to eight cohesion, the gadget neutral current from 3.08Arms to zero.46Arms, the THDisx from 35% to less than 7%, which satisfies the global fashionable of THD ≤15%. The blunders percentage of reactive power injection is 1.0%, that's lower than PI and hysteresis PWM controller. Fig. 10(e) and
(h) Additionally illustrates the phase a supply modern harmonics spectrum earlier than and after repayment. Since the PMR controller uses service-primarily based PWM approach to generate cause indicators for the VSI, the switching frequency is constant at two hundredth order (10kHz), as proven in Fig. 11(c). Compared with Fig. 11(a), both noise and distortion in low frequency band have been significantly decreased.

D. Deadbeat Current Controller

Fig. 10(d) shows the simulation results of deadbeat cutting-edge controller for the LC-HAPF. Compared with hysteresis PWM controller case, the gadget modern- day ripples after reimbursement were reduced drastically. From Fig. 10(d) and Table IV, it is able to compensate the system DPF from 0.Eight to cohesion, the gadget neutral present day from 3.08Arms to 0.47Arms, the THDisx from 35% to much less than 6.5%, which satisfies the international widespread of THD ≤15%.It has the bottom percent blunder of reactive electricity injection of much less than 1%. Fig. 10(e) Fig. Eleven (d) suggests that the switching frequency of the proposed deadbeat contemporary manipulate is constant at

200th order (10kHz). Compared with Fig. Eleven (a), each noise and distortion in low frequency band had been reduced drastically. Therefore, the proposed deadbeat present day controller obtains the first-class reimbursement performances as compared with hysteresis, PI and PMR control.

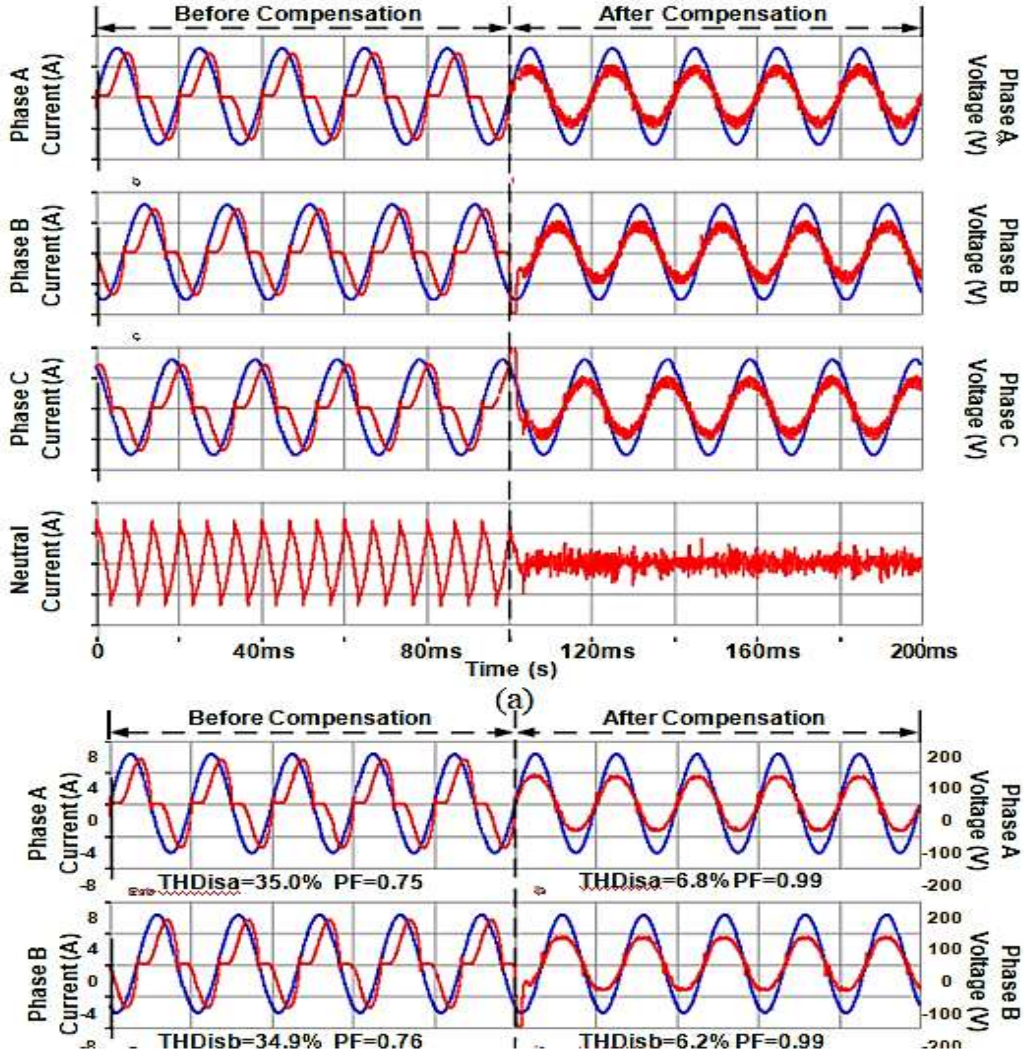

Figure 5: Before compensation with filters

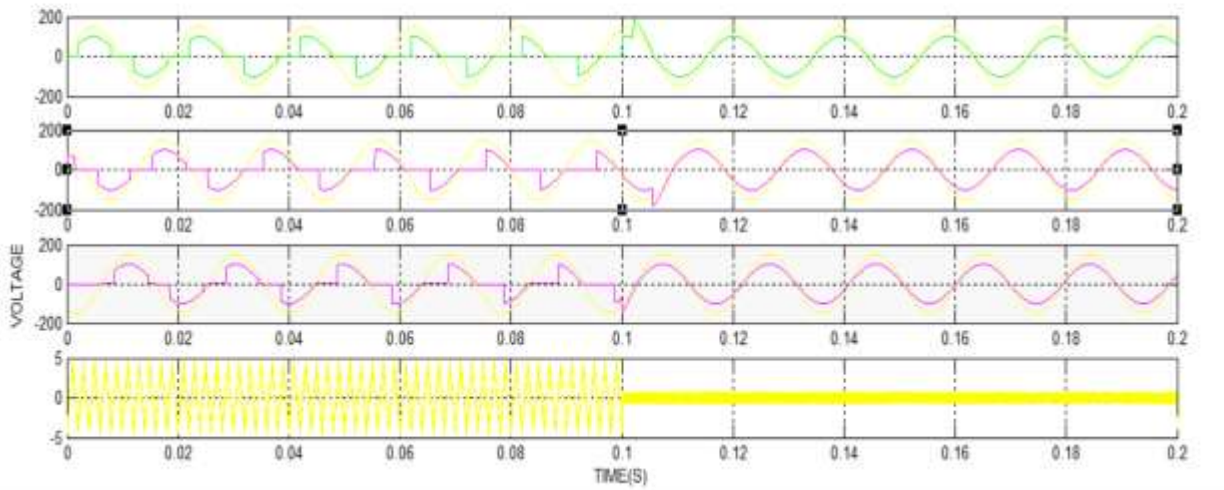

Figure 6: After compensation with filters

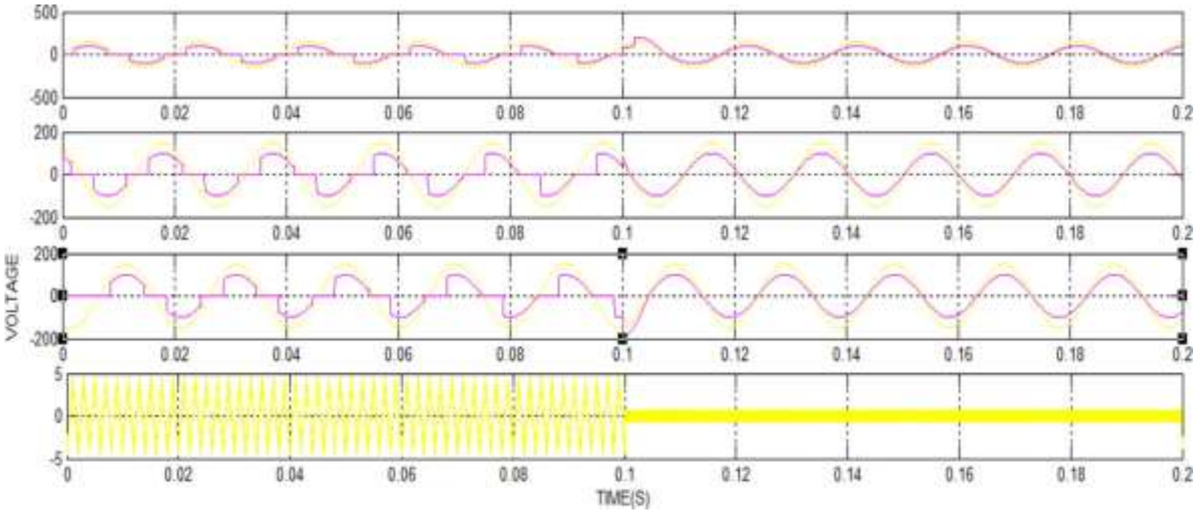

Figure 7: After compensation with filters

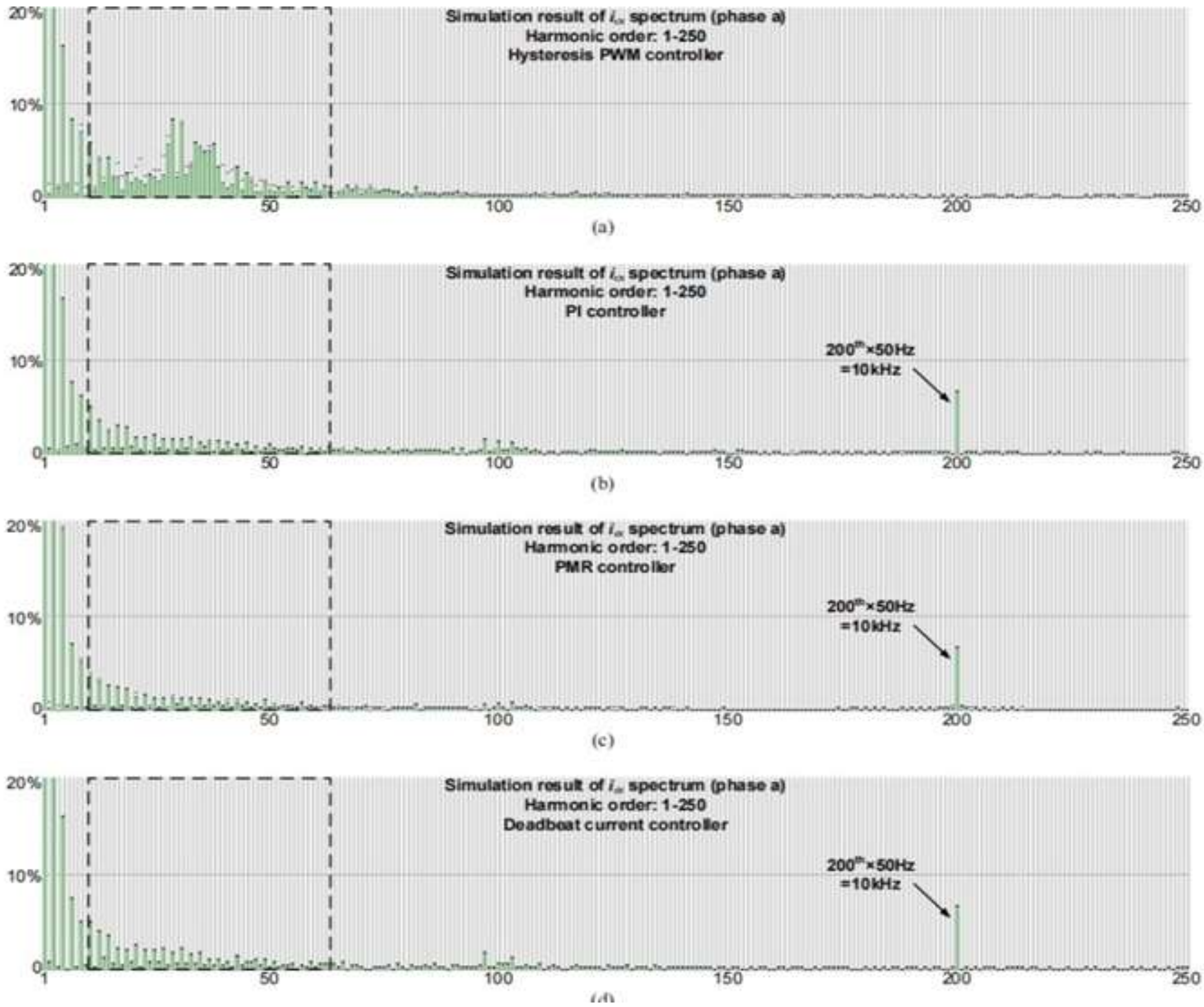

Figure 8: Simulation results of compensating current iex harmonics spectrum (phase a) (a) Hysteresis Pwm control (b) PI Control (c) PMR control (d) Proposed deadbeat current control

V. CONCLUSION

In this paper, a loser current control technique of LC-HAPF is proposed, which can give a practical power quality pay arrangement with little consistent state blunder, quick dynamic reaction and low result current waves. As a matter of first importance, the numerical displaying and the control block chart of the proposed miscreant current controlled LC-HAPF is inferred and assembled. In view of it, the strength issue and boundary plan thought are investigated and talked about. At long last, delegate recreation and exploratory aftereffects of the loser current regulator for the LC-HAPF are surrendered examination with customary hysteresis regulator, PI regulator and PMR regulator, which shows its viability also, unrivaled remunerating exhibitions.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

[1] W. G. Morsi and M. E. El-Hawary, "Defining Power Components in Non-sinusoidal Unbalanced Polyphase Systems: The Issues," IEEE Trans. Power Deliv., vol. 22, no. 4, pp. 2428–2438, 2007.
[2] H. Fujita and H. Akagi, "A practical approach to harmonic compensation in power systems-series connection of passive and active filters," IEEE Trans. Ind. Appl., vol. 27, no. 6, pp. 1020–1025, 1991.
[3] L.H.S. Duarte & M.F. Alves, "The degradation of power capacitors under the influence of harmonics", Proc. IEEE 10th Int. Conf. on Harmonics and Quality of Power, vol. 1, pp. 334–339, 2002.
[4] J. S. Subjak, Jr. and J. S. McQuilkin, "Harmonics-Causes, effects, measurements, and analysis: An Update," IEEE Trans. Ind. Appl., vol. 26, no. 6, pp. 1034-1042, 1990.
[5] R.C. Dugan, M.F. McGranaghan, H.W. Beaty, Electrical power systems quality. New York: McGraw-Hill, pp. 36, 1996.
[6] J.C. Das, "Passive filters - potentialities and limitations," IEEE Trans. Ind. Appl., vol.40, no.1, pp.232-241, Feb. 2004.
[7] S. T. Senini and P. J. Wolfs, "Systematic identification and review of hybrid active filter topologies," in Proc. IEEE 33rd Annu. Power Electron. Spec. Conf., vol. 1, pp. 394–399, 2002.
[8] F. Z. Peng, H. Akagi, and A. Nabae, "A new approach to harmonic compensation in power systems: A combined system of shunt passive and series active filters," IEEE Trans. Ind. Appl., vol. 26, no. 6, pp. 983–990, Nov./Dec. 1990.
[9] H. Hu, Y. Xing, "Design considerations and fully digital implementation of 400-Hz active power filter for aircraft applications," IEEE Trans. Ind. Electron., vol.61, no.8, pp.3823-3834, Aug. 2014.
B. Plunkett, "A current-controlled PWM transistor inverter drive,"
[10] L. Malesani and P. Tenti, "A novel hysteresis control method for current- controlled voltage-source PWM inverters with constant modulation frequency" IEEE Trans. Ind. Appl., vol. 26, no. 1, pp. 88-92,1990.
[11] Fereidouni, M. A. S. Masoum, K. M. Smedley, "Supervisory Nearly Constant Frequency Hysteresis Current Control for Active Power Filter Applications in Stationary Reference Frame," IEEE Power and Energy Technology Systems
[12] Journal, vol. 3, pp. 1-12, 2016.
[13] N. M. Ismail and M. K. Mishra, "Study on the design and switching dynamics of hysteresis current controlled four-leg voltage source inverter for load compensation," IET Power Electron., vol. 11, no. 2, pp. 310-319, 2018.
[14] M. P. Kazmierkowski, R. Krishnan, and F. Blaabjerg, "Control in power electronics: selected problems," Amsterdam: Academic Press, 2003.
[15] A. Chandra, B. Singh, B.N. Singh and K. Al-Haddad, "An improved control algorithm of shunt active filter for voltage regulation, harmonic elimination,power-factor correction, and balancing of nonlinear loads," IEEE Trans. Power Electron., vol.15, no.3, pp. 495-507, 2000.
[16] P. Jintakosonwit, H. Fujita, and H. Akagi, "Control and performance of a fully-digital-controlled shunt active filter for installation on a power distribution system," IEEE Trans. Power Electron., vol. 17, no. 1, pp. 132–140, Jan. 2002.
[17] S. Rahmani, N. Mendalek and K. Al-Haddad, "Experimental design of a nonlinear control technique for three-phase shunt active power filter," IEEE Trans. Ind. Electron., vol. 57, no. 10, pp. 3364 - 3375,2010.
[18] R. Teodorescu, F. Blaabjerg, M. Liserre, and P. C. Loh, "Proportionalresonant controllers and filters for grid-connected voltage- source converters," IEE Proceedings - Electric Power Applications, vol. 153, no. 5, pp. 750–762, 2006.
[19] M. Liserre, R. Teodorescu and F. Blaabjerg, "Multiple harmonics control for three-phase grid converter systems with the use of PIRES current controller in a rotating frame," IEEE Trans. Power Electron., vol.21, no.3, pp.836-841, 2006.
[20] T. Hornik and Z. Qing-Chang, "A current-control strategy for voltage source inverters in microgrids based on h∞ and repetitive control," IEEE Trans. Power Electron, vol. 26, pp. 943-952, 2011.
[21] L. Herman, I. Papic, and B. Blazic, "A proportional-resonant current controller for selective harmonic compensation in a hybrid active power filter," IEEE Trans. on Power Deliv., vol. 29, no. 5, pp. 2055-2065, 2014.
[22] A. Javadi, L. Woodward, and K. Al-Haddad, ‘‘Real-time implementation of a three-phase THSeAF based on a VSC and a P+R controller to improve the power quality of weak distribution systems,’’ IEEE Trans. Power Electron., vol. 33, no. 3, pp. 2073–2082, Mar. 2018.