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Ananlysis of an LCL filter out applied in Energetic Direct Current-traction substations

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Abstract **-** This paper at the LCL filter with damping resistance meant to suplied the shunt lively power filter of an lively dc-traction substation to the point of common coupling with the transmission grid. As a way to discover design condition and conceive a design set of Algoritham, interest is directed to the transfer functions related to currents and the related frequency response. The mathematical basis of the design approach is primarily based at the assembly the necessities related to the widespread attenuation of the high-frequency switching current, simultaneously with the unaltered drift of the current that desires to be compensated by way of energetic filtering. It's miles pointed out that there are realistic obstacles and a compromise must be made among the two requirements. To quantify the quantity to which the harmonics to be compensated are encouraged by means of enforcing the value reaction at both maximum harmonic frequency to be compensated and switching frequency, a overall performance indicator is defined. As an additional design criterion, the damping strength losses are considered. The validity and effectiveness of the proposed approach are proved via simulation consequences and experimental tests on a laboratory check bench of small scale reproducing the precise situations of a dc-traction substation with six-pulse diode rectifier.

Index Terms—DC-traction substations, LCL filter, passive damping, regeneration, shunt active power filters.

I. INTRODUCTION

The problem of connecting the energy inverters to the ac power deliver through a passive interface filter, permitting the injected current to be freed from high order switching harmonics, has attracted the specialists in recent years. Compared to the easy l clear out, the higher order LCL filter out is a extra appealing answer due to the advanced overall performance, observed by means of lower price of needed inductances, the general length and fee. Maximum investigations on the LCL clear design are related to its connection at the output of easy power supply-tied voltage supply inverters (vsis), wherein the global manage approach is especially directed to the fundamental frequency. Attaining strong operation, averting the undesirable resonance and gradual dynamic response are tough duties [1]–[13]. Numerous characteristics are considered in designing the LCL filter out, which includes current ripple, power thing variant visible via the grid, and switching ripple attenuation [7]. A generalized design algorithm for grid-related LCL filter, to meet the specified switching frequency attenuation and the reactive energy compensation limits, is proposed in [8], in which the exact role of the resonance frequency is identified. In [12], a complete minimal-weight LCL filter out design procedure is proposed, incorporating the parameters choice, cutting-edge control, damping limits, balance margin, semiconductor power losses, and cooling situations

growing fashions for grid-related vsis, which includes the LCL filter out, is some other situation, facilitating the design and validation of superior control techniques. Distinct models with one-of-a-kind combinations of simplifications are discussed in [13], that's specifically directed to the state-space-primarily based modeling.

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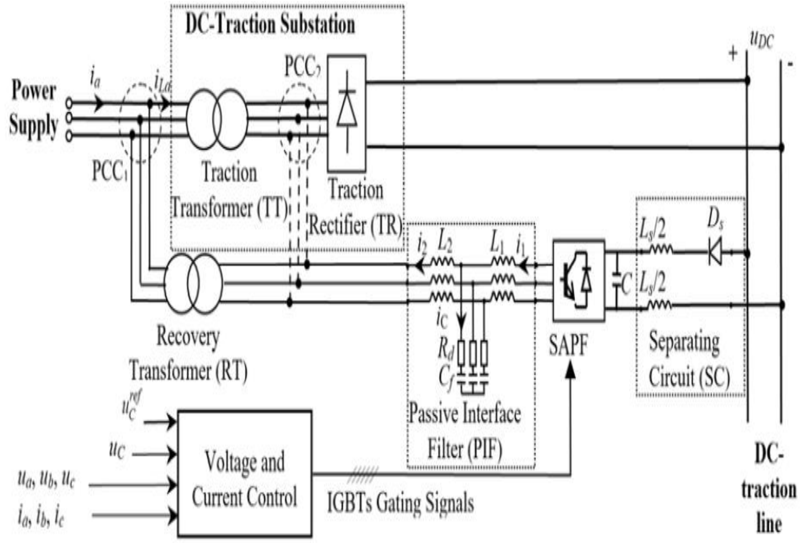
Many kinds of passive-damped filters used as interface between VSI and the utility grid, are these days reviewed and then evaluated in [9], in phrases of damping functionality and power loss in the damping circuit. Which will lessen the system volume and value, a magnetic integrated LLCL filter for grid-related VSI is proposed in [10]. As expressed, compared to the conventional LCL filter out, a reduction of the clear out inductance by 50 % can be anticipated

II.STRUCTURE OF THE ACTIVE DC-TRACTION SUBSTATION

With uncontrolled rectifier turns into an active substation by using including a VSI-based SAPF in anti-parallel with the traction rectifier, through a isolating circuit at the dc-side and a coupling circuit at the ac-aspect. On this manner, the braking power recuperation is permitted and the improvement of energy satisfactory by means of lively filtering is feasible at some stage in the traction regime [20]. The separating circuit including a diode in series with an inductor cut up into two equal components ensures the decoupling of SAPF from the dc-line throughout the operation in traction regime so as to achieve the characteristic of energetic filtering and acts as an strength buffer for the duration of the operation in regeneration regime to make certain the current dynamics and sufficiently easy the SAPFoutput currents laid low with the switching frequency harmonics, an lcl filter out with damping resistors interfaces the connection to the factor of not unusual coupling (p. C) with the strength supply. In choosing the proper %, it should be taken into account that the rated dc-line voltage must exceed the value of the line-to-line voltage on the SAPF output, in order to inject a great satisfactory cutting-edge into the ac-line. Therefore, when the traction transformer (TT) secondary is taken into consideration as a possible %, the above-expressed circumstance is achieved only inside the case of the 12 pulse series rectifier. Whilst the traction substation is ready with a six pulse rectifier or 12 pulse parallel rectifier, a properly-designed recuperation transformer (RT) guarantees the coupling condition, so that p. C becomes the primary of TT (p. C. In fig. 1) [25]. The manipulate scheme proposed to provide the gating alerts for igbts (fig. 2) entails the oblique control of the SAPF output currents by means of the deliver currents upstream of p. C [21]. As a consequence, relying on the scheme of the traction rectifier, the supply currents (ia, ib, ic) and voltages (ua, ub, uc) in fig. 1 are associated both to the number one or secondary of tt. The equal applies for the load currents (ila, ilb, ilc). The reference supply currents at some stage in the active filtering regime are generated based totally at the measured ac voltages and dc-capacitor voltage. Synthetically, a voltage controller of proportional-necessary (pi) type presents the importance of the set currents, whereas a section locked loop (pll) circuit substances their sinusoidal shape [26].



. Fig. 1. Block diagram of the active DC-traction substation.

III. VOLTAGE AND CURRENT CONTROL

CURRENT CONTROL METHODS

Several VSI current control methods have been evolved. They are differ from the type of modulation and control used and these are

a. Linear control
b. Hysteresis control
c. Predictive control
d. Delta and sigma delta modulation
e. Fuzzy logic controls
f. Neural networks

Linear control the other name for linear manipulate is ramp contrast or sine triangle current regulator it rent with two three unbiased PI errors amplifiers and PR mistakes amplifiers to produce reference voltages for a three-section triangular pmw modulator. Specifically in case of load emf, feed forward errors correction has been used. Modification is completed on this method in order that it nicely suited to drives and to all sinusoidal modern-day and voltage waveforms are required is that of the rotating body modern regulator proven in figure1. The advantages of this manipulate are quality for drives of low and medium performance, cinch and sturdy, unresponsive to load parameters and by means of increasing the switching frequency, performance of linear control can be improved.

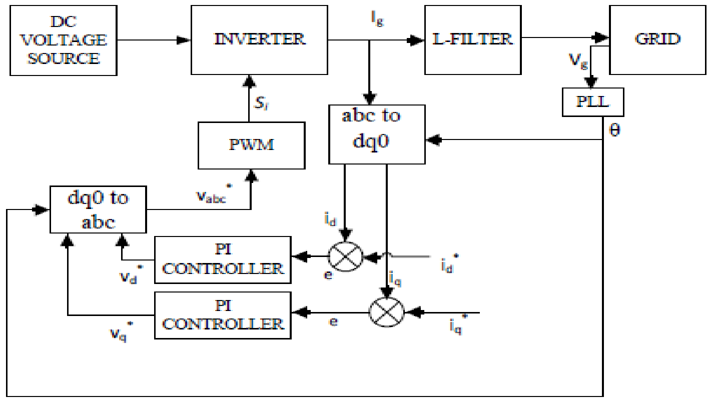


Fig.2. Rotating Frame Linear Current Regulator

Hysteresis control It is a fast fuel back system. It detects the errors in current and it directly gives the commands to the switches if and only if an error exceeds and aligned band shown in figure 2. The advantages of this control are simple, more Robust and it gives good accuracy.

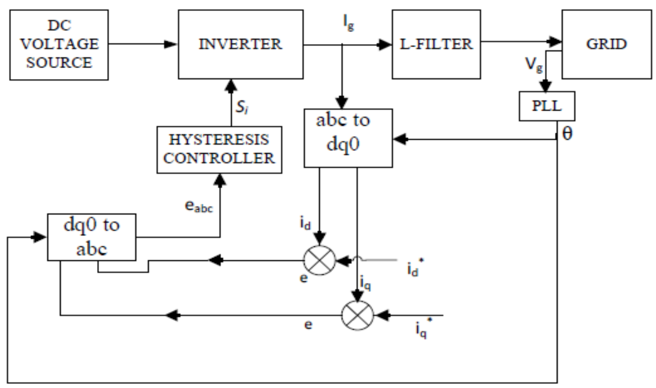


Fig.3. Control Diagram of Hysteresis Current Controller

Predictive current manipulate this technique prognosticate the error in cutting-edge vector on the inception of every modulation and it additionally determines the voltage vector which is advanced by way of pwm at some stage in the subsequent modulation cycle to lessen the forecast blunders shown in determine three. Correct response may be received via giving more facts to the regulator and it is also suitable for virtual implementation.

As the optimization is a powerful device to layout controllers and the switch function within the ahead direction of the voltage manipulate loop has a easy pole in beginning, the pi voltage controller has been designed in step with the symmetrical choicest criterion [29].

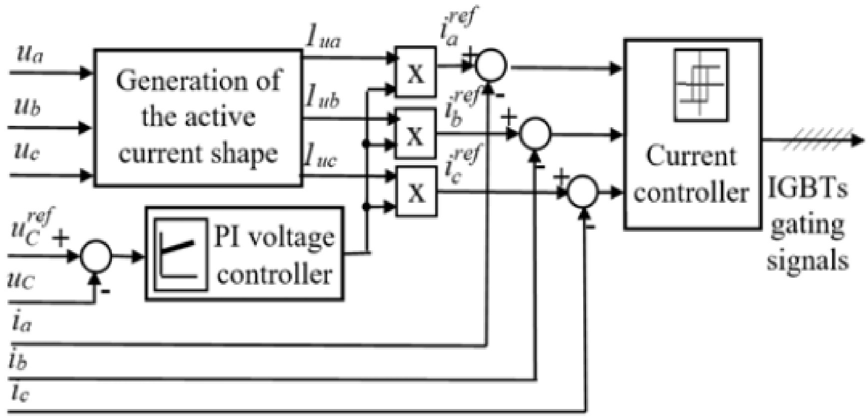


Fig. 4. Block diagram of the control system

IV. LCL FILTER TRANSFER FUNCTIONS AND FREQUENCY RESPONSE

Considering the structure of the LCL clear out with damping resistors (fig. 1) and the equal scheme for high order harmonics (fig. Three) [28], [30], the following switch functions among the enter current i1 and output currents i2 and ic may be expressed as follows:

$$G_1(s) = \frac{I_2(s)}{I_1(s)} = \frac{1 + sR_dC_f}{1 + sR_dC_f + s^2L_2C_f}; \quad (1)$$

$$G_2(s) = \frac{I_C(s)}{I_1(s)} = \frac{s^2L_2C_f}{1 + sR_dC_f + s^2L_2C_f} \quad (2)$$

It should be precise that, via neglecting the low values of the inner resistances of the inductors and capacitor, the worst scenario in terms of damping is obtained. All facts associated with filter out performance is supplied by using the two switch features g1(s) and g2(s). Certainly, the ideal operation of the active filtering machine involves the subsequent: - the contemporary i1 at the sapf output includes the modern-day harmonics to be compensated together likely with the issue related to the reactive power repayment, however additionally the excessive order harmonics associated to the switching frequency fsw; - the modern ic via capacitor should include as a good deal of switching harmonics and as little of harmonics to be compensated; simplest the harmonics to be compensated need to be included inside the current i2 at the filter output. As a first locating, each switch features are not dependent on the inverter-side inductance l1. Based on (1), the amplitude response and the resonance frequency (□res) associated to g1(s) can be expressed by means of highlighting their dependence on most effective pairs l2cf and rdcf

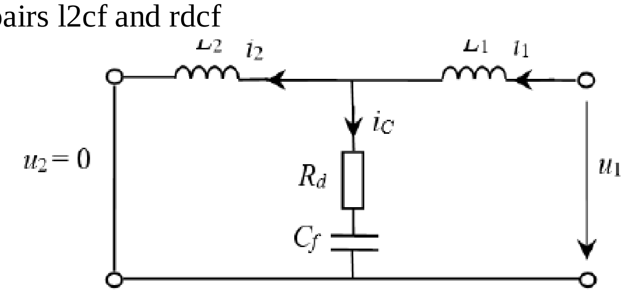


Fig. 5. Equivalent scheme of the LCL filter with damping resistor, for high

order harmonics.

All facts associated with clear out performance is provided with the aid of the two transfer functions g1(s) and g2(s). Indeed, the appropriate operation of the energetic filtering gadget entails the subsequent:

- the modern i1 at the sapf output incorporates the contemporary harmonics to be compensated collectively in all likelihood with the factor associated to the reactive strength reimbursement,

however additionally the excessive order harmonics related to the switching frequency fsw; the modern ic through capacitor should contain as a whole lot of switching harmonics and as little of harmonics to be compensated;

only the harmonics to be compensated have to be covered within the present day i2 on the filter out output. As a primary statement, both switch features aren't depending on the inverter-side inductance l1. Primarily based on (1), the amplitude reaction and the resonance frequency (ωres) associated to g1(s) may be expressed byhighlighting their dependence on only pairs l2cf and rdcf :

$$\left|G_1(j\omega)\right| = \sqrt{\frac{1+\left(R_d C_f\right)^2\omega^2}{(1-L_2C_f\omega^2)^2+\left(R_d C_f\right)^2\omega^2}}\ ; \qquad (3)$$

$$\omega_{res} = \frac{1}{R_d C_f}\sqrt{\sqrt{1+\frac{2\left(R_d C_f\right)^2}{L_2 C_f}}-1}\ . \qquad (4)$$

This aspect is useful in the filter design

V. LCL FILTER MATHEMATICAL MODEL

The power circuit of a three segment grid connected electricity converter is supplied in discern 1a. As depicted in this figure, the LCL filter is used to interface among the grid and the power converter. Vg(a,b,c) (respectively i2(a,b,c)) discuss with the grid voltage vector additives (respectively the grid current vector components) within the stationary reference frame, while vi(a,b,c) (respectively ii(a,b,c)) seek advice from the additives of the output energy converter voltage vector (respectively the additives of the output electricity converter modern-day vector) inside the desk bound reference frame. Li (respectively l2) consult with the converter aspect inductor of the LCL filter (respectively the grid aspect inductor of the lcl filter), even as ri (respectivelyr2) confer with the inner resistance of the converter aspect inductor,(respectively the internal resistance of the grid facet inductor). Cf seek advice from the LCL filter capacitor, even as vc(a,b,c) (respectively ic(a,b,c)) seek advice from the voltage across the filter capacitor vector additives (respectively the capacitor current vector components)in the stationary reference frame. Lg (respectivelyrg) confer with the inductive part of the grid impedance(respectively the resistive part of the grid impedance),whilst lg 2 (respectively rg 2) consult with the filter grid side inductor in collection with the grid inductor (respectively the inner resistance of the filter grid inductor).

Algorithm of the LCL filter design methodology -

The algorithm of LCL filter design methodology that allows tuning of LCL filter parameters according to the input data of the controlled system.

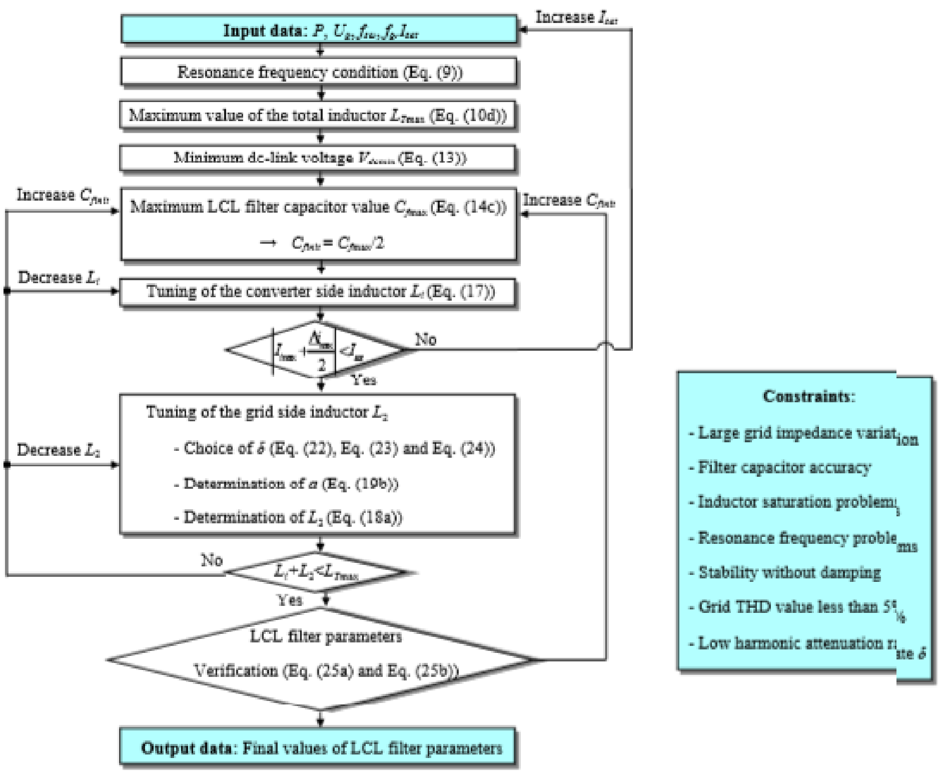


Fig 6. LCL filter design algorithm

VI. PERFORMANCE OF THE SYSTEM FOR ACTIVE FILTERING AND REGENERATION

Simulation Results

To verify the proper behavior and evaluate the performance of the passive-damped LCL filter in coupling the SAPF of an active dc-traction with six-pulse parallel diode rectifier to the strength deliver, the matlab/simulink version of the whole gadget has been conceived. It makes use of the real shape of the system, according with fig. 1. The parameters correspond to a small scale setup related to the conceived laboratory take a look at bench, with the intention to evaluate the simulation and experimental results. The main parameters of the electricity gadget are covered in desk i. In modeling the traction dc-line, it was considered that, in traction regime, it's far an energetic load with a again electromotive pressure related to the operation pace and equal parameters (resistance and inductance) of the traction automobiles and dc-line. In regeneration-mode, by way of implementing a consistent acceleration and a maximal dc-linevoltage, the dc-line cutting-edge is consistent [26]. The waveforms of currents within the tt’s primary in traction regime (fig. 9) and the related harmonic spectrum (fig. 10) illustrate the want for harmonic and reactive strength compensation. The full harmonic distortion element (thd) is 23. 7% and the global energy issue is 0. Ninety four. Moreover, the harmonics of order over 37 are under zero. 5 % of the fundamental element (fig. 10).

TABLE I
MAIN PARAMETERS OF THE SYSTEM

Items	Values
Rated apparent power (S_N)	30 kVA
AC system voltage (U_N)	380 V
Traction transformer (connection Y/y)	380 V/ 150 V ; R_1=0.292 Ω; R_2=0.045 Ω; R_m=2.57 kΩ; $L_{\sigma1}$=1.5 mH ; $L_{\sigma2}$=0.23 mH; L_m=1.03 H
Recovery transformer (connection Y/d)	380 V/130 V; R_1=0.966 Ω; R_2=0.337 Ω; R_m =566.83 Ω; $L_{\sigma1}$=3.1 mH; $L_{\sigma2}$=1.1 mH; L_m=4.682 H
Rated DC-line voltage (U_{DCN})	190 V
DC-link capacitance (C)	2200 μF
Inductance of the DC-separating circuit (L_s)	4.9 μH
PI voltage controller parameters	K_p=3.53; T_i=1.8·10^{-3} s
Hysteresis band of the current controller	0.75 A

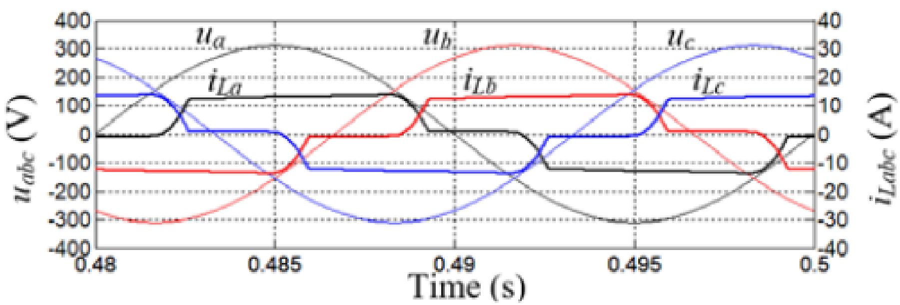


Fig. 7. Voltages and currents in the TT's primary in traction regime

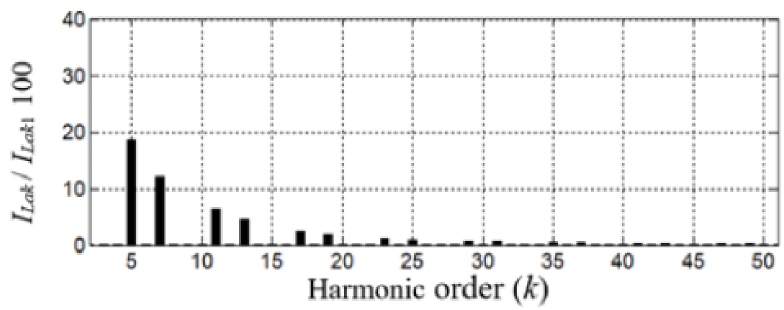


Fig. 8. Harmonic spectrum of the current in the primary of TT.

The resulted value for MPI is 1. 01 and the associated indicator of the electricity losses is reach=seventy six. 64 □, which represents about 54% of the maximum value of 141. 94 □. A small inverter-side inductance, l1=34 μh, is followed, to limit the igbts' switching losses, the use of the relationship between the dc-link voltage, hysteresis band, overall inductance and maximum switching frequency [14]. The associated bode magnitude diagram (fig. Eleven) indicates the inevitable low amplification of a few harmonic close to order n. With the aid of prescribing the proper reference present day for general reimbursement (modern harmonics and reactive electricity), the SAPF presents a contemporary on the LCL filter out input (fig. 12) which is tormented by the inverter switching. The present day flowing through the capacitor of the interface clear out is proven in fig. 13 and the harmonic spectra of input and output currents (fig. 14) illustrate the insignificant have an effect on of the interface filter at the harmonics as much as n= 37. It should be notified that the life of the fundamental thing corresponds to the need of reactive energy compensation. The LCL filter out fulfills its project to reduce substantially the switching element of the modern, so that the modern-day upstream of percent is near a sinusoide (fig. 15), having a total harmonic distortion of about 2. 37%. Furthermore, almost team spirit electricity component (0. 999) is received, as the fundamental of the deliver modern has the identical section because the deliver voltage. The waveforms of the deliver current and voltage whilst the energetic traction substation operates successively in traction (active filtering) and braking (regeneration) regimes (fig. 16) verify the right conduct and proper performance of the system, consisting of the ideal interface filter.

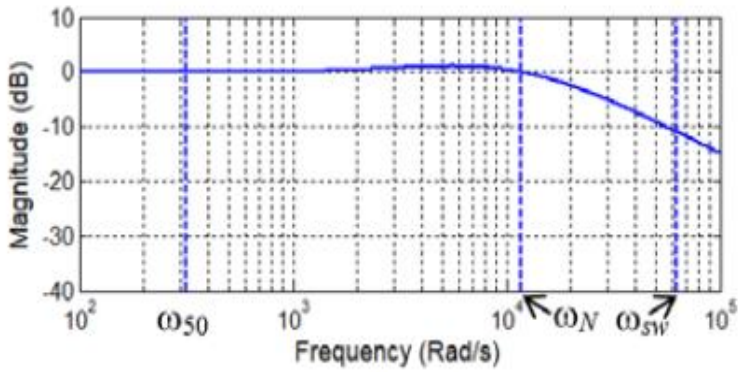


Fig. 9. Bode magnitude diagram for *Cf* =10F, *Rd* =27; *L*2 =1.48mH

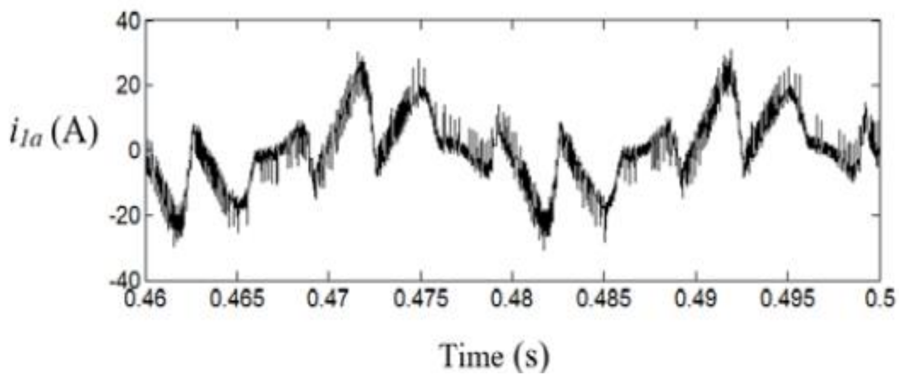


Fig. 10. LCL filter input current

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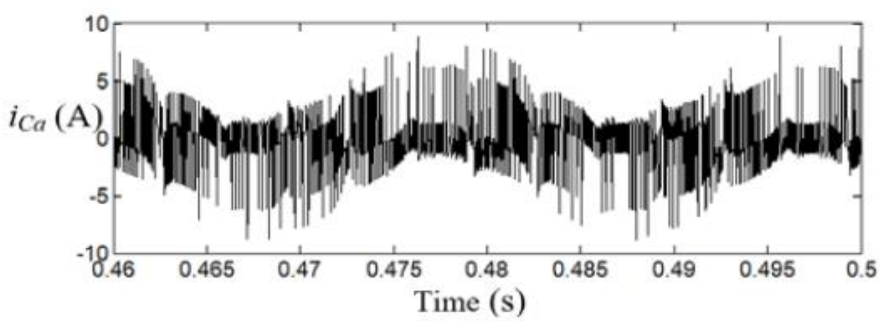

Fig. 11. Current flowing through the capacitor of the interface filter.

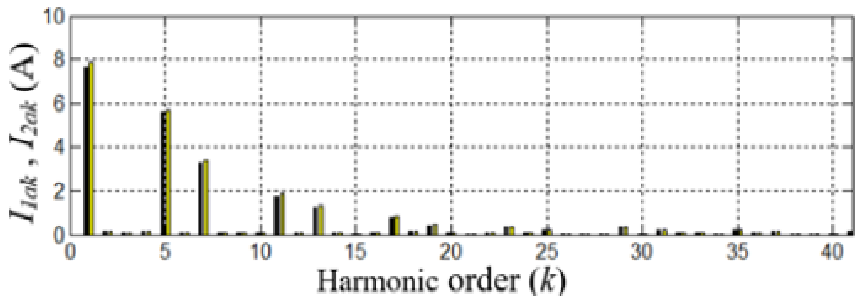

Fig. 12. Harmonic spectra of the LCL filter input current (black bars) and output current (yellow bars) for harmonic order $k \in [1, 37]$.

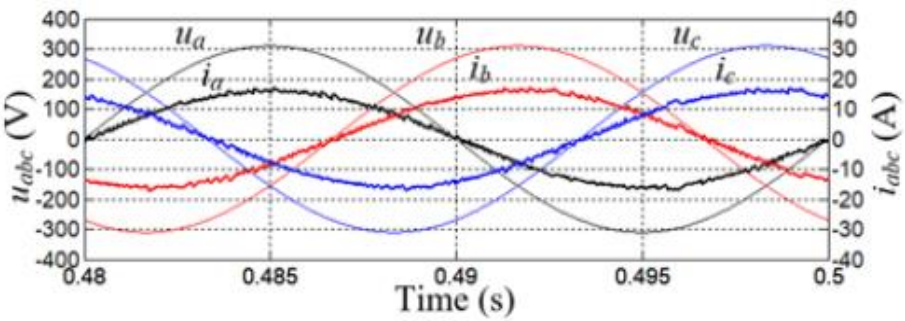

Fig. 13. Voltages and currents upstream of PCC during the operation in traction regime.

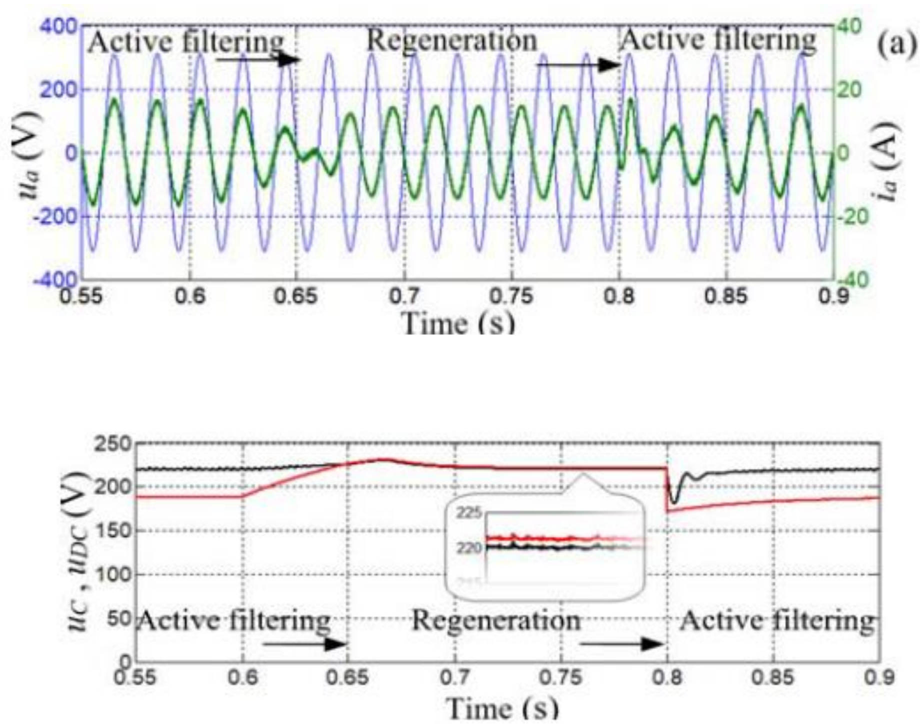

Fig. 14. Succesive traction (filtering) and braking (regeneration) regimes:
(a) phase voltage (blue line) and supply current (green line)
(b)DC-capacitor voltage (black line) and DC-line voltage (red line).

As illustrated in fig. 14 (b), the voltage throughout the dccapacitor is stored at its set value of 220 v at some point of the steady state regimes of lively filtering regime and regeneration. The transition to the regeneration regime is observed by using a low overshoot (approximately 4 %) generated with the aid of the ramp increase of the dc-line voltage, while an oscillation of higher amplitude (about 15%) occurs at some stage in the transition from the regeneration mode to the energetic filtering mode because of the speedy decrease of the dc-line voltage. The regeneration regime corresponds to the situation in which uc < udc, whereas, in active filtering regime, uc > udc.

VI. CONCLUSIONS

A new design technique of an LCL clear out with damping resistance intended to couple the 3-segment vsi of an energetic dc-traction substation to the strength deliver has been proposed in this paper. The subsequent elements of originality are outlined. 1) the theoretical substantiation is based at the frequency response from transfer capabilities related to currents, taking into account the existence of the series damping resistances. 2) the expressed amplitude response and resonance frequency spotlight their dependence on handiest pairs l2cf and rdcf, it's miles a very vital locating for the conceived design algorithm. 3) the expression of the electricity losses within the damping resistances is highlighted and an equivalent resistance is delivered as a quantitative indicator of them. 4) by considering the switching frequency as major parameter and thinking of the frequency of the best order harmonic to be compensated, the design set of rules is based totally on the imposition of the related attenuations.5) In the substantiation of the design algorithm, a detailed analysis is performed on the existence of physical-sense solutions, providing the domain in which the values of the parameters must be located.

6) As a large number of parameters values sets can be obtained, a new performance indicator (*MPI*) is proposed, to quantify the extent to which the harmonics to be compensated are influenced. The analysis and the simulation results achieved for an active DC-traction substation with six-pulse diode rectifier and LCL coupling filter have indicated that the proposed method is valid and effective. The experimental tests conducted in a laboratory test bench of small scale reproducing the specific conditions of a DC-traction substation illustrate good performance of the system for active filtering and regeneration connected to the power supply by the passive damped LCL filter. The design proposal can be applied in any three-phase LCL-filter-based shunt active power filter.

REFERENCES

[1] A. Ghoshal and V. John, “Active damping of LCL filter at low switching to resonance frequency ratio,” IET Power Electron., vol. 8, no. 4, pp. 574–582, 2015.

[2] G. E. Mejia Ruiz, N. Munoz, and J. B. Cano, “Modeling, analysis and design procedure of LCL filter for grid connected converters,” in Proc. 2015 IEEE Workshop Power Electron. and Power Quality Appl. (PEPQA), pp. 1–6.

[3] M. Hanif, V. Khadkikar, W. Xiao, and J. L. Kirtley, “Two degrees of freedom active damping technique for filter-based grid connected PV systems,” IEEE Trans. Ind. Electron., vol. 61, no. 6, pp. 2795–2803, June 2014.

[4] X. Wang, F. Blaabjerg, and P. C. Loh, “Grid-current-feedback active damping for LCL resonance in grid-connected voltage source converters,” IEEE Trans. Power Electron., vol. 31, pp. 213–223, 2016.

[5] W. Xia, J. Kang, “Stability of LCL-filtered grid-connected inverters with capacitor current feedback active damping considering controller time delays,” J. Mod. Power Syst. Clean Energy, vol. 5, no. 4, pp. 584– 598, July 2017.

[6] M. B. Said-Romdhane, M. W Naouar, I.. S. Belkhodja, and E Monmasson, “An improved LCL filter design in order to ensure stability without damping and despite large grid impedance variations,” Energies, vol. 10, no. 3, pp. 336, Mar. 2017.

[7] A. Reznik, M.G. Simões, A. Al-Durra, and S.M. Muyeen, “LCL filter design and performance analysis for grid-interconnected systems,” IEEE Trans. Ind. Appl., vol. 50, no. 2, pp. 1225–1232, Mar./Apr. 2014.

[8] S. Jayalath .and M. Hanif, “Generalized LCL-filter design algorithm for grid-connected voltage-source inverter”, IEEE Trans. Ind. Electron., vol. 64, no. 3, pp. 1905–1915, Mar. 2017.

[9] R. N. Beres, X. Wang, M. Liserre, F. Blaabjerg, and C. L. Bak, “A review of passive power filters for three-phase grid-connected voltagesource converters,“ IEEE J. Emerg. Sel. Topics Power Electron, vol. 4, no. 1, pp. 54–69, Mar. 2016.

[10] J. Fang, H. Li, and Y. Tang, “A magnetic integrated LLCL filter for grid-connected voltage-source converters, IEEE Trans. Power Electron., vol. 32, no. 3, pp. 1725–1730, Mar. 2017.

[11] M. Liserre, F. Blaabjerg, and S. Hansen, “Design and control of an LCL-filter-based three-phase active rectifier,” IEEE Trans. Ind. Appl., vol. 41, no. 5, pp. 1281–1291, Sept./Oct. 2005.

[12] K.-B. Park, F.D. Kieferndorf, U. Drofenik, S. Pettersson, and F. Canales, “Weight minimization of LCL filters for high-power converters: impact of PWM method on power loss and power density,” IEEE Trans. Ind. Appl., vol. 53, no. 3, pp. 2282–2296, May/June 2017.

[13] B. Hoff and W. Sulkowski, “Grid-connected VSI with LCL filter— models and comparison,” IEEE Trans. Ind. Appl., vol. 50, no. 3, pp. 1974–1981, May/June 2014. [14] M. T. Bina and E. Pashajavid, “An efficient procedure to design passive LCL-filters for active power filters,” Elect. Power Syst. Res., vol. 79, no. 4, pp. 606–614, Apr. 2009.

[15] L. Li, Y. Guo, and X. Zhang, “Analysis and application of passive damping LLCL filter in active power filter,” in Proc. 2015 IEEE Conf. CYBER, pp. 751–755. [16] Y. Tang, P. C. Loh, P. Wang, F. H. Choo, F. Gao, and F. Blaabjerg, “Generalized design of high performance shunt active power filter with output LCL filter,” IEEE Trans. Ind. Electron., vol. 59, no. 3, pp. 1443–1452, Mar. 2012.

[17] N. Yu, J. Yang, S. Chen, and M. Ye, “Design of LCL-filter based threelevel active power filters,” TELKOMNIKA Indonesian J. Electr. Eng., vol. 12, no. 1, pp. 48–56, Jan. 2014.

[18] Q. Liu, L. Peng, Y. Kang, S. Tang, D. Wu, and Y. Qi, “A novel design and optimization method of an LCL filter for a shunt active power filter,” IEEE Trans. Ind. Electron., vol. 61, no. 8, pp. 4000–4010, 2014. [19] A. Terciyanli, A. Acik, A. Cetin, M. Ermis, et al, “Power quality solutions for light rail public transportation systems fed by mediumvoltage underground cables”, IEEE Trans. Ind. Appl., vol. 48, no. 3, pp. 1017–1029, May/June 2012.

[20] W.A.G. de Jager, M. Huizer, and E.K.H. van der Pols, “Implementation of an active regeneration unit in a traction substation,” in Proc. EPE'14ECCE Europe, pp. 1–9, Aug. 2014.

[21] S. Lim and J. Choi, “LCL filter design for grid connected NPC type three-level inverter,” Int. J. Renew. Energy Res., vol. 5, no. 1, 2015.