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Analysis of Harmonic Mitigation in Distribution Network using Internal Model Controllers and Synchronous Reference Frames

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ABSTRACT

This paper presents an exhaustive survey of controller strategies in synchronous reference frames recently adopted. With the general use of harmonic generating devices, controlling the harmonic currents to maintain a high level of quality of energy becomes increasingly important. This paper presents a detailed approach of conventional PI control strategy and two-degrees-of-freedom internal model control strategy. The advantage of 2DF-IMC strategy over the conventional PI solution is a significant increase in the speed of harmonic detection and mitigation. Furthermore, this control strategy reduces the computational burden when applied in a digital controller. These characteristics make this strategy desirable for applications where fast/harmonic detection and mitigation are needed. The techniques are mathematically analyzed and simulation results are obtained for convention PI strategy which are compared in terms of compensation performance..

KEYWORDS: *Power Quality Synchronous Reference Frame, I, 2DF-IMC strategy, Harmonic mitigation*

I. INTRODUCTION

Modern power system is a complex network where many generating stations and load centers are interconnected through long power transmission and distribution network. Nowadays distribution system is facing poor power quality at the load ends. [1]. with the increase of nonlinear loads drawing non-sinusoidal currents, power quality distortion has become a serious problem in electrical power systems. Conventionally passive L–C filters were used to reduce harmonics and capacitors were employed to improve the power factor of the ac loads. The increased severity of power quality problems and other problems associated with the passive filters such as large size and weight, higher cost, fixed compensation, and resonance problems with loads and networks have required a focus on a power electronic solution, that is, active power filters (APF). . In recent years, many publications [4] have also appeared on the harmonics suppression using active power filters. Selection of a control method and proper topology of harmonic suppression, best suited to particular conditions, requires that advantages, disadvantages and limitations of these devices, which exhibit a very broad range of properties. The control strategy for a shunt active power filter generates the reference current, that must be provided by the power filter to compensate reactive power and harmonic currents demanded by the load. This involves a set of currents in the phase domain, which will be tracked generating the switching signals applied to the electronic Converter by means of the appropriate closed-loop switching control technique such as hysteresis or deadbeat control. Some ac loads provide fast transient harmonics, such as when the current is drawn by an electric drive during startup, acceleration [4], during fast speed control adjustment in electric drives [4] or in the traction system of high speed trains. During those events, the faster the harmonic compensation is carried out, the better for the optimal performance of the converter.

The control techniques for MIs with selective mitigation of harmonics using fixed switching frequency can be divided in two main branches:

1) *The proportional-resonant based controllers* Proportional-resonant (PR) based controllers [6]-[8] are able to follow sinusoidal harmonic references at their respective resonant frequencies without steady state error by introducing an infinite gain at the desired resonant frequency. Additionally, PR-based controllers provide fast response for set point changes.

The disadvantages of PR-based controllers are that attaining adequate controller tuning and stability is a complex process; moreover, the controller resonant frequency should be well tuned to the reference frequency, as the infinite gain band is narrow, making this control technique susceptible to grid frequency variations [9]. Non-ideal PR-based controllers use second order generalized integrators, which results in wider resonant band but with the penalty of an increased tracking error [10].

2) *The synchronous reference frames (SRF) based controller.* This type of controller applies several synchronous d-q harmonic frames and low pass filters to detect the harmonic currents. The control of the harmonic currents coming from the MI is carried out using PI controllers. The advantage of using SRF-based controllers is that they enable individual harmonics to be measured and controlled using dc signals, where easy-to-tune PI controllers can provide stable control with no tracking error; additionally, an active power filter using SRF-based controllers is immune to grid frequency variations.

The main disadvantage of using the SRF-based controllers for harmonic mitigation is that it results in slow harmonic detection/compensation, because of the delay produced by the low pass filter in the SRF control topology, and also that the use of multiple synchronous *d-q* harmonic frames and low pass filters produces an increased computational burden [1]-[3].This paper proposes a solution that overcomes the slow harmonic detection/compensation of SRF-based controllers, and eliminates delays to accelerate harmonic compensation without affecting the positive properties of the SRF-based controllers. This is achieved by removing the low pass filters from the conventional SRF control topology and replacing the PI controllers with two-degrees-of-freedom internal model controllers (2DF-IMC). By doing this, the 2DF-IMC of the individual harmonic control loops are able to simultaneously track the harmonic current set-point without delay. Additionally, the 2DF-IMCs collectively reject the ac disturbances produced by the operation of a filter-less SRF in the dc domain). By doing this, the 2DF-IMC of the individual harmonic control loops is able to simultaneously track the harmonic current set-point without delay. Additionally, the 2DF-IMCs collectively reject the ac disturbances produced by the operation of a filter-less SRF in the dc domain. When 2DF-IMC is used along with SRF, one obtains, among other benefits, a dramatic increase in the speed of harmonic detection and mitigation, since the proposed controller configuration does not require low pass filters to detect and compensate the harmonics in the SRF. This paper is organized as follows: section II Harmonic Mitigation of the conventional SRF-based harmonic and the past/current research. Section III describes the theory of the 2DF-IMC and the control rule derivation. Section IV analyzes the implications of removing the low pass filters from the conventional SRF controller and the positive effects of using the second-degree-of-freedom feature of the 2DF-IMC. Section V presents simulations results of the conventional SRF PI controller. Section VI presents the Conclusions

II. HARMONIC DETECTION/MITIGATION USING CONVENTIONAL SRF-BASED CONTROLLERS

SRF control is one of the efficient controls to suppress voltage and current harmonics. It referred d-q technique, in which transformations and its inverse transformations of a-b-c to d-q-0 are used [15]. The basic SRF Control technique to generate reference currents from nonlinear balanced/unbalanced load is depicted in Fig. The load currents of a-b-c coordinates (I_{Labc}) are transformed into d-q-0 coordinates with the help of modified PLL according to the equation (1).These d-q-0 coordinates comprises of an oscillatory component ($\tilde{I}_{oSd}$ and $\tilde{I}_{oSq}$) and averaged component ($\bar{I}$ ASdand $\bar{I}$ ASq) resulting to oscillatory in nature. In order to avoid oscillatory response and maintain only averaged components of d-q-0 coordinates, a 2nd ordered Butterworth LPF is used. These averaged components are stable in nature and are referred to as source current averaged component ($\bar{I}$ SdL).fig. (1) Shows the conventional SRF based Harmonic Controller.

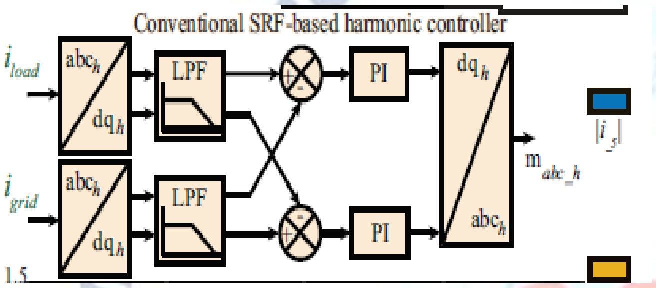

Fig (1): Conventional SRF based Harmonic Controller.

$$\begin{bmatrix} I_{S0} \\ I_{Sd} \\ I_{Sq} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \sin(wt) & \sin(wt - 2\pi/3) & \sin(wt + 2\pi/3) \\ \cos(wt) & \cos(wt - 2\pi/3) & \cos(wt + 2\pi/3) \end{bmatrix} \begin{bmatrix} I_{Loa} \\ I_{Lob} \\ I_{Loc} \end{bmatrix} \quad .... (1)$$

Reference currents (I_{refSa} , I_{refSb} and I_{refSc}) and load currents (I_{La} , I_{Lb} and I_{Lc})

The filtered *d-q* components of i_{load} are used as set points for the PI controllers. The PI controllers generate, as a control action, a modulator signal that would produce harmonic currents of magnitudes that match those of the load, but in opposite polarity. Needless to say, all these developments make use of the conventional approach for SRF-based controllers where low pass filters are used to detect/mitigate harmonic currents, which results in a slow harmonic compensation. Other research focuses on eliminating the use of the low-pass filters in the conventional SRF-based controllers by implementing a harmonic *d-q* transformation that averages the values of the harmonic *d-q* signals by applying a recursive algorithm within the transformation [6]. However, this technique requires an extra workaround to avoid a frequency drift effect caused by grid frequency variations.

III. THEORY AND IMPLEMENTATION OF 2DF-IMC.

The internal model control (IMC) technique relies on the "internal model" principle, the philosophy of which states that a control action over a plant can be achieved only if the control system includes, either implicitly or explicitly, some representation of the process to be controlled.

The IMC design procedure requires, for a realizable control, a low pass filter $L(s)$ in cascade to the IMC controller; otherwise the IMC controlled transfer function would include the use of pure differentiators. The filter $L(s)$ is of the type

$$L(s) = (\alpha / (s + \alpha))^z \quad .... (2)$$

Where the order of the filter, z , is chosen according to the order of the plant $G(s)$, and a can be interpreted as the closed loop bandwidth of the control system. Fig. 2 shows the structure of the IMC controller modified to graphically group the controller section and the plant section in the closed loop system. By doing this, the structure of the IMC controller resembles that of a PI controller for first order plants. Also, Fig. 2 includes the representation of an inner feedback loop of gain R in the plant, which is designed to provide a second degree of control freedom. This additional degree of control is used to speed up the natural response of the plant by moving the pole of the plant away from the origin within the negative side of the real axis. The additional degree of control freedom greatly improves the load disturbance rejection characteristic of the plant which, by itself, is independent of the set-point tracking controller. The load disturbance rejection feature of the 2DF-IMC is specifically designed to reject dc disturbances with 0 steady state error. This feature is the key factor for the filter-less realization of a SRF controller since, as it will be explained in section IV, the negative effects of removing the low pass filters from the conventional SRF control structure, is a control loop polluted with ac harmonic signals. Nevertheless the 2DF-IMC is able to deal-with this harmonic pollution in the dc domain.

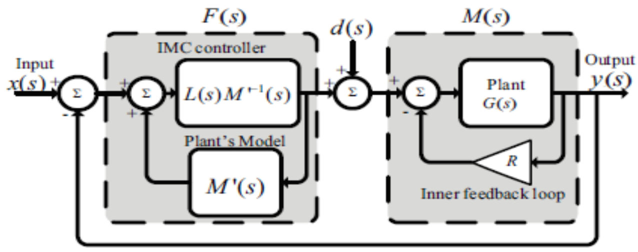

Fig (2): The 2DF IMC configured as a PI controller

By adding a feedback loop of gain R, the transfer function of the improved plant is

$$M(s) = G(s)/\left[1+G(s)R\right] = 1/\left[G^{-1}(s)+R\right] \quad \text{.... (3)}$$

Where M(s) is the improved transfer function of the plant

One way to define R as a function of α is to make the plant load disturbance rejection as fast as the controller's set-point closed loop dynamics. To achieve this, the pole R is set in the inner feedback loop to match the pole of the closed loop transfer function from the disturbance to output signal of the plant.

The relationship between the rise time, T_r, and the closed loop bandwidth of the controller is given by

$$a = 2.2\ /\ T_r \ \text{(rad).} \quad \text{.... (4)}$$

IV. ANALYSIS OF THE FILTER-LESS SRF IMPLEMENTATION

This section explains how the harmnic signals propagate inside the control loops of a SRF when the low pass filter stage is removed from the controller structure. Fig (3) shows the 2DF-IMC based SRF controller.

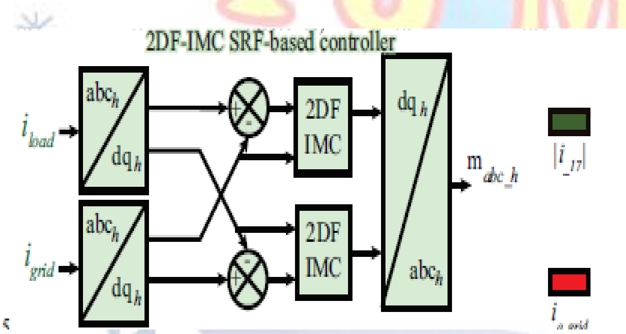

Fig (3): The 2DF-IMC SRF based controller

Equations (5),(6) presents the generalized harmonic $dq0$ transformation T_n used in the SRF technique to obtain the d-q components of the n harmonic. This transformation is based on the modified $dq0$ transformation, in which a 3 phase sinusoidal signal of magnitude 1 and no phase shift would produce a value of d =1, q =0

$$T_n = \frac{2}{3}\begin{pmatrix} \sin\left(\Gamma_n n(\omega_s t)\right) & \sin\left(\Gamma_n n(\omega_s t - 2\pi/3)\right) & \sin\left(\Gamma_n n(\omega_s t + 2\pi/3)\right) \\ \cos\left(\Gamma_n n(\omega_s t)\right) & \cos\left(\Gamma_n n(\omega_s t - 2\pi/3)\right) & \cos\left(\Gamma_n n(\omega_s t + 2\pi/3)\right) \\ 1/2 & 1/2 & 1/2 \end{pmatrix} \quad \text{.... (5)}$$

$$i_{n\_d} = \underbrace{\Gamma_n i_n \cos(\beta_n)}_{\text{dc component}} + \underbrace{\sum_{k=1, k\neq n}^{\infty} \Gamma_k i_k \cos\left(-\Gamma_k\left[(\Gamma_n n - \Gamma_k k)(\omega_s t)\right] + \beta_k\right)}_{\text{ac component}}$$

$$i_{n\_q} = \underbrace{i_n \sin(\beta_n)}_{\text{dc component}} + \underbrace{\sum_{k=1, k\neq n}^{\infty} i_k \sin\left(-\Gamma_k\left[(\Gamma_n n - \Gamma_k k)(\omega_s t)\right] + \beta_k\right)}_{\text{ac componentl}} \quad \text{.... (6)}$$

If the ac components of the d-q currents in (5,6) are allowed to propagate in the control loops then the controller output will become a hybrid signal composed of a dc part (the useful control action) plus a ac part (the ac harmonic pollution). The modulator signal fed to the inverter by a filter-less SRF is a hybrid waveform composed of 2 parts:

1) A useful control action (the dc dynamics of the fundamental and harmonic d-q current loops) plus
2) constant harmonic disturbances (product of using filter-less SRF) which are meaningless (even dangerous) for control purposes.

The Effects of a 2DF-IMC in a filter-less SRF is as dangerous at it may seem, the constant ac harmonic disturbances produced by the filter-less 2DF-IMC are actually innocuous for a selective harmonic compensator based on the 2DF-IMC. The reason for this is that an n constant ac harmonic disturbance, produced by any given 2DF-IMC controller of the system, is reflected as a constant dc signal disturbance in the 2DF-IMC dedicated to the control of the n harmonic.

Since the 2DF-IMC is specifically designed to reject step-like, constant dc disturbances, is an ideal fit to compensate the ac disturbances produced by the other 2DF-IMC controllers with the same robustness and speed of response of its set-point tracking characteristics, since they will be reflected as a dc disturbance signal. Because of this, an array of 2DF-IMCs dedicated to compensating individual harmonics, will collectively compensate the ac disturbances produced by one another as fast as they track a set point change. The result of the collective control action of all the 2DF-IMC is simply a fast collective harmonic compensation, where the difference between the disturbance rejection and the set-point tracking dynamics is indistinguishable.

Since the disturbances produced by the ac components in the filter-less 2DF-IMC are readily compensated by the rest of the harmonic SRF controllers, and no filter is present in the SRF controller architecture, the set-point/disturbance rejection closed loop current dynamics (for both fundamental and harmonic currents) can be selected to be as fast as necessary, being limited only by the desired controller robustness, the accuracy of the internal model, the sampling frequency and the quantization errors.

Here it is important to highlight that if the controller inside a filter-less SRF is not actively damping external disturbances, (e.g. a conventional PI controller), then, collective input of disturbances would produce instability in the control loops (especially in the case of the poorly damped process of v_{dc}) .

This is because the first-harmonic signals that propagate throughout the non-first harmonic controllers eventually become a large exogenous dc disturbance added to the control action of the controllers dealing with first-harmonic-based variables.

Fig. 4 shows a diagram of the collective disturbance rejection and harmonic control of the filter-less 2DF-IMC harmonic controllers. The colored spectrum shown next to some sections the controllers in Fig. 7 reflects how the harmonics propagate throughout the controller. As seen in Fig. 4, some of the harmonics that enter from the *d-q* transformations propagate at different frequencies and magnitudes throughout the control loops, eventually becoming an ac disturbance at the output of the harmonic controller. These ac disturbances are reflected as dc disturbances in another controller loop (as shown by the dotted connecting arrows) where the disturbances are rejected completely with 0 steady state error.

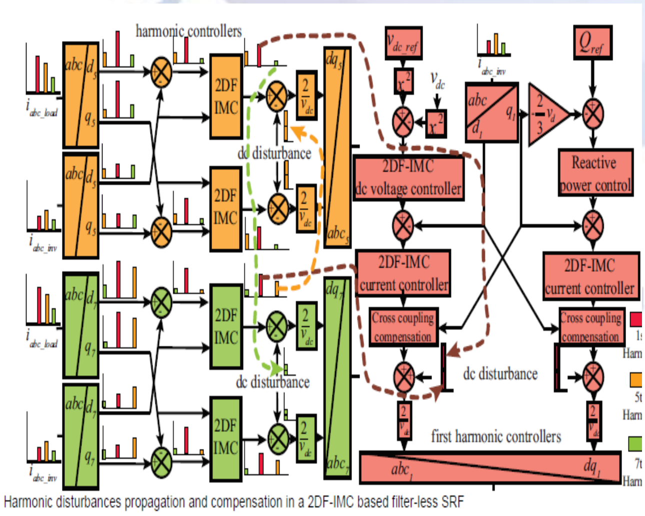

Fig (4): Harmonic disturbances propagation and compensation in a 2DF-IMC based filter-less SRF

V. SIMULATIONS

The conventional SRF based PI controller is simulated. The 2DF-IMController is analyzed mathematically, the simulation yet to be done. Fig. 5&6 shows a diagram of the simulated network of conventional SRF using PI Controller and five level diode clamped MLI-D-STATCOM configuration with SRF control for a three phase four wire system .

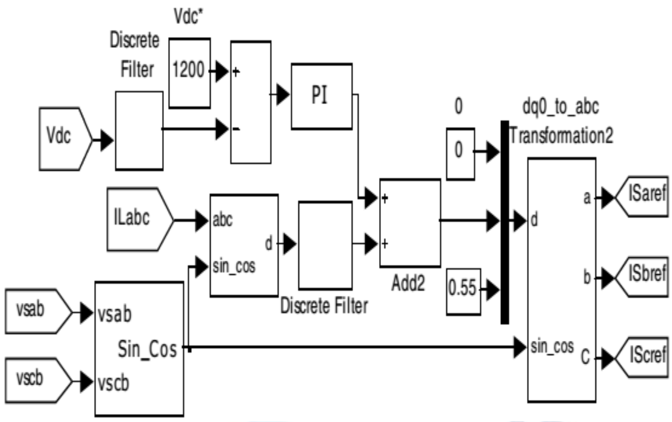

Fig (5) Conventional SRF-PI model in matlab/simulink

The proposed system is analyzed in two different cases i.e., case 01: is a three phase system with non linear balanced load and case 02: is a three phase system with non linear unbalanced load. In the two cases five level diode clamped MLI DSTATCOM is connected to the system at 0.5 sec .Load currents supply currents and supply voltages with out and with compensation can be seen in fig (7 a-f)

For proper compensation, voltage of DC link capacitor must be kept constant at rated value (i.e. 1200V in this case).The PI controller is therefore used to compensate the loss component of active current (IDloss). Using Ziegler-Nichols'method, proportional gain (Kp) and Integral gain (Ki) are estimated and are fine tuned to values of 0.003 and 0.0025. These reference currents (I_{refSa} , I_{refSb} and I_{refSc}) are compared with load currents (I_{La} , I_{Lb} and I_{Lc}) to generate DSTATCOM reference currents i_{Shabc_ref}. The currents of the DSTATCOM are maintained at reference values using Hysteresis current controller. The hysteresis current controller is operated with a lower band 0.25A and higher band of 0.5A to generate switching pulses to a five level diode clamped MLI-DSTATCOM.

The proposed MLI DSTATCOM injects currents into the system in phase opposition to the harmonic currents generated by nonlinear load and restricts nonlinear currents to the load end.

This makes the supply currents free from harmonics in order to compensate the supply current harmonics and unbalanced currents.

Fig(8) Depicts %THD for supply currents before and after compensation is observed before compensation the %THD is 21.20% and after compensation the fundamental component of the supply current is reduced to 3.46%.

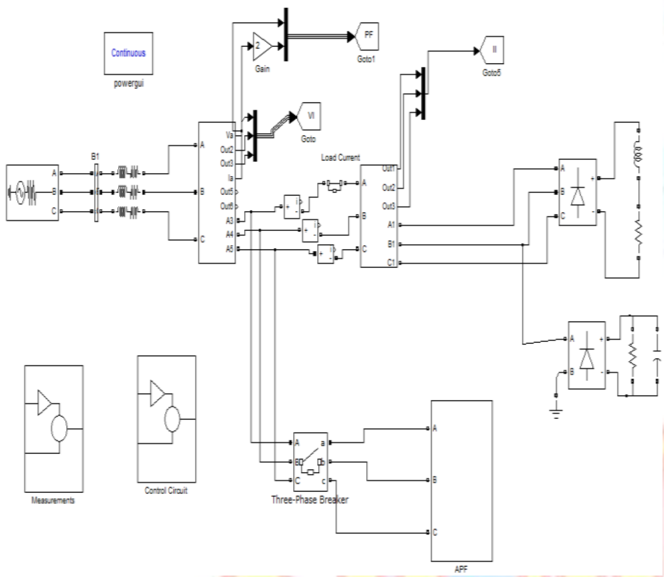

Fig.(6): Matlab/Simulink circuit for DSTATCOM model of Three Phase four Wire System

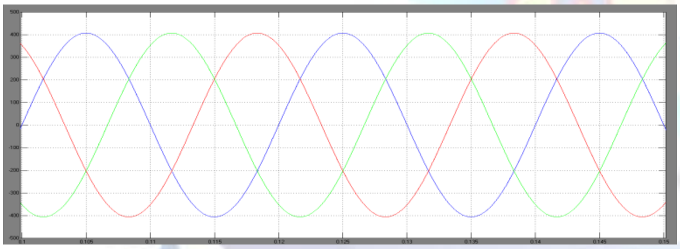

Fig.(7a): Output waveform of Supply voltage

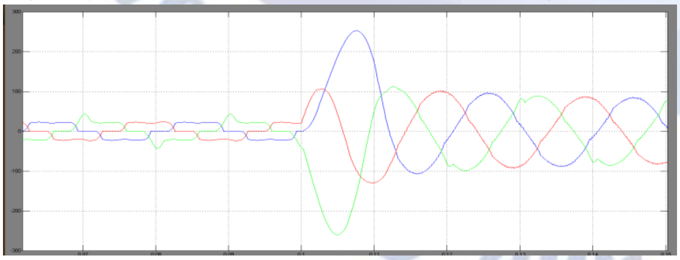

Fig.(7b): Output waveform of Supply current

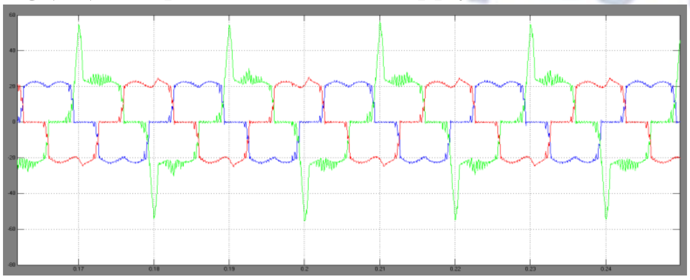

Fig.(7c): Output waveform of Load current

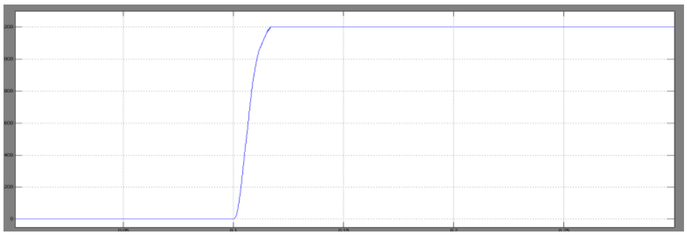

Fig.(7d): Output waveform of DC link voltage

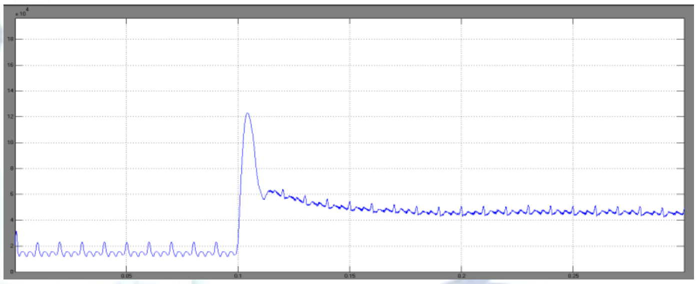

Fig.(7e): Output waveform of Active power at supply side

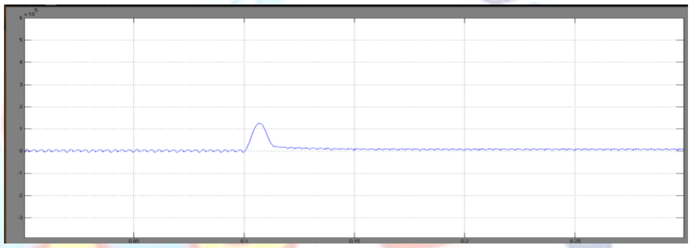

Fig.(7f) :Output waveform of Active power at load side

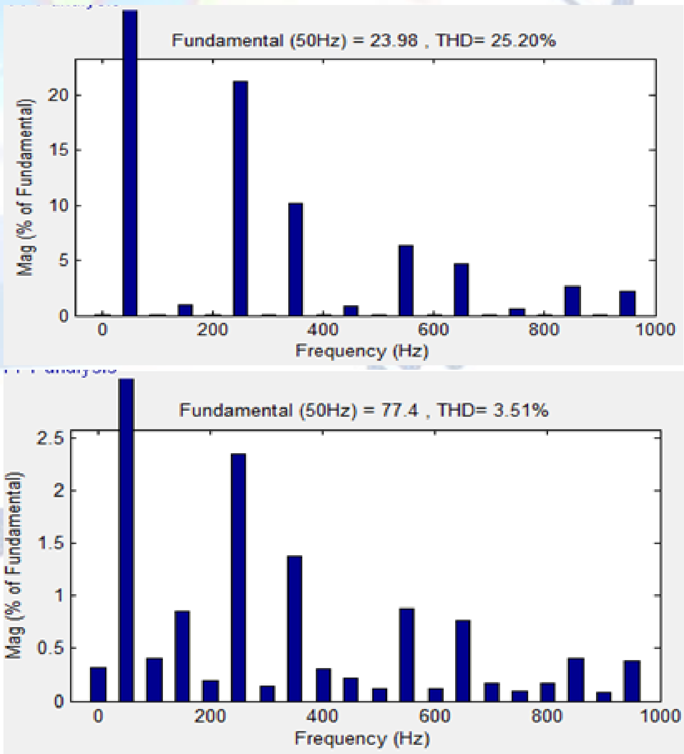

Fig.8: % THD of supply current (a) before compensation (b) after compensation.

VI CONCLUSION

This paper presents harmonic detection/mitigation strategy for power distribution networks using filter-less SRF and 2DF-IMC controllers. The filter-less implementation of the SRF enables harmonic currents to be detected/mitigated with remarkable rapidity compared with conventional SRF solutions. The key to implementing the filter-less SRF without affecting the stability of the converter is to deal with the collective disturbances, produced by the filter-less SRF, by using a 2DF-IMC structure. The 2DF-IMController is mathematically analysed.The Conventional SRF based PI controller is simulated by implementing to MLI-DSTATCOM.The performance of a proposed five level diode clamped MLI-DSTATCOM is analyzed using Synchronous Reference Frame based control scheme under nonlinear balanced/unbalanced load. From simulation results, it can be observed that the proposed five level MLI-DSTATCOM compensates supply harmonics more effectively compared to the two-level and three level diode clamped MLI-DSTATCOM. The %THD of the supply current is observed to be very small after connecting the proposed five-level DSTATCOM.

REFERENCES

[1]. Campos-Gaona *Member, IEEE*, R. Peña-Alzola, J.L. Monroy-Morales, M. Ordonez "Fast Selective Harmonic Mitigation in MI using Internal Model Controllers and Synchronous Reference Frames-", *Member, IEEE*, O.Anaya, *Member IEEE*, and W.E. Leithead-' DOI10.1109/TIE.2017.2682003,IEEE Transactions on Industrial Electronics

[2]. Alireza Javadi, *Member*, *IEEE*, Lyne Woodward, *Member*, *IEEE*, and Kamal, "Real-time Implementation of a Three-phase THSeAF Based on VSC and P+R controller to Improve Power Quality of Weak Distribution Systems" *Fellow*, *IEEE*, DOI10.1109/TPEL2017.2697821 IEEE Transactions on Power Electronics

[3]. Paul C. Krause, *Life Fellow, IEEE*, Oleg Wasynczuk, *Fellow, IEEE*, Timothy C. O'Connell, *Senior Member, IEEE*, and Maher Hasan "Tesla's Contribution to Electric Machine Analysis "Ieee Transactions On Energy Conversion, Vol. 32, No. 2, June 2017

[4]. On design and implementation of three phase three level shunt active power filter for harmonic reduction using synchronous reference frame theoryElango Sundaram ⇑, Manikandan Venugopal EEE Department, Coimbatore Institute of Technology, Coimbatore, Tamil Nadu, India

[5]. Luis M. Castro, Enrique Acha, *Senior Member, IEEE*, and Claudio R. Fuerte-Esquivel, *Senior Member* "A Novel STATCOM Model for Dynamic Power System Simulation", *Ieee* Ieee Transactions On Power Syste ms, Vol. 28, No. 3, August 2013

[6]. Mohammad Monfared†, Saeed Golestan**, and Josep M. Guerrero"New Synchronous Reference Frame-Based Method for Single-Phase Shunt Active Power Filters" Journal of Power Electronics, Vol. 13, No. 4, July 2013

[7]. N.Srinivasa Rao, H.J.Jayatheertha"Modeling And Simulation Of Various Srf Methods For Shunt Active Power Filter And Application To BLDC Drive" , IJAERS/Vol. I/ Issue IV/July-Sept., 2012/18-22

[8]. Luis M. Castro, Enrique Acha, *Senior Member, IEEE*, and Claudio R. Fuerte-Esquivel"A Novel STATCOM Model for Dynamic Power System Simulations" IEEE Transactions On Power Systems, Vol. 28, No. 3, August 2013/3145-3154

[9]. Monfared, M., Golestan, S., & Guerrero, J. M. (2013). A New Synchronous Reference Frame-Based Method for Single-Phase Shunt Active Power Filters. Journal of Power Electronics,13(4),692-700.DOI:10.6113/JPE.2013. 13.4.692.

[10].Bhim Singh, P. Jayaprakash, D.P. Kothari "New control approach for capacitor supported DSTATCOM in three-phase four wire distribution system under non-ideal supply voltage conditions based on synchronous reference frame theory" Electrical Power and Energy Systems 33 (2011) 1109–1117

[11].Sakthivel[1], Dr. P. Vijayakumar[2], Dr. L. Lakshminarasimman[3] and D. Gnanaprakasam "Simulation and Design of SRF based Control Algorithm for Three Phase Shunt Active Power Filter" *Proc. of Int. Conf. on Advances in Control System and Electricals Engineering 2013*/39-42 DOI: 03.LSCS.2013.1.521.

[12].Elango Sundaram ⇑, Manikandan Venugopal "On design and implementation of three phase three level shunt active power filter for harmonic reduction using synchronous reference frame theory" Electrical Power and Energy Systems 81 (2016) 40–47

[13].Krupa M. Patel[1], Prof. Kaushik K Patel"Synchronous Reference Frame Theory For Reduction Of Voltage Swell" *International Journal For Technological Research In Engineering Volume 2, Issue 9, May-2015,ISSN (Online): 2347 – 4718.*

[14].James K. Phipps, *Member, ZEEE,* John P. Nelson, *Senior Member, ZEEE,* and Pankaj K. Sen, *Senior Member, ZEEE* "Power Quality and Harmonic Distortion on Distribution Systems" IEEE Transactions On Industry Applications, Vol. 30, No. 2, Marcwapril 1994/476-484/

[15].Tzung-Lin Lee, *Member, IEEE*, and Shang-Hung Hu, *Student Member, IEEE* "Discrete Frequency-Tuning Active Filter to Suppress Harmonic Resonances of Closed-Loop Distribution Power Systems" IEEE Transactions On Power Electronics, Vol. 26, No. 1, January 2011/137-148

[16].Tzung-Lin Lee, *Member, IEEE,*, Shang-Hung Hu, *Student Member, IEEE* and Yu-Hung Chan "D-STATCOM with Positive-Sequence Admittance and Negative-Sequence Conductance to Mitigate Voltage Fluctuations in High-Level Penetration of Distributed Generation Systems" 2011 IEEE/1-12.

[17].Xingjian Jing and Li Cheng "An Optimal PID Control Algorithm for Training Feedforward Neural Networks" IEEE Transactions On Industrial Electronics, Vol. 60, No. 6, June 2013/2273-2283

[18].P. S. Sensarma, *Student Member, IEEE*, K. R. Padiyar, *Senior Member, IEEE*, and V. Ramanarayanan "Analysis and Performance Evaluation of a Distribution STATCOM for Compensating Voltage Fluctuations" IEEE Transactions On Power Delivery, Vol. 16, No. 2, April 2001/259/264

[19].Salem Rahmani, *Member, IEEE*, Nassar Mendalek, *Member, IEEE*, and Kamal Al-Haddad, *Fellow, IEEE* "Experimental Design of a Nonlinear Control Technique for Three-Phase Shunt Active Power Filter" IEEE TRANSACTIONS ON Industrial Electronics, Vol. 57, No. 10, October 2010/3364-3375.

[20].Mahendra Kumar[1], Prof. Vandana V. Patel "Tuning of Two Degree of Freedom PID Controller for Second Order Processes" International Journal of Science, Engineering and Technology Research (IJSETR), Volume 4, Issue 5, January 2015 ISSN: 2278 – 7798.