A New Online Optimal Controller for Tracking of Currents of two-level Voltage Source Converters

R.Fathi
Department of Electrical Engineering, Urmia University, Urmia, Iran
rahimfathi@yahoo.com

M.Farsadi
Department of Electrical Engineering, Urmia University, Urmia, Iran
m.farsadi@urmia.ac.ir

***Abstract*—This paper proposes a new optimal feedback controller for two-level voltage source converters VSC's, for current regulatedvoltage source converte*r*s, which allows compensate the harmonics of current produced by nonlinear loads and load reactive power. The aim of the present paper is to describe a novel switching signal generation technique called optimal controller which guarantees that the injected currents follow the reference currents determined by the compensation strategy, with the smallest possible tracking error and fixed switching frequency. Reference currents is calculated by instantaneous positive sequenceload currents and utility voltageswith PQ theory. It is compared with well-known hysteresis current controller HCC.The mathematical model of VSC will be addressed in detail. The validity of presented method and its comparison with HCC is studied through simulation results by MATLAB software.**

***Keywords*—*Hysteresis Current Controller HCC, Optimal Controller, Switching Pattern, Voltage Source Converter VSC*

I. INTRODUCTION

Increasing of imbalance and nonlinear loads in distribution systems has resulted in excessive harmonic injection and reactive power burden in the utility.

Active power filters have been developed to reduce the harmonics [1-3]. The current control system is the key problem to realize compensation objectives of active power filters. Different control strategies have been presented to control these systems but they differ in dynamic response and the switching frequency [4-5]. HCC is a popular current controller in active filter. In this controller three units are used independently, one for each phase. The output from this HCC drives directly the switches of VSC. It is obvious that there is no relation between switching function of the three phases. This lack of coordination between the three individual units, result in high number of switching. By using HCC, it is not possible to control the switching frequency.

In practice, the conventional two-level or three-level three phase's bridge structure is adopted to build up the VSC. For distribution networks, the power switch device such as IGBT has more superiority over GTO because IGBT can switch at high frequency and control easily.

Conventionally HCC method were used for its improved stability and higher accuracy in current tracking [6], but with fixed hysteresis band results in uneven switching frequency that causes acoustic noise and difficulty in designed input filters, which suggested us to vary the hysteresis band [7].

In this paper, an optimal controller, which the decision about its switching on/off is in fixed time intervals, is proposed. The aim of the present paper is to describe a novel switching signal generation technique called optimal controller which guarantees that actual currents track its reference compensating currents as close as possible.

Other method that is called deadbeat control is a digital feedback strategy that is designed to control the pulse width so that the output of converter can trace the reference at every sampling instant [8].

It is easy to notice that in deadbeat control method, the system states equal to desired values at the end of the sampling interval while in proposed method the difference between system states and desired values is minimized for getting the appropriate switching functions.

The aim is to prove that the proposed technique performs better at minimizing the square tracking error between the reference and real currents than the other controllers.

Features of this controller are simplicity, quick response, insensitivity and stability to distortion and lower number of switching. In addition it has fixed decision time intervals i.e, fixed switching frequency. A comparison is made with HCC applied to the same system.

II. MATHMATICAL MODEL TWO-LEVEL CONVERTER

Figure 1 shows the main circuit topology of VSC in connection with three-phase utility and loads.

From reference [9] the equations of converter are:

$$Va = Lc\frac{di_{ca}}{dt} + Vsa$$
$$Vb = Lc\frac{di_{cb}}{dt} + Vsb \qquad (1)$$
$$Vc = Lc\frac{di_{cc}}{dt} + Vsc$$

and

$$Va = (Sa - \frac{Sa + Sb + Sc}{3})Vdc$$
$$Vb = (Sb - \frac{Sa + Sb + Sc}{3})Vdc \qquad (2)$$
$$Vc = (Sc - \frac{Sa + Sb + Sc}{3})Vdc$$

Where i_{ca}, i_{cb} and $i_{cc}$are actual compensating currents, V_a, V_b and $V_c$are terminal voltages of VSC, V_{sa}, V_{sb} and V_{sc} which are common coupling point voltages. In eq.2 S_a, $S_b$and S_c are switching functions and are defined as follows:

$$S_i = \begin{cases} 1 & if \quad S_{1i} \quad is \quad conducting \\ 0 & if \quad S_{2i} \quad is \quad conducting \end{cases} \qquad i = a,b,c$$

The state variables are chosen as follows:

$$\underline{x} = [i_{ca}(t) \quad i_{cb}(t) \quad i_{cc}(t)]^T \qquad (3)$$

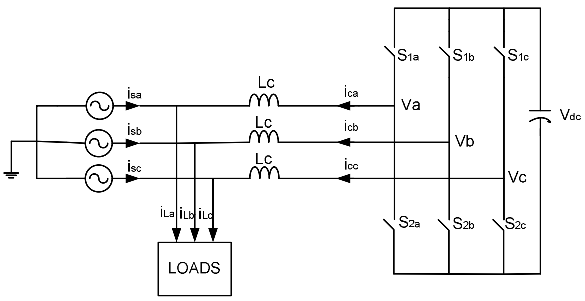

Figure 1. Power circuit topology of VSC

By defining the S_a, S_b and S_c as input controlling signals of control circuit, the optimal controller must generate such a switching signals that actual currents of VSC track its reference compensating currents as close as possible.

III. CONTROL STRATEGY

Control strategy can be divided in two parts as follows:

a) generation of reference compensation currents

b) generation of switching signals

Figure 2 shows the control block diagram for generation of reference compensation currents of active filter. When the non-linear loads inject harmonics into network, the VSC provides a path for the current harmonics and reactive current, which forces them to flow through the VSC. Thus source currents will be sinusoidal. To calculate the compensating currents, instantaneous positive sequence of currents Ipos(abc) in needed first. Subtraction of Ipos(abc) from IL(abc) that is the load currents results in the necessary compensation currents which the VSC must injects to compensate for the harmonics of load without considering of reactive power compensationas.The subtraction of abovementioned signal from I_q(abc) results in the reference reactive power compensating and harmonic currents of load, simultaneously. The I_q(abc) is the reference compensation current of reactive power of load in instantaneous manner. This compensation current is obtained using by well-known PQ theory. The abc to $\alpha\beta$ and $\alpha\beta$ to abc transformation converts three-phase currents and utility voltages to two coordinates system and vice versa. Using I_{pos}(abc) for calculation of I_q(abc) guarantees the correct operation of PQ theory. Injection of reference compensation current, I_C^*(abc) into the phases results in full compensation of reactive and harmonics of load. [10-11]

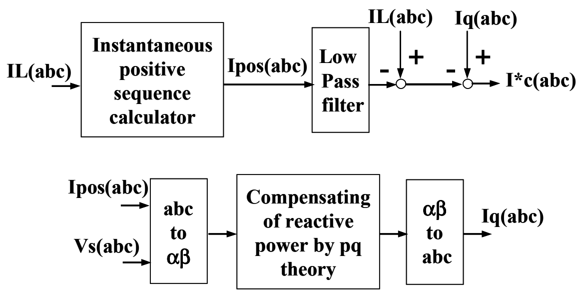

Fig. 2. Control block diagram for generation of reference compensation currents

For generation of switching function can be used:

A. Hysteresis current controller

Each VSC has three legs, one an each phase. Each phase of VSC consist of two switches (an IGBT with a anti parallel diode). Midpoint of a leg is called as converter pole point.

The HCC switching law is described as follows:

1) i_{act}>i_{ref} +hb, upper of a leg is OFF and lower switch is ON.

2) i_{act}<i_{ref} –hb, upper of a leg is ON and lower switch is OFF.

Where hb is hysteresis band around the reference currents, i_{ref}. By decreasing hysteresis band results in higher switching frequency and higher switching losses but better compensation with lower THD is obtained. Also it is not possible to control the switching frequency. Due to lack of coordination among individual HCC of three phases, very high switching frequency may be happen. This will increase the switching losses.Fig.3 shows principle of tracking problem by this controller.

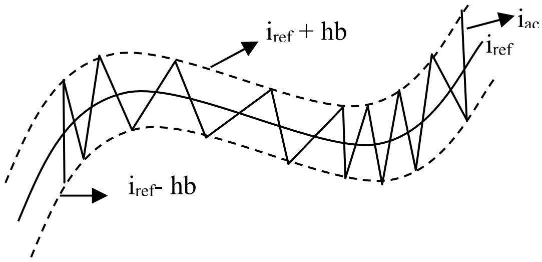

Fig.3. Principle of tracking problem by HCC

B. 0ptimal controller algorithm

Optimal controller is a feedback controller strategy that is designed to control the switching pattern so that the output of converter can track the reference at every sampling instant. Any deviation from the reference due to a load disturbance or nonlinear load is corrected within one sampling interval, Ts. Figure 4 shows principle of tracking problem by this controller and blockdiagram of control system is shown in figure 5.

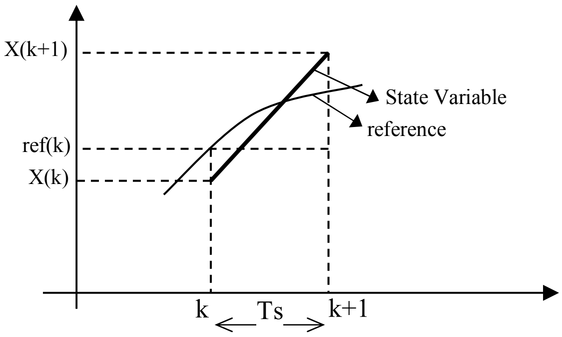

Fig.4. Principle of tracking problem by optimal controller

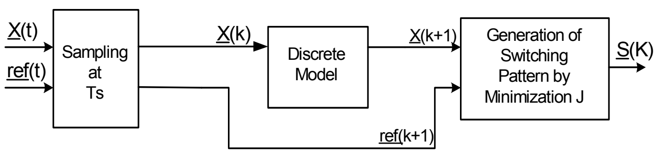

Fig. 5. Block diagram of switching pattern generation method

First the reference and actual currents of VSC are sampled with fixed sampling frequency. Then discrete model of system is applied. Switching signals is derived by minimizing the square tracking error between the reference and actual currents i.e., minimizing J.

Equation (4) shows the procedure to discrete of state variables. In this equation actual currents of VSC are as state variables so the discrete model will be as follows

$$
\begin{aligned}
x_1(k+1) &= x_1(k) + \frac{Ts}{L_C}\left[\left(S_a(k) - \frac{S_a(k)+S_b(k)+S_c(k)}{3}\right)V_{dc} - V_{sa}(k)\right] \\
x_2(k+1) &= x_2(k) + \frac{Ts}{L_C}\left[\left(S_b(k) - \frac{S_a(k)+S_b(k)+S_c(k)}{3}\right)V_{dc} - V_{bs}(k)\right] \\
x_3(k+1) &= x_3(k) + \frac{Ts}{L_C}\left[\left(S_c(k) - \frac{S_a(k)+S_b(k)+S_c(k)}{3}\right)V_{dc} - V_{sc}(k)\right]
\end{aligned} \tag{4}
$$

Where V_{dc} is the voltage of DC side of VSC and T_s is the sampling time interval.

Equation (5) shows an objective function J, which the switching pattern should be in such a way that this objective function be minimized. In this equation $\underline{x}_{k+1}$ and $\underline{ref}$ are vector of discrete actual and reference compensation current of VSC respectively. Considering an initial condition $\underline{X(k)}$, optimal controller must generate such a switching functions $\underline{S}(k)$ that system states $\underline{X(k)}$, reach to desired state, $\underline{ref}$.

$$J = \frac{1}{2}\left\| \underline{X}(K+1) - \underline{ref}(k+1) \right\|^2 \tag{5}$$

We have three controlling signals the S_a, S_b and S_c, so we have 2^3 combination of input signals. Now by check of objective function for each state, optimal controller will be derived and will applied to the switches then selected state that better at minimizing the square error between reference and state variables.

IV. SIMULATION RESULTS

The performance of the proposed scheme is evaluated by computer simulation. The simulation parameters are given as follows:

DC side voltage of VSC 630 volt.

Sampling time, T_s = 0.1 ms

The nonlinear loads consists of two following parts:

1) A balanced R-L load, R=15, L=35mH
2) A diode rectifier load, R=35 L=25mH. This load is switched on at t = 0.05 (sec).

The demonstrate the reduction in the switching number accomplished by this technique, figs.6,7 show a comparison between the optimal controller and HCC (bang-bang) that band width of HCC is adjusted while THD in two method be same. It is obvious that the accumulated number of switching of optimal controller reduced compared to the HCC. For example at time scale 0.04 second, Fig. (8) Shows the compensated currents in utility side.Fig.9 (a) shows the reference compensating current and actual injected current of VSC in a phase using the proposed optimal switching method . This figure shows that it is possible to track the reference current with very fast response dynamic response and fixed frequency. It is clear that the proposed strategy can generate any desired reference current for VSC's for different application easily. This figure shows a good performance and acceptable dynamic response of proposed control strategy.

Fig.9 (b) and Fig.9(c) show switching pattern in phase a by optimal controller and HCC method respectly. Fig.9(c) depict that high number of switching is needed by HCC in comparison optimal controller as similar result.Figure10(a) shows that current error is increased when switching pattern is similar to optimal controller. Figure 11 shows load side currents that it consist harmonics and reactive power demand.

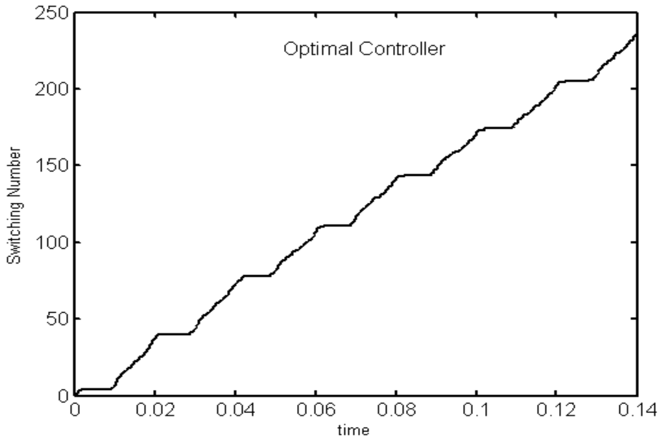

Fig.6. Switching number by optimal controller in phase a

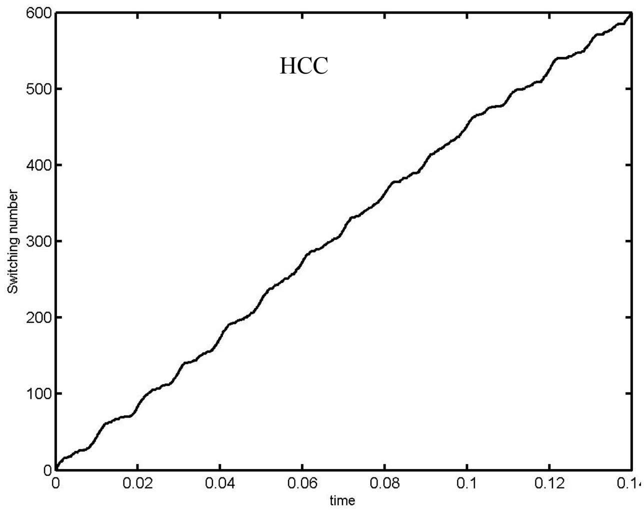

Fig.7. Switching number by HCC controller in phase a

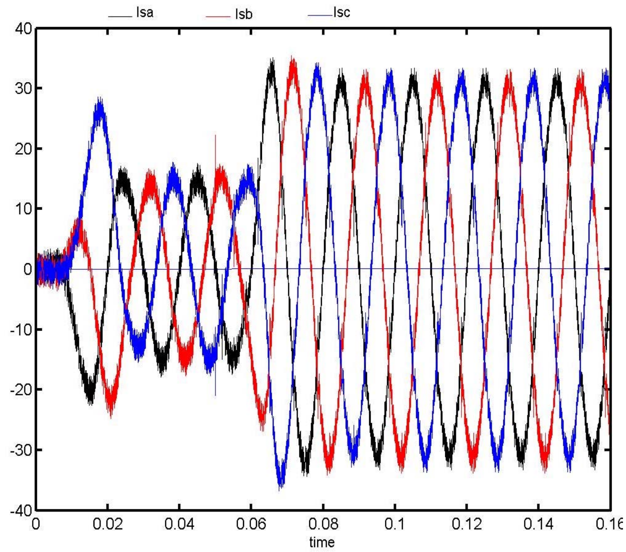

Figure.8. Source side currents

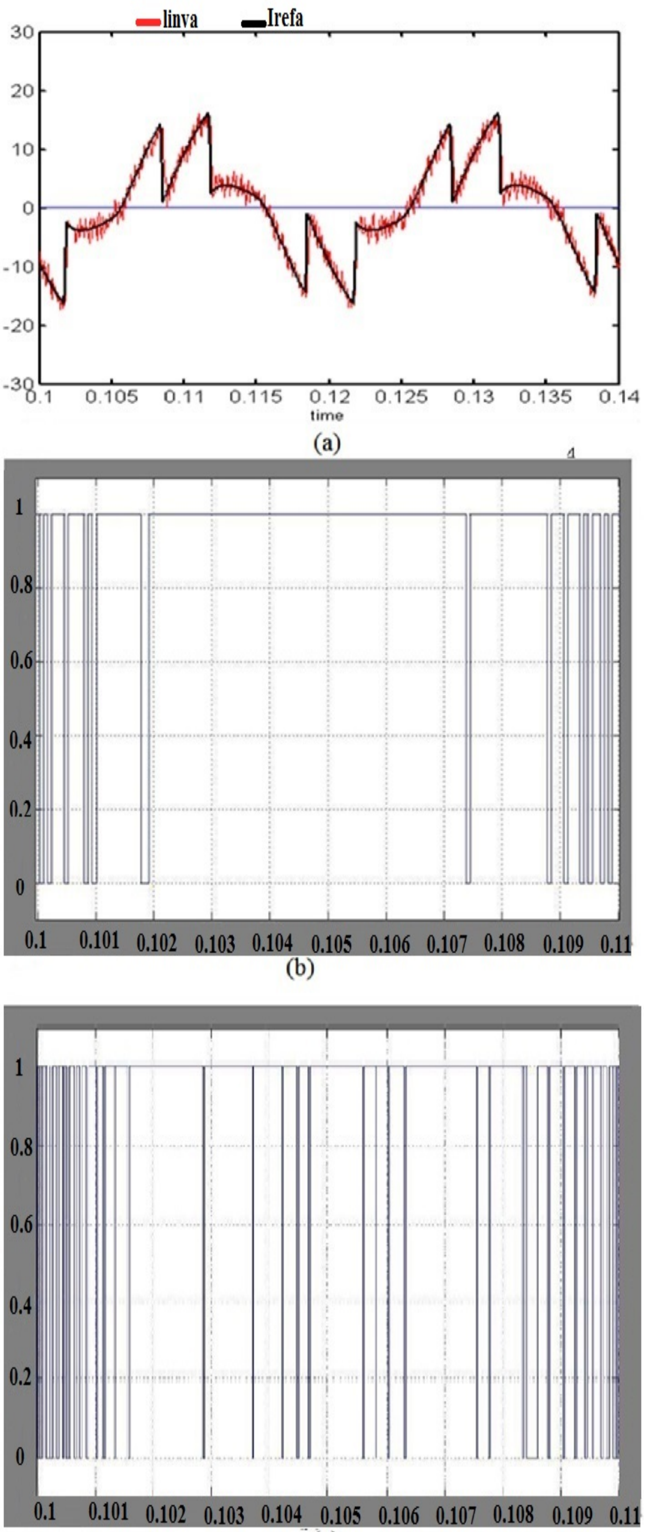

Figure. 9. (a)Tracking of reference current by optimal controller, (b) Switching Pattern in phase a by optimal Controller (c) Switching Pattern in phase a by HCC for same THD

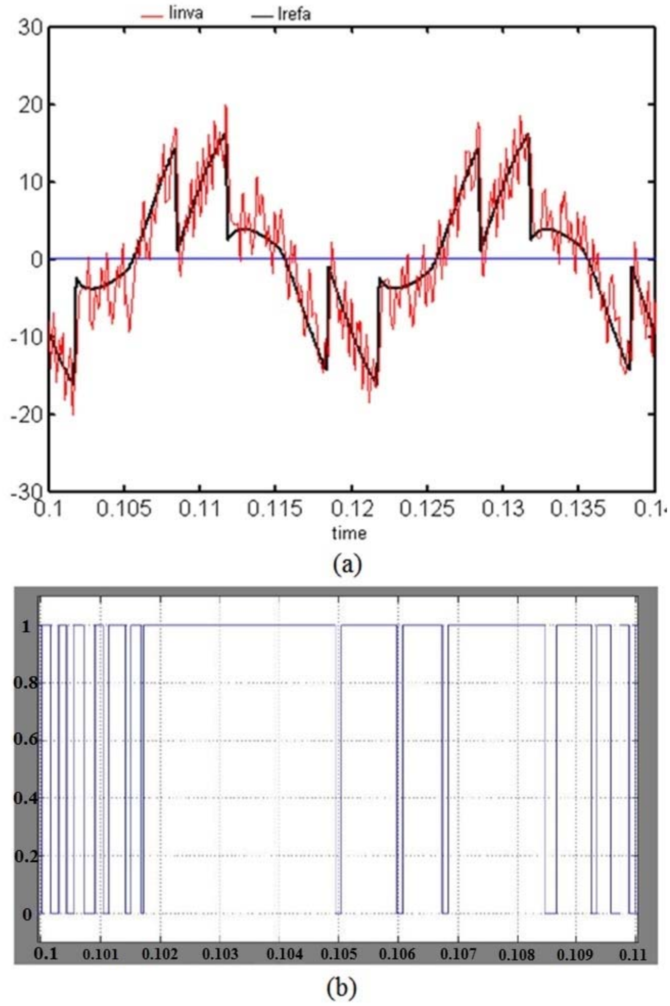

Figure. 10. (a) Tracking of reference current by HCC (b) Switching Pattern in phase a by HCC for THD 10%

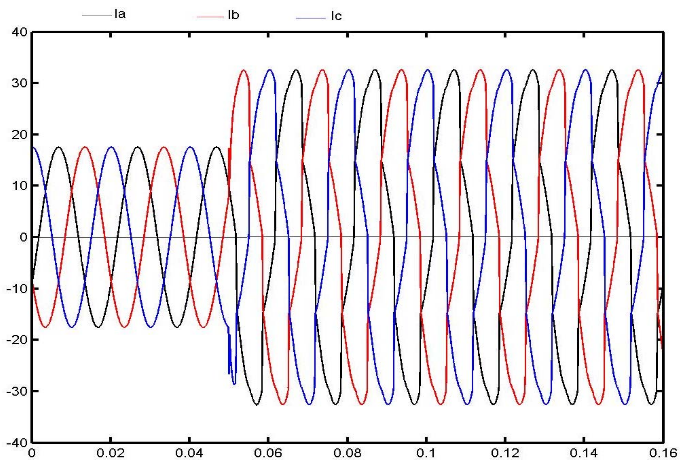

Fig. 11. Load side currents

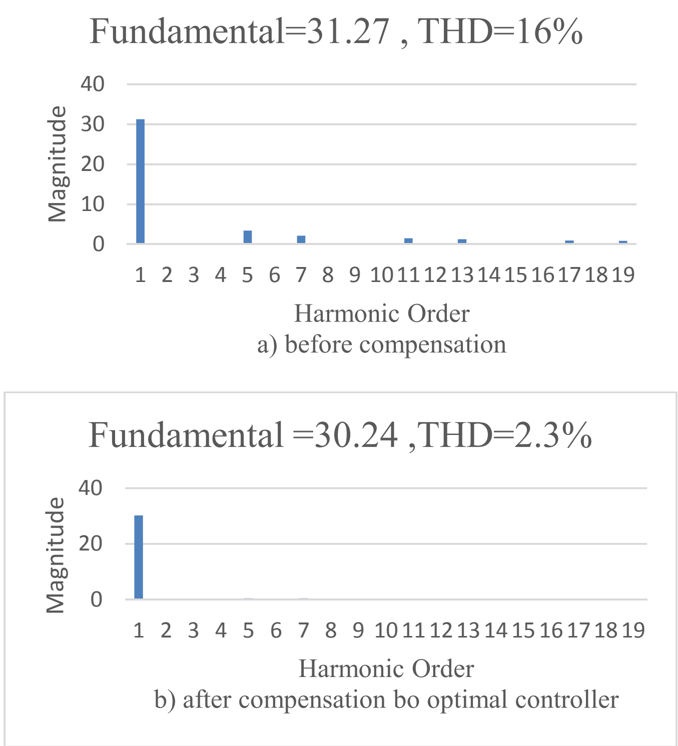

Figure. 12. (a) THD of current source before compensation (b) THD of current source after compensation by boptimal controller

V. CONCLUSIONN

A new optimal controller is presented for generation of switching pattern of VSC. The proposed optimal controller is a good operating technique to generate the gating control signals for VSC with optimal controller.The results of simulation confirm the efficiency of optimal controller. It has a fast response in tracking of reference compensation currents by actual compensation currents of VSC. In addition to the lower ripple of injection currents it has fixed decision time intervals. This results in limiting the maximum switching frequency on a fixed value. It is obvious that the proposed strategy can generate any desired reference current for VSCs for different applications, easily.

Features of this controller are simplicity, quick response and lower number of switching and better compensation with lower THD. The THD of source current to 2.3% from 16% while reducing the switching losses. In addition it has fixed frequency switching but HCC has not constant switching frequency.

REFERENCES

[1] B. Singh, K.Al.Haddad and A. Chandra, “A new approach to three-phase active filter for harmonics and reactive power compensation” IEEE Trans.on PWRD, Vol.13, NO.1, Feb 1998, pp.133-138.

[2] El. Habrouk M., Darvish M.K. and Metha P., “Active power filters: A review”, IEE Proc.-Elect. Power Appl., Vol.147, No.5, September 2000.

[3] W. M. Grady, M. J. Samotyj and A. H. Noyola, “Survey of active power line conditioning methodologies”, IEEE Trans. on PWRD, Vol.5 , No.3 , July 1990 , pp.1536-1542.

[4] A.Nabae, S.O.Ware and H.Akagi, “A novel control sheme for current controled PWM inverters,” IEEE.Trans. Ind. Appl. , Vol.22, No.4, July/Auqust 1986, pp.697-701.

[5] M.I.Marei , EI-Saadany, M.M.A.Salama, “A new contribution into performance of active filter utilizing SVM based HCC technique,” Power Engineering Society Summer Meeting, 2002 IEEE Vol.2, 21-25 July, pp.1022-1026.

[6] Mahesh A. Patel, Ankit R.Patel, Dhaval R.Vyas and Ketul M.Patel, “Use of PWM Techniques for Power Quality Improvement,” Int.Journal of Recent Trends in Engineering, Vol.1, no. 4 , pp.99-102,May 2009.

[7] Sudarshan swain, P.C. Panda, B.D.Subdhi,, “Three Phase Shunt Active Power Filter using a new Weighted Adaptive Hysteresis Band Controller” International conference on Circuits, Power and Computing Technologeis 2014 , pp.781-786.

[8] F.Kamnan, T.G. Habetler, “Combined Deadbeat of Control of a Series-Parallel controller combination used as a Universal Power Filter”. IEEEPower Electronics Specialist Conference pp:193-201, 1995

[9] M. Tarafdar Haque, R. Fathi, “A novel optimal controller for tracking of reference compensating currents of parallel active filter,” EPE power electronic,Pelincec2005,paper ID:66, Warsaw, October 2005,.

[10] M. Tarafdar Haque, T.Ise and S.H.Hosseini, “A novel control strategy for active filters usable in harmonic polluted and/or imbalanced utility voltage case,” Journal of Japan Society for Power Electronics, Aug 2000, Vol.26, No.1 , pp.86-94.

[11] M. Tarafdar Haque, S. H. Hosseini, T. Ise, “A Control Strategy for Parallel Active Filters Using extended p-q Theory and Quasi-instantaneous Positive Sequence Extraction Method”, 2001 IEEE International Symposium on Industrial Electronics - ISIE' 2001, June 12-16, Pusan- Korea, Vol.1, pp.348-353.