VOL. 10, NO. 7, APRIL 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

# EFFECTIVE CURRENT CONTROL DESIGN AND ANALYSIS OF SINGLE PHASE INVERTER FOR POWER QUALITY IMPROVEMENT

Rameshkumar Kanagavel[1] and A. Sakthivel[2]
[1] Department of Electrical and Electronics Engineering, VSB College of Engineering Technical Campus, Coimbatore, India
[2]Department of Electrical and Electronics Engineering, Dr.Mahalingam College of Engineering and Technology, Pollachi, India
E-Mail: rameshvel.k@gmail.com,

## ABSTRACT

Using an effective Predictive Current Control strategy to a single phase voltage source inverter and to analysis it's performance for various parameters variations is the main objective of this paper. An improved performance of the proposed predictive current control method has been analyzed with various conditions is carried out such as steady state, transient state, non sinusoidal references, input frequency variations, sampling frequency variations, current reference amplitude variations and filter inductance variations, that offers excellent reference tracking with less current harmonic distortion for all conditions. The control algorithm and inverter model was developed in Matlab/Simulink software.

**Keywords:** Voltage Source Inverter (VSI), current control, Pulse Width Modulation (PWM), Model Predictive Control (MPC), Total Harmonic Distortions (THD).

## 1. INTRODUCTION

Nowadays, the voltage source inverter is common topologies have been used in wide diversity of applications and give more attention of the researchers to control and conversion of power. For a grid connected inverter, the power quality mainly depends on performance of the current controller's in inverter.

The development of PWM techniques is the most popular control technique for grid-connected inverters. As compared with the open loop voltage PWM converters, the current-controlled PWM has several advantages such as fast dynamic response and inherent over-current protection [1]. Several control technique that has been developed till now to control the current in inverter.

In the Ref [1-16] a Varity of available current control techniques and its advantages and disadvantages are discussed.

Nowadays, Predictive current control technique has been used for control the current of three phase inverter[27], three phase four-leg inverter[24], three-phase two- level and three-level neutral-point-clamped inverter[29],[30], cascaded H-Bridge inverter[31], single phase boost rectifier[32],multilevel converter[33],matrix converter[34] and corresponding their application such as Active-Front-End Rectifier[18],[19], Distributed Generation Systems[20], Active Filters and Power Conditioning[23, 24], Non-Conventional Renewable Energy[20], uninterruptible power supplies (UPS) [25], drives [22], and power factor correction [26].

This current control method used in various wide power converters and the control scheme is to predict the future load current in terms of the measured actual load current and predicted load voltages.

Compared with the Classic Linear PI-PWM the MPC offers many advantages such as good reference tracking and minimum output distortion [24, 22].In the all above mentioned strategies are only considering three phase inverter, multilevel inverter , matrix converter for various conditions is described. But the detailed investigation of single phase two level two-leg inverter for various conditions is not being described.

In this paper, we use improved current controller used to control the current of single phase inverter for various condition are evaluated through simulation results. This paper is organized as follows. In Section II, the mathematical model of the converter-load system is presented, followed by the explanation of the proposed control strategy in Section III. In Section IV, Experimental results are presented. Finally in Section V appropriate conclusions are drawn.

## 2. POWER CONVERTER MODEL

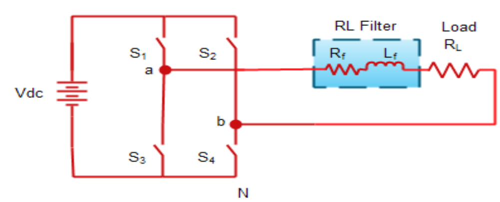


**Figure-1.** Voltage source inverter power circuit.

The power circuit of the converter considered in this work is shown in Figure-1. It is a two leg two level inverter operated by two control signals named $S_a$ and $S_b$ form a total of 4( $2^2$ ) switching state, and the inverter consisting of two controlled switches in each leg ($S_1$, $S_3$) and ($S_2$, $S_4$).The switching states of converter are determined by the control signals $S_a$ and $S_b$ as follows:

$$S_a = \begin{cases} 1 & \text{if } S_1 \text{ on and } S_3 \text{ off} \\ 0 & \text{if } S_1 \text{ off and } S_3 \text{ on} \end{cases} \quad (1)$$

$$S_b = \begin{cases} 1 & \text{if } S_2 \text{ on and } S_4 \text{ off} \\ 0 & \text{if } S_2 \text{ off and } S_4 \text{ on} \end{cases} \quad (2)$$

VOL. 10, NO. 7, APRIL 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

The voltages in a each leg of the two leg inverter, measured from negative point of DC-Link N, that can be represented as

$$\begin{bmatrix} v_a N \\ v_b N \end{bmatrix} = v_{dc}\begin{bmatrix} S_a & S_b \end{bmatrix}^T \quad (3)$$

where $V_aN$ and $V_bN$ are the voltage at the points ‘a’ & ‘b’ with respect to negative point of DC-Link N. The voltage applied to the load is potential difference between points ‘a’ & ‘b’ (or) potential difference between $V_aN$ and $V_bN$ . This can be written as

$$V_i = (v_a N - v_b N) \quad \text{(or)} \quad V_i = v_{dc}\left[S_a - S_b\right] \quad (4)$$

Then the output voltages can be related to the switching state vector $S_i$ by

$$V_i = v_{dc}\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \cdot \left[S_i\right]^T \quad (5)$$

where $V_i$ is the output voltage (or) voltage vector generated by the switching states $S_i$ with $i$ = 0,...4.

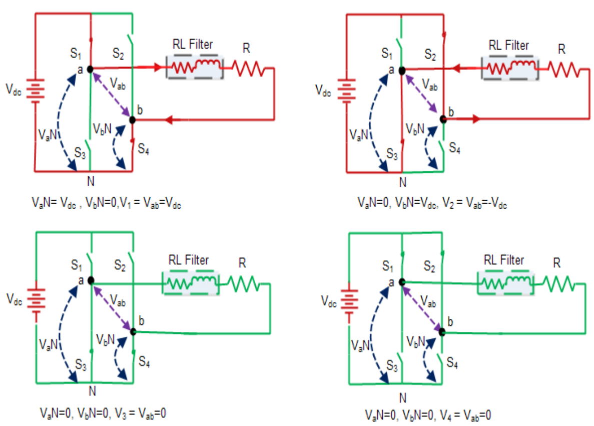


**Figure-2.** Voltage vectors and current flow direction in.

The switching state with their corresponding voltage vectors are shown in Table-1.

For different switching condition, the Voltage vectors and current flow direction in proposed predictive current control are shown in Figure-2.

The output voltage of inverter can be represented in a space vector form that is shown in Figure-3. The space vectors are classified in to two active voltage vector (V1, v2) and two zero voltage vector (V3, V4) so that a single-phase two-level inverter consisting of only three different voltage vectors.

**Table-1.** Switching states with their corresponding voltage vectors.

| Switching state | S | S | $v_a N$ | $v_b$ | Voltage vector |
|---|---|---|---|---|---|
| 1 | 1 | 0 | $v_{dc}$ | 0 | $v_{dc}$ |
| 2 | 0 | 1 | 0 | $v_{dc}$ | $-v_{dc}$ |
| 3 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | $v_{dc}$ | $v_{dc}$ | 0 |

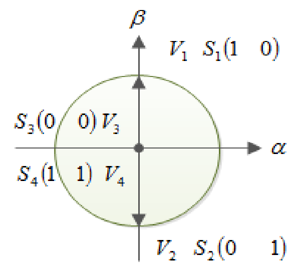


**Figure-3.** Space vector diagram of inverter output voltage.

$$V_i = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \cdot \begin{bmatrix} i_a & i_b \end{bmatrix}^T \quad (6)$$

The load current can be represented by the following equation

$$\mathrm{V} = (R_f + \mathrm{R})\,\mathrm{i} + L\frac{di}{dt} \quad (7)$$

Where $R_f$ filter leakage inductance is $R$ is the load resistance $L$ is the load inductance, V is the voltage generated by the inverter.

## 3. MODEL PREDICTIVE CURRENT CONTROL

### a) Predictive current control technique

The proposed current control scheme is shown in Figure-4. It uses the discrete-time model of inverter and load for predicting the load current at a future sample instant for each of the available output voltage vector that can be generated by the inverter. The quality function or cost function or error between the reference and predicted values is calculated. The switching state that minimizes g is selected and applied during the next sampling period. The model need input voltage and actual load currents at instant of k. By using the system` input voltage to generate voltage vectors, which is given to the predictive model to predict the inverter future current.

The current references are generated according to the application we are using. In this system a simple

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

designing and analysis of the inverter. So that the references are user defined. By changing the reference it can be used for any applications.

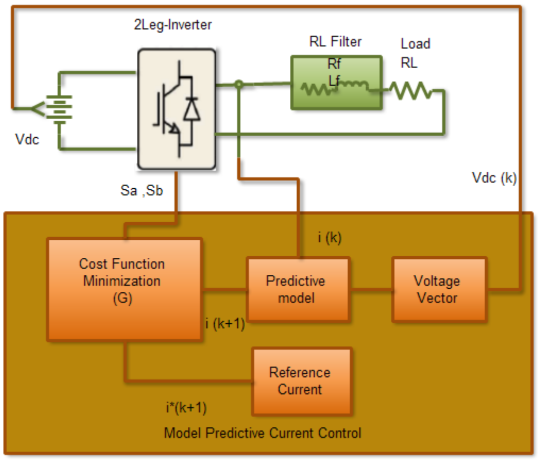


**Figure-4.** Configuration of MPC current control.

A discrete-time form of the load current for a sampling time $T_S$ can be used to predict the future value of load current by using measurement of load current and supply voltage at the sampling instant k.

Approximating the derivative $\frac{di}{dt}$ by

$$\frac{di}{dt} = \frac{\mathrm{i}(k) - \mathrm{i}(k-1)}{T_S} \tag{8}$$

Substituting equation (8) in equation (7) the following expression as

$$\mathrm{v} = (R_f + \mathrm{R})\,\mathrm{i} + L\frac{\mathrm{i}(k) - \mathrm{i}(k-1)}{Ts} \tag{9}$$

Then the load current at instant k as

$$\mathrm{i}(k) = \left(1 - \frac{(R_f + \mathrm{R})T_S}{L}\right)\mathrm{i}(k-1) + \frac{T_S}{L}\mathrm{v}(k) \tag{10}$$

Shifting the discrete-time one step forward in the future load current can be determined by

$$\mathrm{i}(k+1) = \left(1 - \frac{(R_f + \mathrm{R})T_S}{L}\right)\mathrm{i}(k) + \frac{T_S}{L}\mathrm{v}(k+1) \tag{11}$$

Where $R$ and $L$ are the load resistance and inductance, respectively $T_S$ is the sampling time, i(k) is the measured load current, and v(k+1) is the inverter predicted voltage is the decision variable to be calculated by the controller.

The cost function is error between the reference current and the measured load current at the next sampling instant can be expressed as follows

$$g = \left| i^*(k+1) - i(\mathrm{k}+1) \right| \tag{12}$$

where, $i^*(k+1)$ is the reference current vector and $i(\mathrm{k}+1)$ is predictive load current vector. In this work, the absolute error is used for computational simplicity. Other quality functions such as error squared could also to be used, that can be expressed as follows

$$g = (i^*(k+1) - i(\mathrm{k}+1)) * (i^*(k+1) - i(\mathrm{k}+1)) \tag{13}$$

Finally the corresponding switching state is given to the inverter.

### b) Proposed algorithm

**Step 1: Parameter initialization**

Set supply voltage $V_{dc}$=100,
Load Resistance =10,Load inductance =24mH,
Initial cost function g_opt = inf
Initial voltage vector = $V_1$, and Switching State= $S_1$
Voltage vector = $V_i$ /*voltage vector

$$V_i = v_{dc}\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \cdot [S_i]^T */$$

Switching State $S_i$ /* Switching State: 1 0; 0 1; 0 0 ; 1 1 */

**Step 2: Current prediction**

for i= 1 to n /* n: number of switching state */
Current prediction in k+1 instant
Ik1 = (1 – ($R_f$+R)*Ts/L)*i_meas + Ts/L*(v_o1); /* using measured current and previous voltage vector*/
vector v(i)*/

**Step 3: Calculate the cost function (G)**

/* cost function (G) : g = (abs(real(i_ref – ik1))) */
Selection of the optimal cost function and switching state value
if (g<g_opt)
g_opt = g; /*update the optimal cost function*/
x_opt = i; /*update the optimal switching state*/
End
End
Update the optimal voltage vector in the equation---
$S_a$ = S (x_opt, 1);
$S_b$ = S (x_opt, 2);
Send the optimal switching signal to the inverter.
Send the optimal switching signal to the inverter.

## 4. SIMULATION RESULTS

The Control of single phase voltage source inverter has been designed and developed in the laboratory to validate the performance of inverter. To validate the proposed current control strategy, for the single phase inverter is evaluated by simulation by using Mat lab/Simulink software and simulation is done using Intel core i3-2350M Processor 2.30GHz computer system. To analyze and to improve the performance of the proposed predictive control method the various cases are considered , such as of steady state, transient state, supply frequency variations, sampling frequency variation, Reference Amplitude variations and filter inductance variation are carried out.

Specification parameters of single phase voltage source inverter

| Variable- description | Value |
|---|---|
| $V_{dc}$ - DC supply voltage | 100 V |
| $L_f$ -Filter inductance | 24 mH |
| $R_f$ - Filter leakage resistance | 0.05 Ω |
| $R_L$ - Load resistance | 10 Ω |
| $T_S$ - Sampling Time | 50µs |
| f- Rated Frequency | 50Hz |

**a) Steady state analysis**

The performance of proposed predictive control in steady state operation for resistive load is 10 ohm and filter inductance is 24mH. The amplitude of reference current is set as 2A, frequency is 50Hz and DC-Link voltage to be kept at 100V.

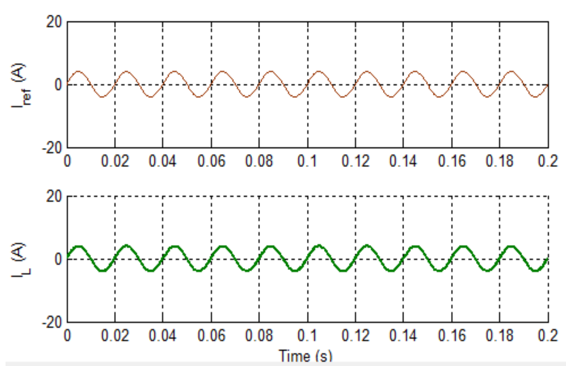


**Figure-5.** Simulation result of predictive control for steady state operation.

In Figure-4 shows that actual load current to track their references with less ripple content.

**b) Transient analysis**

The transient state analysis for the model, a amplitude of reference current step changes from 4A to 2A with frequency is 50Hz.that is shown in Figure-6. where good dynamic response of the load currents is observed with low harmonic distortion with fast rise time and no overshoot. The load is the same as of the steady-state analysis discussed earlier.

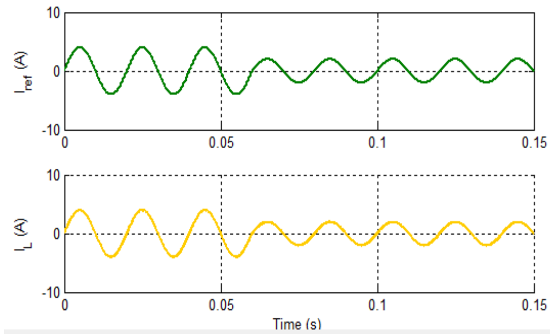


**Figure-6.** Simulation result of predictive control for Transient operation.

**c) Analysis with non sinusoidal reference**

In this Third, fifth, seventh and ninth harmonic references are given separately with amplitude of 10 A; The load Resistance = 0.5ohm; Filter inductance =24mH are used.

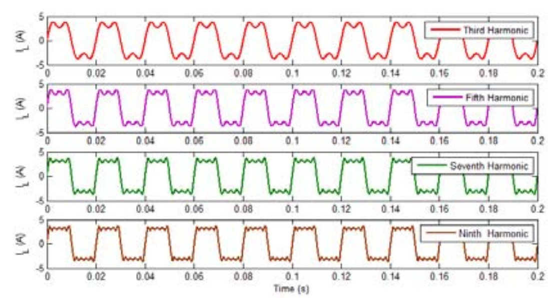


**Figure-7.** Simulation result with third, fifth, seventh and ninth harmonic load current.

The results are indicated in Figure-7. where a good tracking of the load current to its references are observed, which demonstrates that this control strategy can be applied effectively in a single phase voltage source converter operating as an active filter.

**d) Analysis with input frequency variations**

In this analysis the Reference frequency F = (50-20-70) Hz, Ref current =4 A , and the load is the same as of the steady-state analysis discussed earlier.

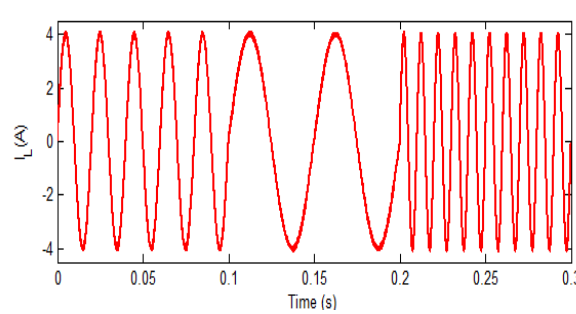


**Figure-8.** Simulation result with input frequency variations.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

In the Figure-8 shows that good reference tracking with frequency variations and fast response is observed.

**e) Sampling frequency variation**

The effect of varying the sampling time was tested with different load inductance values, in that the load current THD and Switching frequency of controller are varies with the sampling time variations.

The simulation result is depicted in Figsure-9 that shows the THD of the load current is minimum and switching frequency is maximum at higher sampling frequency or small sampling time, and also it shows that THD of the load current is reducing from 12 mH value of the load inductance to 72mH. After increasing the inductance the THD is going to reach maximum value. Similarly the switching frequency of the controller is increase from 12mH to 36mH of load inductance and reducing for increasing the load inductance. A switching frequency have a significant relation to the THD is high when THD is low value.

where THD1 indicate with the sampling time( Ts) of 100µs , THD2 for 50µs and THD3 for 20µs. And fsw1 indicate with the switching frequency of the controller is 100µs, fsw2 for 50µs and fsw3 for 20µs respectively.

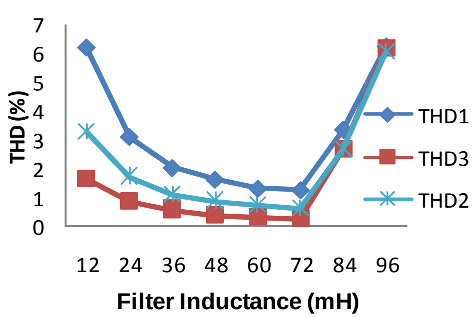


**Figure-9.** Comparison of % THD and sampling frequency with filter inductance variations.

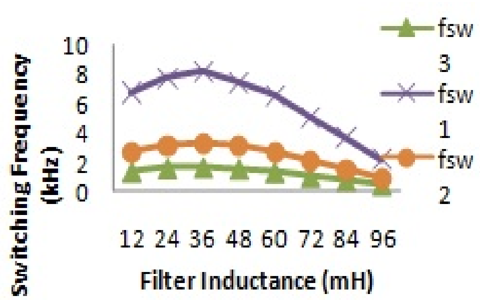


**Figure-10.** Comparison of switching frequency and sampling frequency with filter inductance variations.

The switching frequency of the controller for different operating points is presented in Figure-10. The fig shows that by varying sampling time with different filter inductance values, the load current THD is observed at minimum in minimum sampling time or higher sampling frequency. And switching frequency of the controller is observed as maximum in minimum sampling time or higher sampling frequency .When the filter inductance is increasing above 72mH the load current THD is maximum and load current is not sinusoidal in nature.

**f) Current reference amplitude variations**

The effect of varying the reference amplitude was tested with different filter inductance values, in that the load current THD and Switching frequency of controller are varies with the reference amplitude variations.

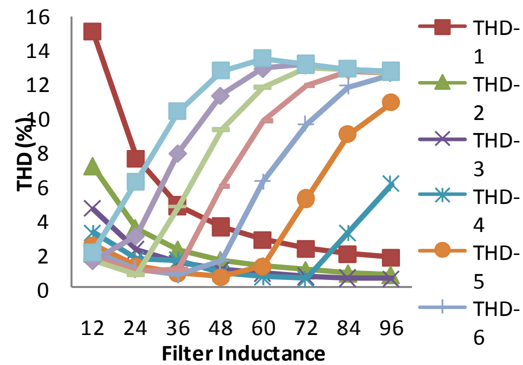


**Figure-11.** Comparison of %THD and reference amplitude variations with filter inductance variations.

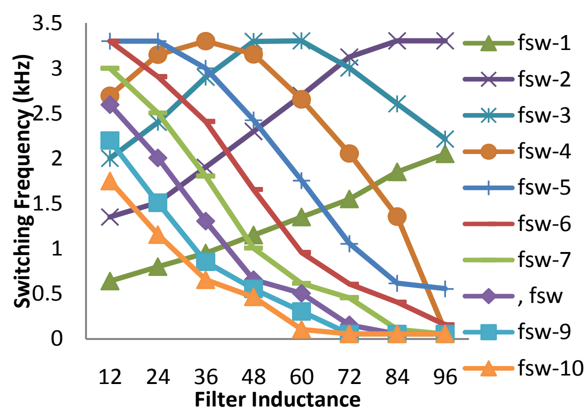


**Figure-12.** Comparison of switching frequency and reference amplitude variations with filter inductance variations.

Figure-11 and 12 shows that variation of load current THD and switching frequency for different current reference amplitude. where THD-1 indicate with the sampling time( Ts) of 50 µs and reference amplitude of 1A , THD-2, THD-3, THD-4, THD-5, THD-6, THD-7, THD-8, THD-9 and THD-10 for the sampling time( Ts) of 50 µs and for reference amplitude of 2A, 3A, 4A, 5A, 6A,7A,8A,9A and 10A respectively.

Similarly fsw -1 indicate with the sampling time( Ts) of 50 µs and reference amplitude of 1A , fsw-2, fsw-3, fsw-4, fsw-5, fsw-6, fsw-7, fsw-8, fsw-9 and fsw-10 for the sampling time( Ts) of 50 µs and for reference amplitude of 2A, 3A, 4A, 5A, 6A,7A,8A,9A and 10A respectively. Where y axis in Figure-12 indicates the switching frequency of the controller in terms of kHz. The current reference amplitude from 1A to 4A, the THD values are gradually decreasing from15.68 % to 0.58 %, and switching frequency of the controller are gradually increasing from 0.35 kHz to 3.21 kHz. And the current reference amplitude from 4 A to 10A , the THD values gradually increasing from 1.74 % to reach 12.88% of THD, and switching frequency of the controller are gradually decreasing from 3.5 kHz to 0.18 kHz.

### g) Controller operation with filter parameter variations

In the second case (CCF: changes to the controller and filter), the correct values of the load are given to the controller for the purpose of comparison. Both the cases are investigated in terms of % THD and Switching frequency

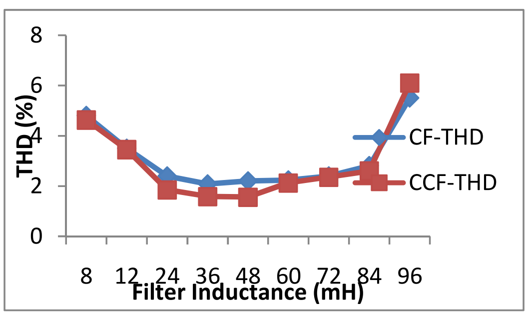


**Figure-13.** THD comparison of CF and CCF with filter inductance variations.

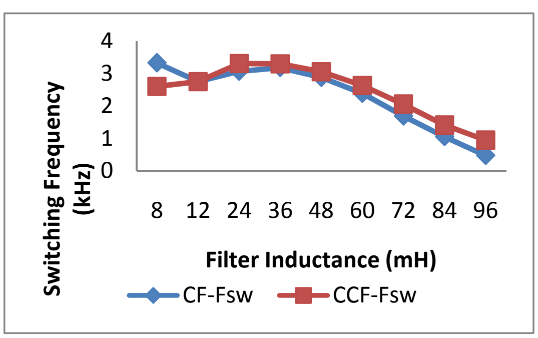


**Figure-14.** THD comparison of CF and CCF with filter inductance variations.

Even though the filter parameters change, the controller chooses a switching state that produces the minimal error in the reference tracking.

A comparison of them is depicted in Fig 13 and 14. where only a small difference is observed in THD and switching frequency of the controller for different filter inductance variations. With this, the proposed control strategy can operate efficiently even under filter inductance variations

## 5. CONCLUSIONS

In this paper the current control of single phase two-level two-leg voltage source inverter has been presented.

The control algorithm has been evaluated with seven different cases through simulation results. The result shows that good performances of the current tracking ability in all conditions with less harmonic distortion and the advantage of proposed technique are related to simplicity, design and modeling. With this the current control technique is a very good alternative solution to classical current control techniques.

In further research on control technique with cost function values variations in control algorithm and to compare with conventional current controllers.

## REFERENCES

[1] Marian P. Kazmierkowski. 1998. "Current Control Techniques for Three-PhaseVoltage-Source PWM Converters: A Survey," IEEE Trans. Industrial Electronics, Vol.45, October pp.691.

[2] D. M. Brod and D.W. Novotny. 1985. "Current Control of VSI-PWMInverters," IEEE Trans. Industry Applications, Vol.IA-2, No.4,May/June, pp.562-570.

[3] B. Yu. 2004. "Predictive Current Controlled PWM Strategy for Grid-connected Single-Phase Inverter," M.Sc. thesis, Univ. New Brunswick, Fredericton, NB, Canada.

[4] Buhl and R. D. Lorenz. 1991. "Design and implementation of neural networks for digital current regulation of inverter drives," in Conf. Rec. IEEE-IAS Annu. Meeting, pp. 415–421.

[5] M. A. Dzieniakowski and M. P. Kazmierkowski. 1995. "Self-tuned fuzzy PI current controller for PWM-VSI," in Proc. EPE Conf., Seville, Spain, pp. 1.308–1.313.[114].

[6] D.G. Holmes and D.A Martin. 1996. "Implementation Of A Direct Digital Predictive Current Controller for Single and Three Phase Voltage SourceInverter," In Conf. Rec. Annual Meeting IEEE Industry Applications, pp.906-913.

[7] S. Buso, S. Fasolo and P. Mattavelli. 2001. "Uninterruptible Power SupplyMultiloop Control Employing Digital Predictive Voltage and CurrentRegulators," IEEE Trans. Industry

Applications, Vol.37, November/Dececember pp.1846-1854.

[8] I. Takahshi. 1982. "A Flywheel Energy Storage System Having Harmonics Power Compensation," University of Wisconsin, Madison, WEMPEC Res. Rep.82-3, June.

[9] J. Holtz and S.Stadtfeld. 1983. "A Predictive Controller for the Stator CurrentVector of AC Machines Fed from a Switched Voltage Source,"In Conf. Rec. Annual Meeting Int. Power Electronics Conf., pp.1665-1675.

[10] K. P. Gokhale, A. Kawamura and R. G. Hoft. 1987. "Dead beat microprocessor control of PWM inverter for sinusoidal output waveform synthesis," IEEE Trans. Ind. Applicat., vol. IA-23, pp. 901–909, September/October.

[11] T. Kawabata, T. Miyashita, and Y. Yamamoto. 1990. "Dead beat control of three phase PWM inverter," IEEE Trans. Power Electron., vol. 5, pp.21–28, January 1990.

[12] A. Kawamura, T. Haneyoshi, and R. G. Hoft, "Deadbeat controlled PWM inverter with parameter estimation using only voltage sensor," in Conf. Rec. IEEE PESC'86, 1986, pp. 576–5.

[13] F. Harashima, Y. Demizu, S. Kondo and H. Hashimoto. 1989. "Application of neural networks to power converter control," in Conf. Rec. IEEE-IAS Annu. Meeting, San Diego, CA, 1989, pp. 1087–1091.

[14] M. P. Kazmierkowski, D. L. Sobczuk and M. A. Dzieniakowski. 1995. "Neural network current control of VS-PWM inverters," in Proc. EPE Conf., Seville, Spain, pp. 1.415–1.420.

[15] S. S. Min, K. C. Lee, J. W. Song and K. B. Cho. 1992. "A fuzzy current controller for field-oriented controlled induction machine by fuzzy rule," in Conf. Rec. IEEE PESC'92, Toledo, Spain, pp. 265–270.

[16] S. Saetieo and D. A. Torrey. 1997. "Fuzzy logic control of a space vector PWM current regulator for three phase power converters," in Proc. IEEE APEC'97, pp. 879–885.

[17] J. W. Kolar, H. Ertl, and F. C. Zach. 1991. "Analysis of on- and off-line optimized predictive current controllers for PWM converter system," IEEE Trans. Power Electron., vol. 6, pp. 454–462, May.

[18] J. Rodriguez, J. Pontt, P. Correa, U. Ammann and P. Cortes. 2005. "Novel control strategy of an AC/DC/AC converter using power relations," in Proc. Int. Conf. PELINCEC, Warsaw, Poland, October 16–19.

[19] J. Rodriguez, J. Pontt, P. Correa, P. Lezana and P. Cortes. 2005. "Predictive power control of an AC/DC/AC converter," in Conf. Rec. IEEE IAS Annu.Meeting, October Vol. 2, pp. 934–939.

[20] Jose Rodriguez, Marian P. Kazmierkowski and Christian A. Rojas. 2013. "State of the Art of Finite Control SetModelPredictiveControl in Power Electronics" IEEE Trans. Ind. Informatic, Vol. 9, no. 2, May.

[21] ] S. Kouro, P. Cortes, R. Vargas, U. Ammann and J. Rodriguez. 2009. "Model predictive control-a simple and powerful method to control power converters," IEEE Trans. Ind. Electron., vol. 56, no. 6, pp. 1826–1838, June.

[22] Cortes P., M. P. Kazmierkowski, R. M. Kennel, D. E. Quevedo and J. Rodriguez. 2008. "Predictive control in power electronics and drives" IEEE Trans. Ind. Electron, vol. 55, no. 12 December.

[23] PabloAcuna, Luis Moran, Marco Rivera, Juan Dixon, and Jose Rodriguez. 2014. "Improved Active Power Filter Performance for Renewable Power Generation Systems" IEEE Trans. Power Electronics, vol. 29, no. 2, February.

[24] VenkataYaramasu, Marco Rivera and Jose Rodriguez. 2013. "Model Predictive Current Control of Two Level Four-Leg Inverters—Part I: Concept, Algorithm,and Simulation Analysis" IEEE Trans. Power Electronics, vol. 28, no. 7, July.

[25] P. Cortes, J. Rodriguez, S. Vazquez, L. and G. Franquelo. 2010. "Predictive control of a three-phase UPS inverter usingtwo steps prediction horizon," in Proc. IEEE Int. Ind. Technol. (ICIT) Conf., pp. 1283-1288.

[26] P. Mattavelli, G. Spiazzi and P. Tenti. 2005. "Predictive digital control of power factor pre regulators with input voltage estimation using disturbance observers," IEEE Trans. Power Electronic., Vol. 20, no. 1, pp. 140–147, January.

[27] J. Rodriguez, J. Pontt, C. A. Silva, P. Correa, P. Lezana, P. Cortes and U. Ammann. 2007. "Predictive current control of a voltage source inverter," IEEE Trans. Ind. Electron., Vol. 54, no. 1, pp. 495–503, January.

[28] H. Miranda, R. Teodorescu, P. Rodriguez and L. Helle. 2009. "Model predictive current control for high-power grid-connected converters with output

ARPN Journal of Engineering and Applied Sciences



LCL filter," in Proc. 2009 35th Annu. Conf. of IEEE Ind. Electron., Nov. pp. 633–638.

[29] R. Vargas, P. Cortes, U. Ammann, J. Rodriguez and J. Pontt. 2007. "Predictive control of a three-phase neutral-point-clamped inverter," IEEE Trans. Ind. Electron., Vol. 54, no. 5, pp. 2697–2705.

[30] S. Aurtenechea, M. A. Rodriguez, E. Oyarbide and J. R. Torrealday. 2007. "Predictive direct power control of MV-grid-connected two-level and, three-level NPC converters: Experimental results," in Proc. Eur. Conf. Power Electron. Applicat., pp. 1–10.

[31] P. Cortes, A.Wilson, S. Kouro, J. Rodriguez and H. Abu-Rub. 2010. "Model predictive control of multilevel cascaded H-bridge inverters," IEEE Trans. Ind. Electron., vol. 57, no. 8, pp. 2691–2699, August.

[32] M. Pérez, J. Rodriguez and A. Coccia. 2009. "Predictive current control in a single phase PFC boost rectifier," in Proc. IEEE Int. Conf. Ind. Technol. ICIT 2009, pp. 1–6.

[33] M. Perez, J. Rodriguez, E. Fuentes and F. Kammerer. 2012. "Predictive control of AC-AC modular multilevel converters," IEEE Trans. Ind. Electron., Vol. 59, no. 7, p. 2839.

[34] R. Vargas, U. Ammann and J. Rodriguez. 2009. "Predictive approach to increase efficiency and reduce switching losses on matrix converters," IEEE Trans. Power Electron., vol. 24, no. 4, pp. 894–902.