# Current model predictive control for three-phase active power filter using cascaded H-bridge multilevel converter

**Abdelkader Yousfi[1], Youcef Bot[2], Fayçal Mehedi[3], Abdelkader Chaker[4]**
[1,2]Department of Electrical Engineering, University Khemis Miliana, Algeria
[3]Department of Electrical Engineering, Laboratoire LGEER, Hassiba Benbouali University Chlef, Algeria
[4]Department of Electrical Engineering, E.N.P Oran, Oran, Algeria

**Article Info**

***Article history:***

Received Apr 29, 2020
Revised Jun 15, 2020
Accepted Jun 27, 2020

***Keywords:***

Cascaded H-bridge inverter
Harmonic
Model predictive control
Multilevel inverter
Shunt active power filter

**ABSTRACT**

Different technologies in particular in the medium and high-power conversion were implemented and taken into consideration in the last few years. These inverter topologies have been demonstrated to ensure the generation of high-quality voltage waveforms based on power half-conductor switches, which operate on the fundamental frequency. The multilevel inverter H-bridge is a promising alternative among the available multi-level inverter topologies. A predictional current control algorithm for multi-level converters and use on a three-phase cascaded inverter H-bridge. This article reports on a comparison of two check methods associated with a shunt active power filter based on the cascaded inverter of the three-Level type. The first approach is the traditional PI control unit and the second is the predictive current control unit. The reference current for the shunt active power filter is provided by the p-q control strategy for reactive power compensation and current harmonics. The cascade-type three-level inverter has more advantages over a two-leaved inverter; the simulation output of APF is checked by MATLAB/Simulink. The predictive controlled the APF associated with the three-level inverter shows more performances and efficiency compared to the conventional control algorithms.



***Corresponding Author:***

Yousfi Abdelkader
Department of Electrical Engineering
University Khemis Miliana
Algeria Street Thniet El Had Khemis Miliana-Ain Defla-Algeria
Email: yousfi_pg@yahoo.fr

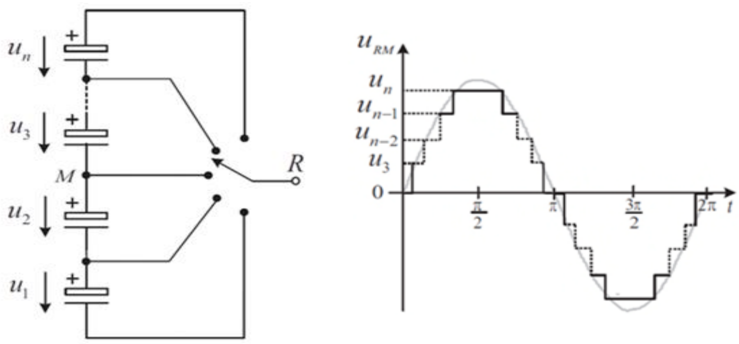
## 1. INTRODUCTION

A lot of power electronics equipment is used in the new electrical power grid. These wide range of power conversion systems, control electronics and nonlinear loads like adjustable speed driving, domestic machinery, transformative saturation, etc. are responsible for increasing harmonics in the ac handles. Because of ongoing technical and electronic equipment advances, the number of nonlinear loads is rising exponentially, as the power system generates characteristics and non-characteristic harmonics. The invention of thyristors led to the versatility for approximately two decades, but on the darker side, it brought harmony to the device too. The development of thyristors has led to versatility over the last two decades, but on the darker side harmonics have been also added to the device. These loads derive non-sinusoidal current from ac power and degrade the output of the system [1-3]. The harmonic features can be eliminated by tuned filters, while harmonics are the main problem to eradicate non-characteristics. The harmonics are non-characteristic other than harmonics and do not fall within any order or equation. Therefore, filters for these types of harmonics are often difficult to build. Many, some telephone interference, are adverse effects of these harmonics. Further losses of core and copper and resonance voltage. There are different methods, primarily active and passive filters, for removing these harmonics. Passive filters can easily be programmed to exclude certain frequencies; other harmonics, particularly not traditional harmonics, need to be removed by using an active power filter [4-6]. There are numerous control algorithms used in the Active power filter system to fire the voltage source inverter. The reliability and efficiency of the APF system mainly depend on its control algorithm. In modern electrical distribution systems, Shunt active power filter requires an accurate control algorithm that ensures robust performance under the source and load imbalances [7-9].

This paper introduces a predictive current algorithm for multi-stage conversion and implementation for a three-stage cascaded inverter H-bridge. This article contrasts the two approaches associated with a shunt active power filter based on a three-stage cascaded inverter. The first procedure is based on the standard PI regulator, and the second one is based on the current predictor. The shunt active power filter reference current is created by using the p-q control strategy for the compensation for reactive power and current harmonics. The three-stage form cascade inverter has more advantages than the bi-stage inverter, the simulation results are tested using MATLAB/Simulink.

## 2. MULTILEVEL INVERTERS

In recent decades, multi-level transformers have been increased because of the advantages in high-quality waveforms, low switching losses, high voltage capabilities and low electromagnetic compatibility problems they are taken into consideration in many high voltage and power applications [10-11]. The basic concept of multi-level converters is to combine many levels of voltage and to generate a sinusoidal voltage. By increasing in numbers, the synthesized output waveform provides additional steps, generating a series of wave steps that have a minimum harmonic distortion in the sinusoidal wave [12-13]. For instance, it can move between the n levels in the generalized n-level inverter as shown in Figure 1(a) and (b). Although there are different types of multilevel topologies, each of them has a unique topological layout. There are usually four major groups. The four types of flight condenser, hybrid H-bridge and multilevel hybrid inverters are widely recognized.




(a) (b)

Figure 1. (a) Simplified circuit of a n-level converter, (b) generated output n-level voltage

## 3. CASCADED H-BRIDGE THREE-LEVEL INVERTER

Several single full-bridge inverter units were included in the H-bridge cascaded multilevel inverter. Each bridge was fed with its dc source, which includes batteries, PV cells or any dc. Each bridge's output can be added to generate near-sine voltage waveform for the nth level of the multi-level inverter H-bridge Cascade per complete bridge inverter which forms the three-level cascaded H-bridge inverter with separate dc. Four semi-conductor switches can generate, depending on switching state, three different voltage levels namely+vdc, 0 and–vdc. Each turn always carries 180 degrees or half a loop, no matter how big the pulse of the quasi-quadrant wave is so that the current stress in each part can be compensated for by that method [14-15]. The three-level cascading H-bridge inverter is displayed in Figure 2. At a certain amount of time each H-bridge was triggered in a different starting angle and because each bridge was supplied with a separate dc source, the output for all three levels cascading H-bridge inverter output was the sum of three-level cascading three-level H-bridge inverter inputs of a different dc source [16]. The following is an output (1-3). From the above equation, the output voltage of the multilevel inverter cascaded H-bridge is the sum of the dc sources on the multilevel inverter. The Fourier bridge series as shown in 4 can be used to construct multi-level voltage waveforms as in Figure 3 [17-18].

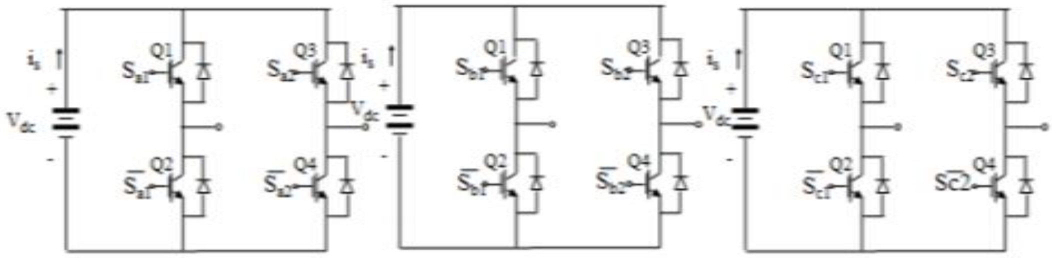


Figure 2. Three levels cascaded H-bridge inverter

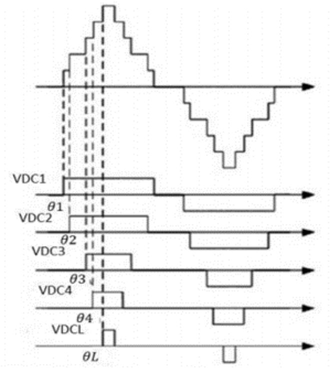



Figure 3. Staircase voltage waveform for single-phase three-level inverter [16]

$$V_{an} = V_{a1} + V_{a2} \tag{1}$$

$$V_{bn} = V_{b1} + V_{b2} \tag{2}$$

$$V_{cn} = V_{c1} + V_{c2} \tag{3}$$

$$V_{out}\,(\omega t) = \sum_{n=1,3,5}^{\infty} b_n \ \sin(n\omega t) \tag{4}$$

## 4. PREDICTIVE CONTROLLER WITH CASCAD H-BRIDGE THREE-LEVEL INVERTER

Two primary control components of the shunt active power filter (SAPF) system are present here. The first is the harmonic extraction method based on the standard regulator PI and the second is the current predictive control. Figure 4 show the overall control strategy block diagram. The output signal of a filter relative to a reference voltage is used as an input to the predictive control, the resulting signals are given by a three-level inverter. The predictive output is processed by carrier modules with the aid of a comparator to produce a switching signal [19-20].

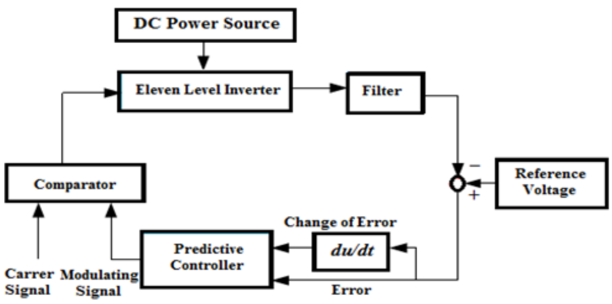



Figure 4. The general block diagram of the predictive control strategy

This predictive control strategy is based on the search for the perfect control vector, which requires first of all the analysis of the variations in the application of each control vector to load absorbed currents, during a time interval equal to the switching period [21-23]. The equation of APF shunt current, output voltage and the typical CCP voltage is shown in Figure 5 as [24-25]. In this case, the equation shows:

$$v_x = L_x \frac{di_{fx}}{dt} + e_x \tag{5}$$

If x is the interfacing inductance, x represents phases a, b or c, $L_x$, $v_x$ the output voltage APF in the x phase and $e_x$ the common point of connection (CCP) phase voltage, and $i_{fx}$ the APF current phase [24-25]. The resistance to the inductor is dismissed. In the discrete form, (5) can be defined as:

$$v_x^*(n+1) = L\left(\frac{i_f^*(n+1) - i_{fx}(n)}{T_s}\right) + e_x \tag{6}$$

For those cases where the phase APF current and its expected output voltage referrals are $i_f^*(n+1)$ and $v_x^*(n+1)$, the sampling time is sampled at the sampling moment $(n+1)$ and $T_s$. Using the common coupling point (CCP) of Kirchhoff's current law:

$$i_{fx}(n) = i_{Lx}(n) - i_{sx}(n) \tag{7}$$

Where the process load and deliver current are $i_{Lx}(n)$ and $i_{sx}(n)$ at the sampling instant $(n)$, respectively. As there is no instant sampling $(n+1)$, $i_f^*(n+1)$ has been replaced with $i_{fx}(n)$. This results in a time delay that is decreased as the amount of sampling increases. The shunt APF reference current can be specified as:

$$i_{fx}^*(n) = i_{Lx}(n) - i_{sx}^*(n) \tag{8}$$

Substituting (7) and (8) into (6) gives:

$$v_x^*(n+1) = L_x\left(\frac{i_{sx}(n) - i_{sx}^*(n)}{T_s}\right) + e_x(n) \tag{9}$$

(9) refers to the predicted output voltage of the inverter in reference and current supply currents. The block diagram for controlling the shunt APF using predictive control, based on three-level inverter is simulated using MATLAB/Simulink is shown in Figure 5.

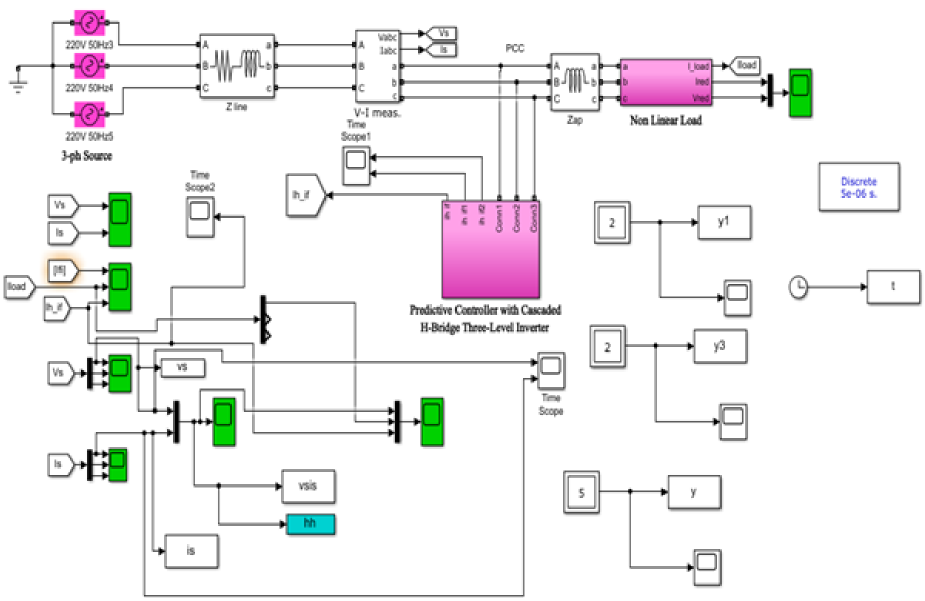



Figure 5. Predictive current control of the APF

## 5. SIMULATION RESULTS

The Figure 6, Figure 7, and Figure 8 are indicate the supply and load current voltage before compensation.

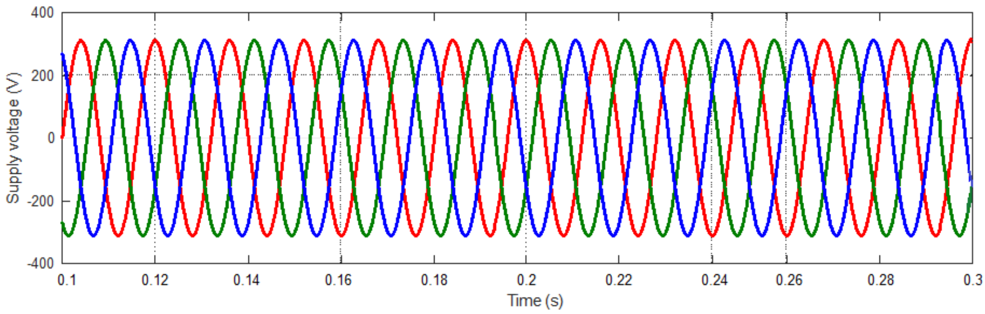



Figure 6. Supply voltages

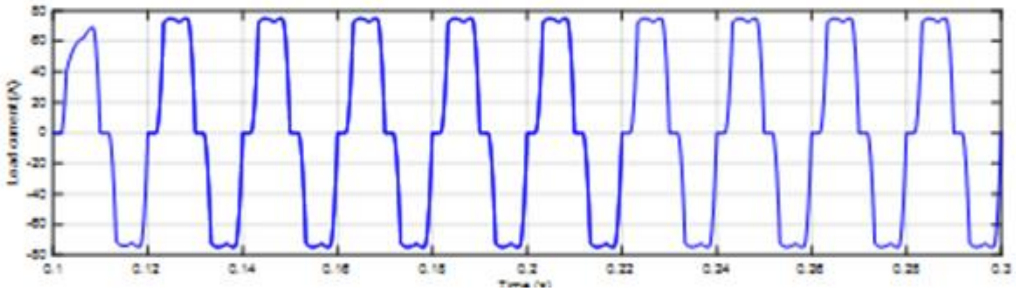


Figure 7. Load current

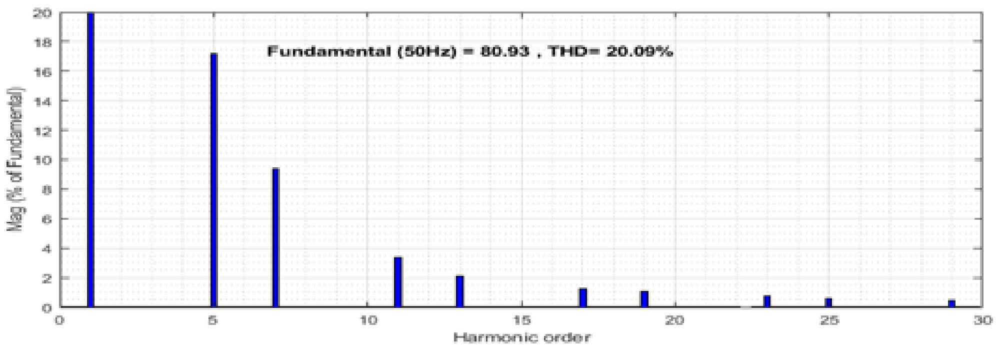



Figure 8. Frequency spectrum

### 5.1. Results and discussion of the APF based on the PI controller

The findings from the previous results show the efficiency of the shunt APF associated with the PI controller based on three-stage inverters. The gross harmonic distortion of the source current (THD) has been reduced to 2.67% as shown in Figure 9. The source current is also similar to the sinusoidal shape as shown in Figure 10, with a balanced network (t=0.15s) measured on the APF. Injected current and reference current as shown in Figure 11. The instantaneous active energy at the source side is also necessary to remember, depending on the magnitude of the source stress, and the imaginary power is pushed to zero as shown in Figure 12. This results in the effective compensation of the reactive force. Since reactive power is not involved in the transfer of active energy, the phase current may be increased. The reactive power can be reduced to zero, it is possible to minimize the current flowing at the source side and the power factor is a unity see Figure 13.

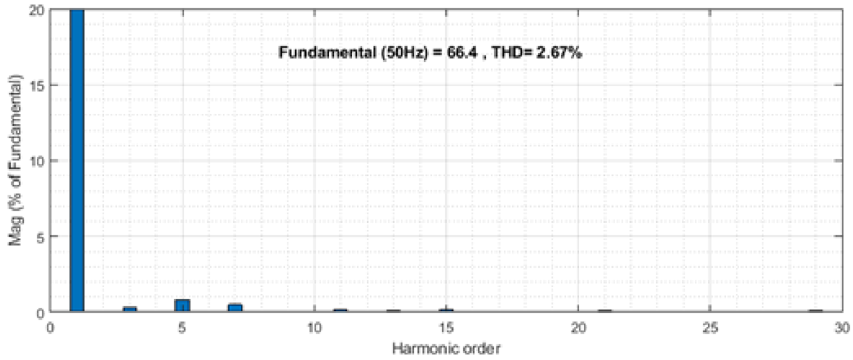



Figure 9. Frequency spectrum

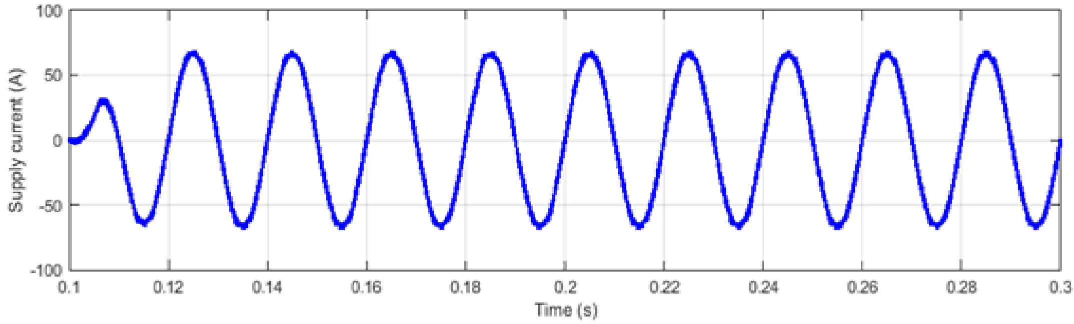



Figure 10. Supply current

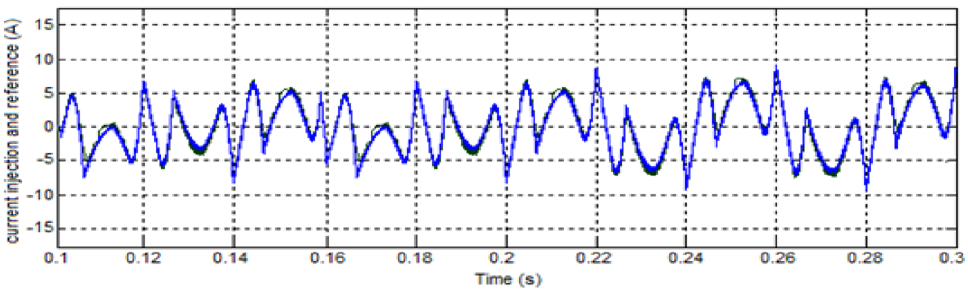



Figure 11. Injected current and reference current

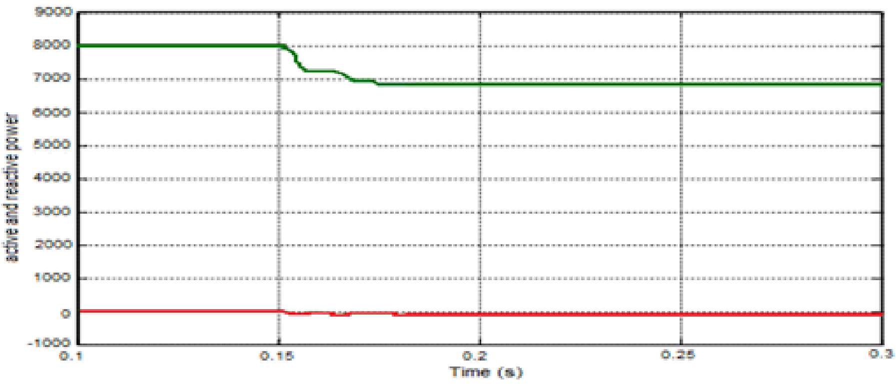



Figure 12. Active and reactive power

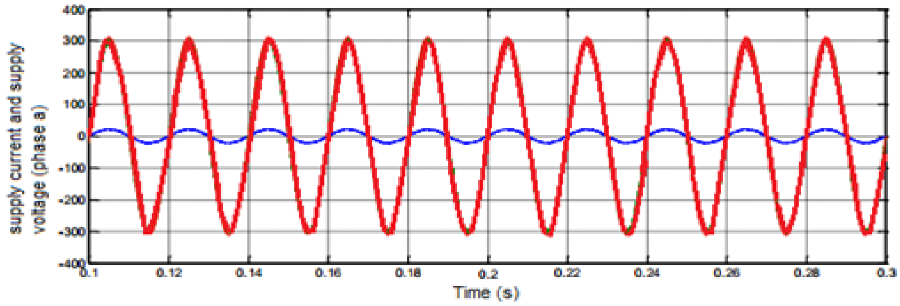



Figure 13. Supply current and supply voltages

### 5.2. Results and discussion of the APF based on the predictive controller

These figures show the injected current and its reference; the source current and its frequency spectrum and finally the active and the reactive power. A THD calculation of the output voltage was carried out concerning Table 1. Predictive control is a quite common class of controls that have been used in power converters very recently. The performance of the shunt APF associated with the predictive controller, based on three-level inverter is illustrated through the previous results as shown in Figure 14-18. To observe further the performance of this filter, it is necessary to carry out the simulation under balanced network condition. The THD of the source current is reduced to 1.56%, compared with the conventional PI controller (2.67%). The active instantaneous force on the source side depends on the source voltage value and the imaginary force with one uniform power factor (cos phi=1) is a force to zero ( 0 VAR). Simulation tests show that the APF shunt associated with the current predictor contributes to higher output than the PI transmitter. The tests obtained from predictive testing verified the positive results.

Table 1. Comparison of controller performance

| Controllers | THD% |
|---|---|
| PI | 2.67 |
| Predictive | 1.56 |

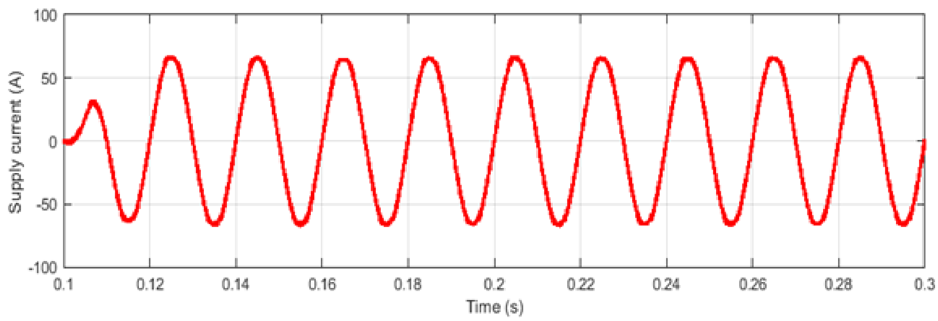



Figure 14. Supply current

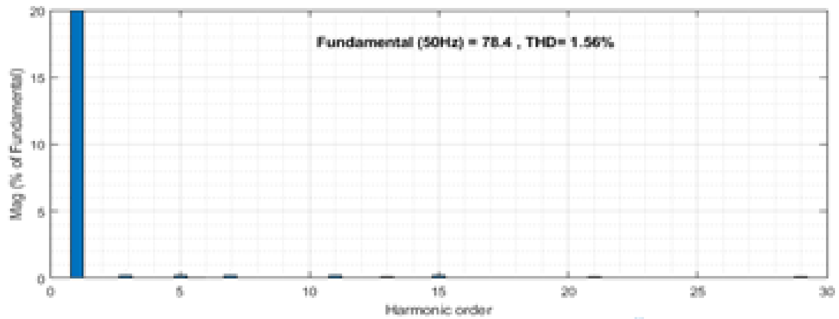



Figure 15. Frequency spectrum

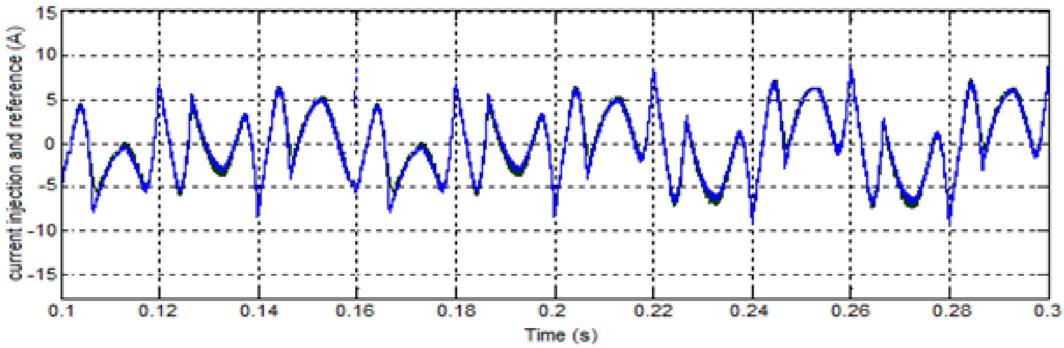



Figure 16. Injected current and reference current

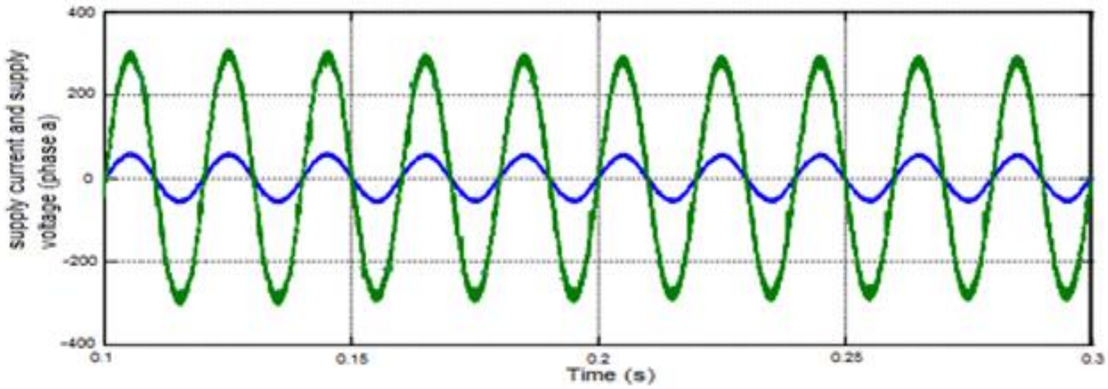



Figure 17. Supply current and supply voltages

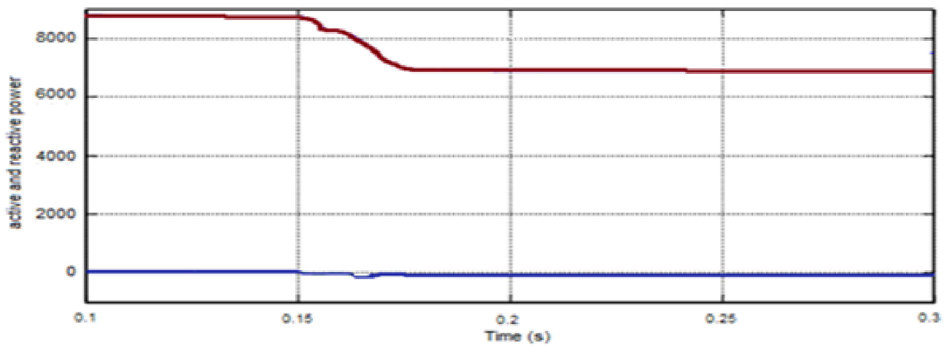



Figure 18. Active and reactive power

## 6. CONCLUSION

This paper uses a three-phase three-level H-Bridge inverter to control the load current, using the current predictive model. Where, in the first place, the ideal set of possible switching states is chos to the number of users switching indicates the device pressure, based on current redundancies. A comparative analysis of two control methods, linked to an APF shunt, based on a cascaded inverter form of three-stage. The first approach is based on the traditional PI control and the second is based on the current predictor. MATLAB/SIMULINK is deployed for the systems proposed. Modelling of the APF with three cascading levels and the efficient control design is presented. A robust current predictor is available that shows excellent dynamic and stable accuracy. The APF performance is tested with MATLAB/Simulink simulation. Compared to conventional control algorithms, the APF predictive associated with the inverter of three- levels shows greater efficiency and performance.

## REFERENCES


[1] W. Mack grady, S. Santoso, “Understanding power system harmonics,” *IEEE power Eng*. Rev. 21(November (11)), pp. 8-11, 2001.

[2] Garima Sinha, Pankaj kumar Goswami, Sudhir kr. Sharma, “Harmonic Mitigation for Non-Linear Load using TSH Active Power Filter with PID Controller,” *International Journal of Applied Power Engineering (IJAPE)*, ISSN: 2252-8792, vol. 7, no. 2, pp. 159-165, 2018.

[3] K. G. Firouzjah, A. Sheikholeslam, “A High Performance Technique in Harmonic Omitting Based on Predictive Current Control of a Shunt Active Power Filter,” *International Journal of Electrical and Computer Engineering*, vol. 3, no. 16, 2008.

[4] B. Singh, A. Chandra, and K. Al-Haddad, “Computer-aided modeling and simulation of active power filters,” *Elect, Mach.power Syst*., vol. 27, pp. 1227-1241, 1999.

[5] T. Rajesh, S. Aravindhan, M. Sowmiya, S. Thenmozhi, “Design of Shunt Active Filter for Reduction of Harmonics,” *International Journal of Engineering Science and Computing*, 2016.

[6] Moh. Jauhari, Dedet Candra Riawan, Mochamad Ashari, “Control Design For Shunt Active Power Filter Based On p-q Theory In Photovoltaic Grid-Connected System,” *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 9, no. 3, pp. 1064-1071, 2018.

[7] Y. Kusuma Latha, Ch. Saibabu, Y. P. Obulesh, “Control Strategy for Three Phase Shunt Active Power Filter with Minimum Current Measurements,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 1, no. 1, pp. 31-42, 2011.

[8] J. Rodriguez, M. P. Kazmierkowski, J. R. Espinoza, P Zanchetta, H Abu-Rub, H. A. Young, and C. A. Rojas, “State of the Art of Finite Control Set Model Predictive Control in Power Electronics,” *IEEE Transactions on Industrial Informatics*, vol. 9, no. 2, pp. 1003-1016, 2013.

[9] A. Fahmy, M. S. Hamad, A. K. Abdelsalam and A. Lotfy, “Power quality improvement in three-phase four-wire system using a shunt APF with predictive current control,” *IECON 2012-38th Annual Conference on IEEE Industrial Electronics Society*, Montreal, QC, pp. 668-673, 2012. doi: 10.1109/IECON.2012.6388748.

[10] Anjali Krishna R and Dr L Padma Suresh, “A Brief Review on Multi Level Inverter Topologies,” *International Conference on Circuit, Power and Computing Technologies*, 2016.

[11] E. Babaei and S. H. Hosseini, “New cascaded multilevel inverter topology with minimum number of switches,” *J. Energy Convers. Manag*. vol. 50, no. 11, pp. 2761-2767, 2009.

[12] Sanjeevikumar P., “Analysis and Implementation of Multiphase Multilevel Inverter for OpenWinding Loads,” *University of Bologna*, Italy, 2012.

[13] McGrath, Brendan Peter, Donald Grahame Holmes, “Multicarrier PWM strategies for multilevel inverters,” *Industrial Electronics, IEEE Transactions on*., vol. 49, no. 4, pp. 858-867, 2002.

[14] Keith C., “Operation and design of multilevel inverters,” *Developed for the office of naval research*, pp. 1-79, 2003.

[15] Rueger Niklas E., Kuhn H., Mertens A., “Harmonic distortion of multicarrier PWM strategies in cascaded multilevel converters with unequal DC sources. Power Electronics and Applications,” *European Conference on IEEE*, 2007.

[16] Mohd Ruddin Ab Ghani, Nabil Farah, Jurifa Lazi, M.R.Tamjis, Md Nazri Othman, Nur Huda Mohd Amin, Syariffah Othman, Zanariah Jano, Tole Sutikno, “Investigation Study of Three-Level Cascaded H-bridge Multilevel Inverter,” *TELKOMNIKA*, vol.15, no.1, pp. 125-137, 2017.

[17] Parkash Aman, Shimi SL, Chatterji S, “Harmonics Elimination in Cascade Multilevel Inverters Using Newton-Raphson and Genetic Algorithm,” *International Journal for Scientific Research & Development (IJSRD)*, pp. 236-239, 2014.

[18] N. A Azli, Member IEEE and Y. C. Choong, “Analysis on the Performance of a Three-phase Cascaded H-Bridge Multilevel Inverter,” *First International Power and Energy Coference*, November 28-29, Putrajaya, Malaysia, 2006.

[19] C. A. Rojas, J. Rodriguez, F. Villarroel, J. R. Espinoza, “Predictive torque and control without weighting factors,” *IEEE Transactions on Industrial Electronics*, vol. 60, no. 2, pp. 681-690, 2013.

[20] S. Vazquez, J. Leon, L. Franquelo, J. Rodriguez, H. Young, A. Marquez, and P. Zanchetta, “Model predictive control: A review of its applications in power electronics,” *IEEE Industrial Electronics Magazine*, vol. 8, no. 1, pp. 1631, 2014.

[21] R. Panigrahi, Bidyadhar Subudhi, Prafulla Chandra Panda, “Model predictive-based shunt active power filter with a new reference current estimation strategy,” *IET Power Electronics*, vol. 8, no. 2, pp. 221-233, 2015.

[22] J. Rodriguez, et al., “Commande Prédictive current control of a voltage source inverte,” *IEEE transaction on industrial electronics*, vol. 54, no. 1, 2007.

[23] Atif Iqbal, Shaikh Moinoddin, Khaliqur Rahman, “Finite State Predictive Current and Common Mode Voltage Control of a Seven-phase Voltage Source Inverter,” *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 6, no. 3, pp. 459-476, 2015.

[24] S. Vazquez, C. Montero, C. Bordons, and L. Franquelo, “Model predictive control of a VSI with long prediction horizon,” in *IEEE International Symposium on Industrial Electronics (ISIE)*, pp. 1805-1810, 2011.

[25] S. Kouro, P. Cortés, R. Vargas, U. Ammann, and J. Rodríguez, “Model predictive control-a simple and powerful method to control power converters,” *IEEE Transactions on Industrial Electronics*, vol. 56, no. 6, pp. 1826-1838, 2009.