ISSN:2716-9227 Algerian Journal of Engineering and Technology 08 (2023) 094–100 e-ISSN: 2716-9278

Algerian Journal of Engineering and Technology

Journal homepage: https://jetjournal.org/index.php/ajet

Original Article

# Power quality improvement using series APF based on multi-level (NPC) inverter topologies with intelligent control approaches

Chennai Salim

*Electrical Engineering Department, CRNB, Aïn-Oussera, B.P.O. 180, 17200 Algeria*

---

**ARTICLE INFO**

*Article history:*
Received 25 November 2022
Revised 06 April 2023
Accepted 23 April 2023

*Keywords:*
Series active power filter;
Five-level (npc) inverter;
Voltage disturbances compensation;
Fuzzy logic control;
Power quality improvement.

**ABSTRACT**

This paper presents the performance of novel configuration of series active power filter (Series APF) based on five-level neutral point clamped (NPC) using modified instantaneous reactive power theory control strategy with fuzzy control scheme. The series filter is adopted to decrease voltage harmonics, compensate all voltage disturbances and regulate the terminal voltage of the load. The series APF injects a voltage component in series with supply voltage which is added or subtracted from the source voltage thus maintaining the load side waveforms as pure sinusoidal. Multi-level inverters are currently being investigated and used in various industrial applications. Five-level (NPC) inverter topology is one of the most converters employed in medium and high power applications, their advantages include the capability to reduce the harmonic content and decrease the voltage or current ratings of the semiconductors. On the other hand intelligent techniques know today a great use, due to the advantages that offers compared to conventional techniques. To benefit of these advantages efficient control scheme for series APF using this techniques is proposed in this work. The fuzzy voltage controller is designed to improve compensation capability of series active power filter by adjusting the voltage error using a fuzzy rule. The simulation is performed using MATLAB-Simulink and SimPowerSystem Toolbox. The performance in steady and transient states show the efficiency and the simplicity of the proposed control scheme based on modified p-q control strategy. Before compensation the source voltage is much distorted with high THDv value equal to 46.93%. After compensation using proposed Series APF the THDv is reduced to 3.57% in conformity with 519-IEEE standard norms.

---

## 1. Introduction

The proliferation of nonlinear loads such as static power converters results in various undesirable phenomena in the operation of power systems, harmonic pollution is being considered as one of the major problems that degrade the power quality [1]. To improve the power quality, some solutions have been proposed by several authors. Among them the shunt and series active power filters have proven as an important and flexible alternative to compensate most important voltage and current related power quality problems in the distribution system [2]. The series APFs have been proposed as an interesting and high performance solution to compensate most important voltage disturbances [3]. The Series APF is specially used to compensate unbalances, sags, swells and harmonics [4]; it is inserted in series between the load and the source voltage and injects a compensating voltage.

Several multilevel inverter topologies are being used for shunt or series active filter applications, but some practical problems like power circuit packaging, switching circuit complexity and dynamic voltage stress have restricted the number of inverter levels to 3 or 5 [5].

The controller is the most important part of any active power filter and has been a subject of many researches in recent years [6]; for improving the performances there's a great tendency to use intelligent control techniques particulary artificial neural natwork, fuzzy logic, expert system and various other optimization methods [7]. These techniques permit to solve system complexity and make control more robust for transient conditions. Fuzzy logic control (FLC) is one of the significant tools in control

---

* *Corresponding author*.Tel.: 0793969461
E-mail address: chenaisalimov@yahoo.fr

Peer review under responsibility of University of El Oued.

DOI: https://doi.org/10.57056/ajet.v8i1.96

design originated by Zadeh. Their advantages compared to conventional controllers are robustness, insensitivity to parameters variations, handling of non-linearity and independent on mathematical models.

The investigation in this paper concentrates on the fuzzy control techniques adopted for Series APF using five-level (NPC) inverter to compensate all voltage disturbances. The performance of the proposed series APF is evaluated using Matlab-Simulink and SimPowerSystem Toolbox under different voltage disturbances.

## 2. Series APF system

Figure (1) shows the proposed series APF, it is inserted between the disturbance voltage source and non-linear loads. Lf and Cf are inductance and capacitance of passive filter used to suppress switching ripples. The three transformers are used to inject the compensating voltages.

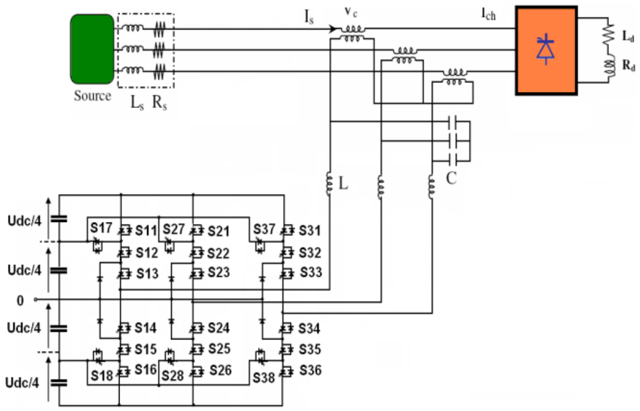


Fig. 1 Series active power filters with five-level (npc) inverter topology.

## 3. Multi-level inverters

In recent years, multilevel converters have shown some significant advantages compared to conventional voltage source inverters (VSIs) [8] especially for high-power and high-voltage applications. Diode clamped Multi-level inverter is the most important topology adopted when high number of output voltage levels are required [9] and five-level inverter topology is the most popular converters employed in medium power applications. In addition to their superior output voltage quality, they can reduce voltage stress across switching devices with lower dv/dt. In general, the more voltage levels of converter has the less harmonic and better power quality. However, the increase in converter complexity and number of switching devices need a complex logic control for switching pulses generation [10]. In case of five-level (NPC) inverter shown in Fig. 2, the DC bus capacitor is split into four, providing a three neutral-point. Each arm of the inverter is made up of eight Insulated Gate Bipolar Transistor (IGBTs) devices. The clamping diodes connected to the neutral-point are used to create the connection with the point of reference to obtain midpoint voltages. This structure allows the switches to endure larger dc voltage input on the premise that the switches will not raise the level of their withstand voltage. For this structure, five output voltage levels can be obtained, namely, Udc/2, Udc/4, 0, -Udc/4 and -Udc/2 corresponding to five switching states given by Table (1) [11, 12].

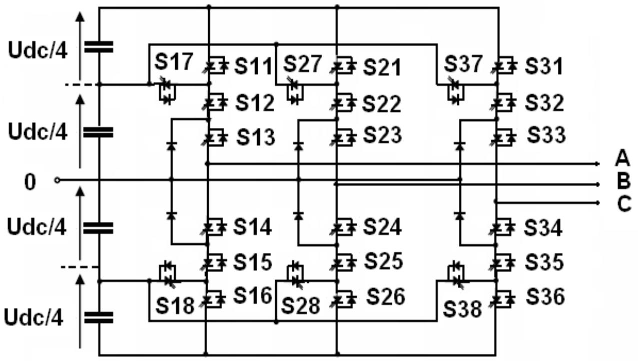


Fig. 2 Five-level (npc) inverter.

Table 1. Switch states of five-level (npc) inverter.

| | Si | A | B | 0 | C | D |
|---|---|---|---|---|---|---|
| **Switching States** | S1 | 1 | 1 | 1 | 1 | 0 |
| | S2 | 1 | 1 | 0 | 0 | 0 |
| | S3 | 1 | 0 | 0 | 0 | 0 |
| | S4 | 0 | 0 | 1 | 1 | 1 |
| | S5 | 0 | 0 | 0 | 1 | 1 |
| | S6 | 0 | 1 | 1 | 0 | 1 |
| | S7 | 0 | 1 | 0 | 0 | 0 |
| | S8 | 0 | 0 | 0 | 1 | 0 |
| **Output voltages** | | Udc1+ Udc2 | +Udc1 | 0 | - Udc3 | - (Udc3 + Udc4) |

To control multilevel inverters, different modulation methods are possible: sinusoidal pulse width modulation (SPWM), selective harmonic elimination (SHE-PWM), space vector modulation (SVM) etc. These methods can be c1assified according to switching frequencies used [13]. In case of multi-level inverters using SPWM techniques various multi-carrier techniques have been developed. In SPWM modulation technique a sinusoidal reference wave is compared with triangular carrier waveform to generate gate pulses for switches of inverter. This traditional PWM technique can be applied to multi-level inverter topologies by using multiple carriers.

## 4. Phase shift modulation

Voltage shifted modulation is way based on the carrier modulation. the carrier number is (m-1) when m is level number of the diode clamped inverter used. All of these carriers have the same frequency and the same amplitude. This (m-1) a triangular carrier in the space is distributed vertically, and the occupied area is continuous, with each other closely connected, symmetrically distributed on the horizontal axis on both sides, and then with a sinusoidal modulation wave is compared, to generate a trigger pulse

[14]. For the three-phase converters configuration the PD-PWM is much better than POD-PWM and APOD-PWM in the aspects of waveform shape and THD of the output line voltages [15]. Hence, this work adopts the PD-PWM to modulate the 5-level (NPC) inverter. Fig. 3 shows the principle of PD shifted voltage modulation in case of five-level inverter topology.

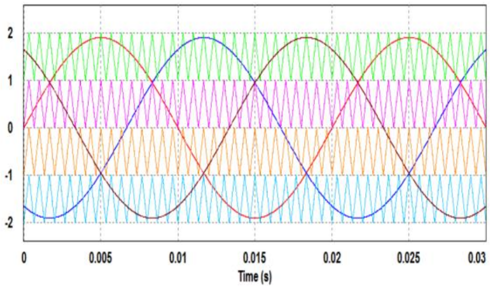


Fig. 3 Waveforms of phase disposition shifted pulse width modulation (PD-SPWM).

## 5. Control strategies

The control strategy is basically the way to generate reference signals for series APFs. The compensation effectiveness of the Series APF depends on its ability to follow with a minimum error and time delay the reference signals to compensate the distortions, unbalanced voltages or currents or any other undesirable condition [16]. When the three-phase load instantaneous voltages $U_{Lu}$, $U_{Lv}$, $U_{Lw}$ and currents $i_{Lu}$, $i_{Lv}$, $i_{Lw}$ are transformed into two-phase (α–β) coordinates. The two phase voltages $u_\alpha$, $u_\beta$ and currents $i_\alpha$, $i_\beta$ are respectively given by [17]:

$$\begin{bmatrix} U_{s\alpha} \\ U_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} U_{Lu} \\ U_{Lv} \\ U_{Lw} \end{bmatrix} = C_{32} \begin{bmatrix} U_{Lu} \\ U_{Lv} \\ U_{Lw} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Lu} \\ i_{Lv} \\ i_{Lw} \end{bmatrix} = C_{32} \begin{bmatrix} i_{Lu} \\ i_{Lv} \\ i_{Lw} \end{bmatrix} \tag{2}$$

On the (α–β) plane, $u$ can be considered to be composed of $u_\alpha$ and $u_\beta$, $i$ of $i_\alpha$ and $i_\beta$:

$$\begin{aligned} u &= u_\alpha + u_\beta \\ i &= i_\alpha + i_\beta \end{aligned} \tag{3}$$

Assume that $u_p$ is the projection of $u$ in the direction of $i$ and $u_q$ the projection of $u$ in the vertical direction of $i$; $u_p$ and $u_q$ can be represented by:

$$\begin{bmatrix} U_p \\ U_q \end{bmatrix} = \begin{bmatrix} \sin(\omega t) & -\cos(\omega t) \\ -\cos(\omega t) & -\sin(\omega t) \end{bmatrix} \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} U_{Lu} \\ U_{Lv} \\ U_{Lw} \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} U_p \\ U_q \end{bmatrix} = C_{pq} C_{32} \begin{bmatrix} U_{Lu} \\ U_{Lv} \\ U_{Lw} \end{bmatrix}$$

$C_{pq}$ is the p-q transformation matrix, which executes the calculation to convert the two-phase voltages $u_{s\alpha}$ and $u_{s\beta}$ into $u_p$ and $u_q$. $U_{Lu}$, $U_{Lv}$, $U_{Lw}$ are the three-phase voltage source, the respective components $\overline{u_p}$ and $\overline{u_q}$ in $u_p$ and $u_q$ are corresponding to the positive sequence fundamental active and reactive components in three-phase voltages.

The fundamental components $U_{Luf}$, $U_{Lvf}$, $U_{Lwf}$ can be obtained by an inverse transformation:

$$\begin{bmatrix} U_{Luf} \\ U_{Lvf} \\ U_{Lwf} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \sin(\omega t) & -\cos(\omega t) \\ -\cos(\omega t) & -\sin(\omega t) \end{bmatrix} \begin{bmatrix} \overline{U_p} \\ \overline{U_q} \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} U_{Luf} \\ U_{Lvf} \\ U_{Lwf} \end{bmatrix} = C_{23} C^{-1}{}_{pq} \begin{bmatrix} \overline{U_p} \\ \overline{U_q} \end{bmatrix}$$

$C^{1}{}_{pq}$ is the inverse matrix of $C_{pq}$, which executes the calculation to convert up and uq back into (α–β) coordinates.

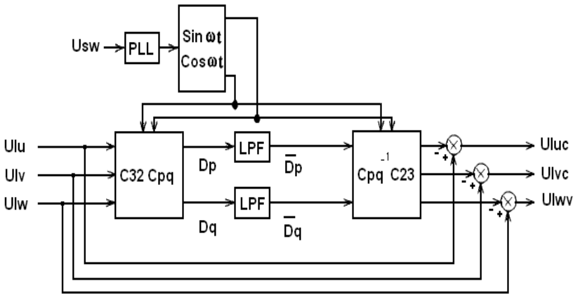


Fig. 4 Control strategies based on modified p-q.

## 6. Series APF Control

Artificial intelligence is one of the key areas to solve such system complexity and make control more robust for transient conditions. Neural network, fuzzy logic, expert system, various other optimization methods are used for the improvement of power quality [18, 19]. Fuzzy logic control (FLC) is one of the significant tools in control design originated by Zadeh [20]. The advantages of FLC over conventional controllers are high robustness, insensitivity to parameters variations, handling of non-linearity and independent on mathematical models. To benefit of these advantages a FLC is proposed to control the Series APF. It is designed to improve compensation capability by adjusting the voltage error using fuzzy rules stored in the knowledge base. The desired inverter switching signals are determined according to the error between the compensate voltages and reference voltages. In this case, the fuzzy logic voltage controller has two inputs, error e and change of error de and one output s [21, 22]. To convert it into linguistic variable, we use seven fuzzy sets: NL (Negative Large), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium) and PL (Positive Large). The membership functions used in fuzzification and defuzzification are shown in Fig. 5.

Triangles or triangular membership function (TMF) have been frequently used in several applications of FLC. TMF are preferred due to simplicity, easy implementation, symmetrical along the axis. The number of linguistic variables is directly related to the accuracy of approximating function and plays an important role for input-output mapping.

The fuzzy controller for every phase is characterized for the following:

- Seven fuzzy sets for each input,
- Seven fuzzy sets for output,
- Triangular and trapezoidal membership function for the inputs and output,
- Implication using the “min” operator,
- Mamdani fuzzy inference mechanism based on fuzzy implication,
- Defuzzification using the “centroid” method.

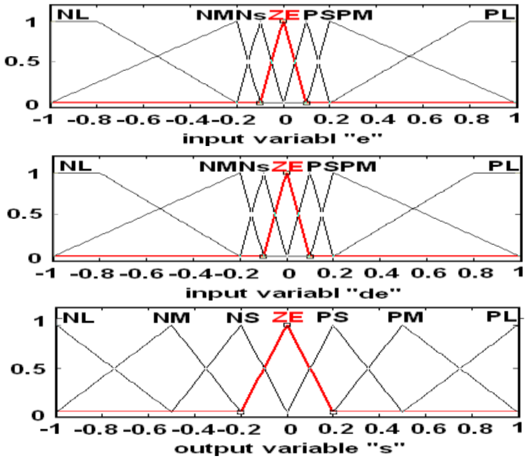


Fig. 5 Membership functions.

The modulation Errors for each phase is discretized by the zero order hold blocks. The error rate is the derivative of the error and it is obtained by the use of unit delay block. The saturation block imposes upper and lower bounds on a signal. When the input signal is within the range specified by the lower limit and upper limit parameters, the input signal passes through unchanged. When the input signal is outside these bounds, the signal is clipped to the upper or lower bound. The outputs of the saturation blocks are inputs of fuzzy logic controllers [23]. The outputs of these fuzzy logic controllers are used in generation of pulses switching signals of the five-level (npc) inverter. The switching signals $S_{13}$, $S_{16}$, $S_{23}$, $S_{26}$, $S_{33}$ and $S_{36}$ are generated by means of comparing a four carrier signals $D_{s1}$, $D_{s2}$, $D_{s3}$ and $D_{s4}$ with the output of the fuzzy logic controller. The Simulink model of the fuzzy logic switching signals generation is given by Fig. 6.

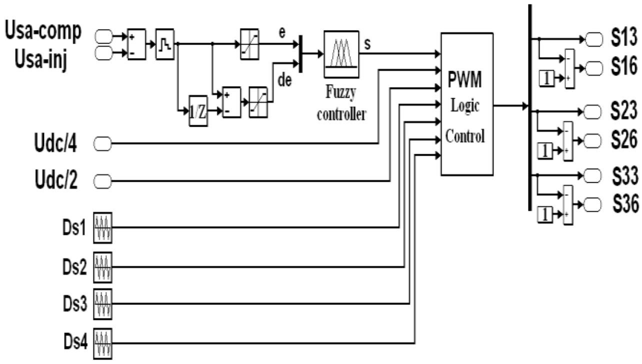


Fig. 6 Series APF switching signals generation.

The difference between the injected voltages and the compensate voltages determines the reference signal control. These signals are compared with four triangular-carrying identical waves shifted from one to the other by a ($+U_{pm}$, $-U_{pm}$ and $-2U_{pm}$) and generating switching pulses.

Determination of the intermediate signals $V_{K1}$ and $V_{K0}$:

- If error $E_c \geq$ carrying 1 Then $V_{k11}=U_{dc}/4$,
- If error $E_c <$ carrying 1 Then $V_{K11}=0$,
- If error $E_c \geq$ carrying 2 Then $V_{K12}=U_{dc}/4$,
- If error $E_c <$ carrying 2 Then $V_{K12}=0$.
- If error $E_c \geq$ carrying 3 Then $V_{K10}=0$,
- If error $E_c <$ carrying 3 Then $V_{K01}= -U_{dc}/4$,
- If error $E_c \geq$ carrying 4 Then $V_{K02}=0$,
- If error $E_c <$ carrying 4 Then $V_{K02}=-U_{dc}/4$,

With: $V_{K1}= V_{k11}+ V_{K12}$ and $V_{K0}= V_{K01}+ V_{K02}$

Determination of control signals of the switches $T_{ij}$ (i=1, 2, 3; j=1, 2, 3):

- If $(V_{K1}+V_{K0})= +U_{dc}/2$ Then $T_{i1}=1$, $T_{i2}=1$, $T_{i3}=0$,
- If $(V_{K1}+V_{K0})= +U_{dc}/4$ Then $T_{i1}=1$, $T_{i2}=1$, $T_{i3}=0$,
- If $(V_{K1}+V_{K0})= 0$ Then $T_{i1}=1$, $T_{i2}=0$, $T_{i3}=0$,
- If $(V_{K1}+V_{K0})= -U_{dc}/4$ Then $T_{i1}=0$, $T_{i2}=0$, $T_{i3}=1$,
- If $(V_{K1}+V_{K0})= -U_{dc}/2$ Then $T_{i1}=0$, $T_{i2}=0$, $T_{i3}=0$,

The Simulink model of the logic control designed for five-level (NPC) inverter is shown in Fig. 7.

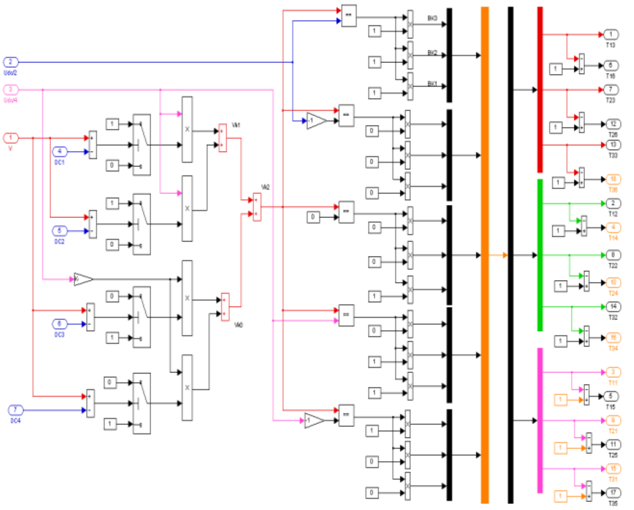


Fig. 7 Five-level (npc) inverter logic control.

## 7. Simulation results and discussion

SimPowerSystems is the Toolbox of Matlab-Simulink that operates in Simulink environment. It consists of electrical power circuits and electromechanical devices. It is developed to simulate electrical drive, power electronics and electrical power systems. The series APF model based on fuzzy voltage controller is shown in Fig. 8. It is designed and performed under MATLAB-Simulink and SimPowerSystem environment.

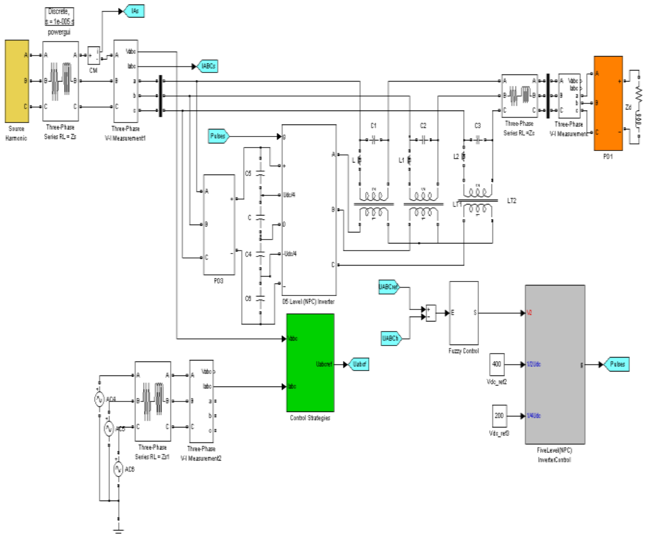
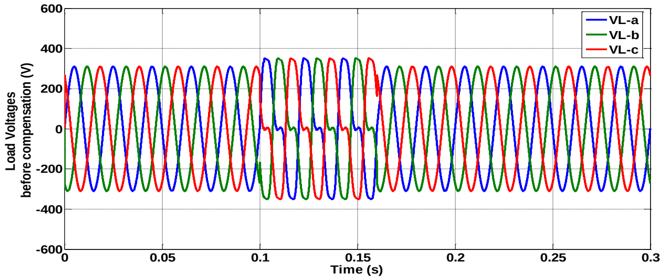
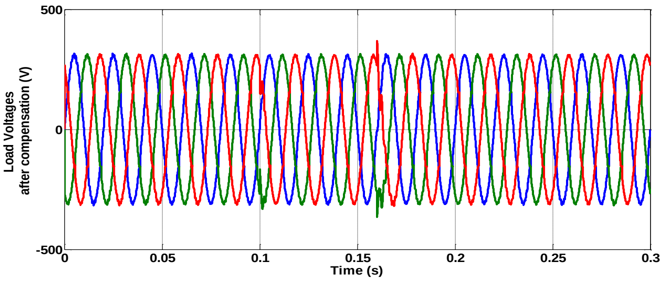


Fig. 8 Five-level (npc) series APF block diagram.

At time t1=0.1sec to t2=0.16sec, harmonic voltage disturbances is introduced voluntarily in the utility. The series APF is put into operation and starts instantly the process of compensation. The load voltage before series active filter operation and the three-phase compensated voltages delivered to sensible load are shown in Fig. 9.



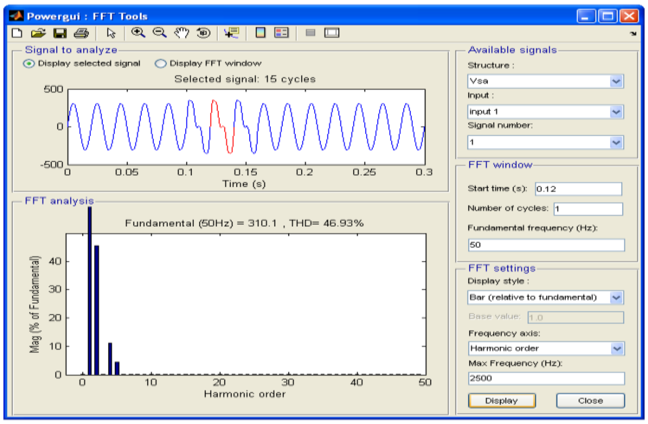
(a) Load voltages without Series APF



(b) Load voltages after compensation with Series APF

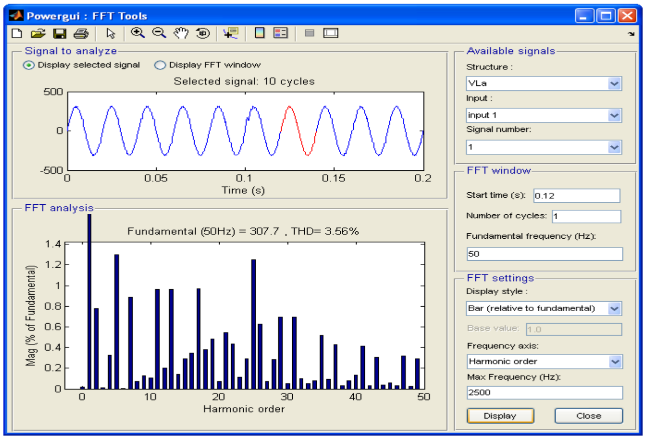
Fig. 9 Simulation results using Series APF for harmonic disturbances compensation.

Figures 10 and 11 presents the voltage harmonic spectruim before and after compensation. The THDv (%) is reduced from 46.93% to 3.56% using p-q control strategies and to 3.57% using proposed modified p-q method in conformity with 519-IEEE standard norms.



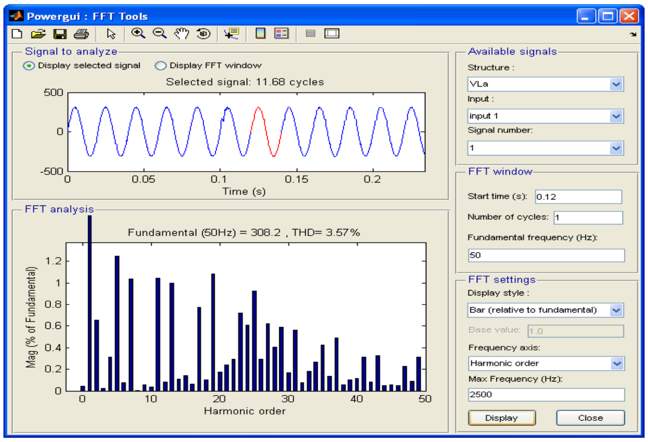
● Display selected signal ○ Display FFT window
Selected signal: 15 cycles
Fundamental (50Hz) = 310.1 , THD= 46.93%
Structure : Vsa
Input : input 1
Signal number: 1
Start time (s): 0.12
Number of cycles: 1
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order
Max Frequency (Hz): 2500

Fig. 10 Load voltage harmonic spectrum without Series APF: THDv=46.93%.



● Display selected signal ○ Display FFT window
Selected signal: 10 cycles
Fundamental (50Hz) = 307.7 , THD= 3.56%
Structure : VLa
Input : input 1
Signal number: 1
Start time (s): 0.12
Number of cycles: 1
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order
Max Frequency (Hz): 2500

(a) p-q control strategies : Fundamental (50Hz) = 307.7: THDv(%)=3.56%

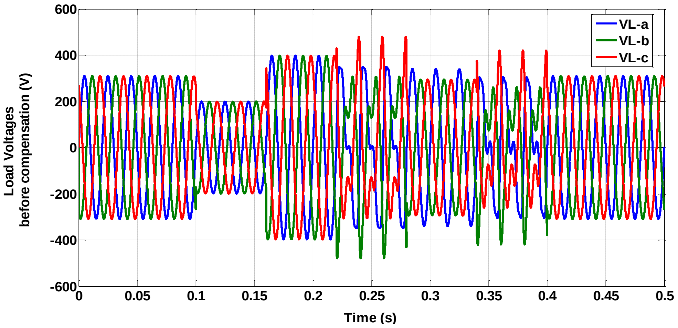


● Display selected signal ○ Display FFT window
Selected signal: 11.68 cycles
Fundamental (50Hz) = 308.2 , THD= 3.57%
Structure : VLa
Input : input 1
Signal number: 1
Start time (s): 0.12
Number of cycles: 1
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order
Max Frequency (Hz): 2500

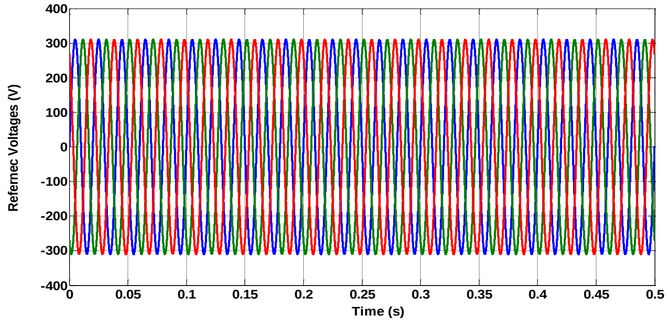
(b) Modified p-q control strategies : Fundamental (50Hz) = 308.2: THDv(%)=3.57%

Fig. 11 Load voltage harmonic spectrum after compensation.

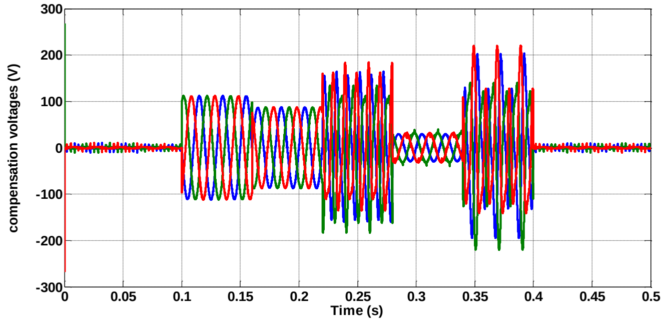
The performance of the proposed Series APF system is also tested under all voltage disturbances introduced simultaneously. The simulation results are shown in Fig. 12.



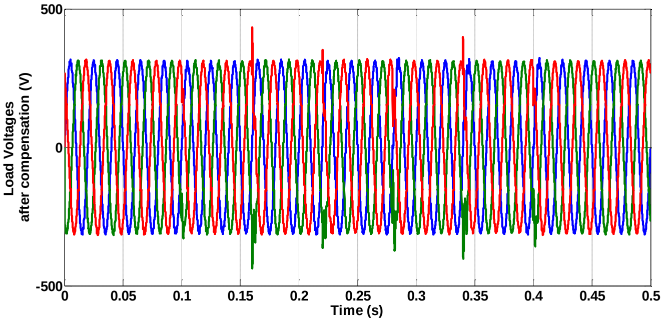
(a) Load voltages before compensation VL-a,b,c (V)



(b) Reference voltages Uabc-ref (V)



(c) Compensation voltages Uabc-comp (V)



(d) Load voltages after compensation UL-abc (V)

Fig. 12 Simulation results using Series APF for all voltage disturbances compensation.

The performance of the proposed series APF system is tested under all voltage disturbances introduced simultaneously: harmonics, swells, sags and unbalances. Figures (10) and (11) show respectively the harmonic spectrum of the voltage delivered to sensitive loads before and after application of the proposed series APF.

It is observed that the load voltage harmonics are widely reduced in conformity with IEEE-519 standard norms from 46.93% to 3.57% using modified p-q control strategies. It is shown in Fig. 12; that after introducing voluntarily the voltage swell (35%), voltage sag (30%) or unbalances in the supply voltage, the load voltage is instantly compensated.

The effectiveness of the proposed series active filter has been demonstrated in maintaining the three-phase load voltages balanced and sinusoidal, moreover the proposed system does not show any disturbance significant effect present in the utility voltages on its compensation capability and the load voltage is maintained constant and sinusoidal under all voltage disturbances.

## 8. Conclusion

To enhance the power quality and improve the voltage delivered to sensitive loads a series APF based on five-level (npc) inverter topologies using fuzzy control techniques has been proposed in this paper.

The most voltage disturbances studied concern voltage harmonics, sags, swells and unbalances, all these disturbances are successfully compensated using the proposed system. The load voltage harmonic levels are maintained below IEEE-519 standard Norms when the source voltage is distorted, the THDv (%) is significantly reduced from 46.93% to 3.57% based on modified instantaneous reactive power theory with fuzzy control approaches. This method is simpler to implement and give good performances compared to other control methods used for a series filter. The simulation results show that the proposed series APF is efficient and compensates effectively the voltage harmonics and all voltage disturbances instantly in conformity with the international IEEE 519-1992 standards norms.

## Acknowledgements

This work was supported by the Electrical Engineering Department of Birine Nuclear Research Center-Algeria, under the scientific Programme [Contribution project: Power energy quality improvement-Federator Program].

## Conflict of Interest

The authors declare that they have no conflict of interest.

## References

1. Honghao Z, Pingping C, Zhengyu L, Zhaoming Q. Novel control scheme based on per-phase reference current calculation for hybrid series active power filter with fundamental current bypass channel in unbalanced conditions. *35th Annual Power Electronics Specialists Conference*, 2004. PESC 04. 2, 2004: 999-1002.
2. Tandjaoui M-N, Kechich A, Benoudfafer C and Habib M. Power quality improvement through unified power quality conditioner UPQC. *Electrotechnica, Electronica, Automatica (EEA)*. 61; 2, 2013: 39-44.
3. Hamadi A, Rahmani S, Al-Haddad K. A new hybrid series active filter configuration to compensate voltage sag, swell, voltage and current harmonics and reactive power. *IEEE International Symposium on Industrial Electronics*, 2009. *ISIE* 2009. 2009: 286-291.
4. Chennai S, Benchouia M-T. Simplified Control Scheme of Unified Power Quality Conditioner based on Three-phase Three-level (NPC) inverter to Mitigate Current Source Harmonics and Compensate All Voltage Disturbances. *Journal of Electrical Engineering & Technology, JEET (KIEE*), 8; 3, 2013: 544-558.
5. Chennai S. Three-level neutral point clamped shunt active power filter performances using intelligent controllers. *Revue Romaine des Sciences Techniques, Série Electrotechnique et Energétique, (RRST)*, 59; 3, 2014: 303-313.
6. Chennai S, and Benchouia M-T. Three-phase Three-level (NPC) Shunt Active Power Filter Performances based on PWM and ANN's Controllers for Harmonic Current Compensation. International *Journal on Electrical Engineering and Informatics, IJEEI*, 6;1, 2014: 213-234.
7. Guiying L, ShiPing S, Peng P. Intelligent Control and Application of All-Function Active Power Filter. *International Conference on Intelligent Computation Technology and Automation (ICICTA)*, 2008, 1, 2008: 1078-1081.
8. Chavali P-S. Ramana Rao P-V. Uma Vani M. A novel multilevel inverter with reduced number of switches using simplified PWM technique, *Springer, J. Inst. Eng. India Ser. B*, 101; 3, 2020: 203-216.
9. Satish Kumar P, Satyanarayana M. Comparative Analysis of Modulation Strategies Applied to Seven-Level Diode Clamped Multi-Level Inverter Fed Induction Motor Drive, *2015 Conference on Power, Control, Communication and Computational Technologies for Sustainable Growth (PCCCTSG)*, India, 2015: 231-237.
10. Chaturvedi P-K. Shailendra J. Agrawal P. A study of neutral point potential and common mode voltage control in multilevel SPWM technique, Fifteenth National Systems conference, 2008: 518-523.
11. Benslimane T. Open switch faults detection and localization in three phase shunt active power filter. Rev. Roum. Sci. Techn. – Électrotechn. et Énerg. 52; 3, 2007: 359-370.
12. Ozdemir S, Ozdemir E, Leon M-T, Surin K. Elimination of harmonics in a five-level diode-clamped multilevel inverter using fundamental modulation. PEDS, IEEE, 2007: 850-854.
13. Aparna P, Sanjay B. A Comparative analysis of classical three phase multilevel (five-level) inverter topologies. *1st IEEE International Conference on Power Electronics. Intelligent Control and Energy Systems (ICPEICES*), *IEEE*, 2016: 1-5.
14. Hongtao J. Yinghong L. Yuheng F. Shengxiong P. Improved carrier phase shift modulation and voltage equalization control strategy in modular multilevel converter, *Archives of Electrical Engineering*, 68; 4, 2019: 803-815.
15. Yuanmao Y, Guoxin Z, J inliang H, Shikai C, Xiaolin W. Comparative analysis of hybrid NPP and NPC seven-level inverter with switched-capacitor. *IEEE*, 9, 2021: 85852-85863
16. Khadkikar V, Chandra A, Barry A, Nguyen T-D. Application of UPQC to protect a sensitive load on a polluted distribution network. *IEEE Power Engineering Society General Meeting*. Montreal, 2006.
17. Hamadi A, Rahmani S, Al-Haddad K. A Novel Hybrid Series Active Filter for Power Quality Compensation. Power Electronics Specialists Conference, 2007. *PESC 2007. IEEE*. 2007: 1099-1104.
18. Chennai S. Five-level (NPC) shunt active power filter performances evaluation using fuzzy control scheme for harmonic currents compensation. IEEE, *6th International Conference on Systems and Control, ICSC'2017*, 07-09 May 2017, Batna, Algeria.
19. Tsengenes G, Adamidis G. Shunt active power filter control using fuzzy logic controllers. *International Symposium on Industrial Electronics (ISIE), 2011 IEEE*, 2011: 365-371.
20. Belaidi R, Haddouche A, Guendouz H. Fuzzy logic controller based three-phase shunt active power filter for compensating harmonics and reactive power under unbalanced mains voltages. *Elsivier*, 2012: 560-570.
21. Chennai S. Power quality improvement using three-level neural point clamped universal conditioner for all voltage disturbances compensation. *Revue Romaine des Sciences Techniques, Série Electrotechnique et Energétique, (RRST)*, June,.61; 2, 2016: 188-193.
22. Chennai S. Steady and dynamic performances evaluation of three-level shunt active power filter for power quality improvement. *Electrotehnica, Electronica, Automatica. (EEA)*, 64;4, 2016: 76-82.
23. Chennai S. Efficient control scheme for five-level shunt active power filter to enhance the power quality. *Electrotehnica, Electronica, Automatica. (EEA)*, 2016, 64;1:124-129.

## Recommended Citation

Chennai S. Power quality improvement using series APF based on multi-level (NPC) inverter topologies with intelligent control approaches. *Alger. J. Eng. Technol. 2023*;8(1):94-100. DOI: https://doi.org/10.57056/ajet.v8i1.96