Using Five-Level Inverter NPC Topology for Harmonic Compensation of Electric Low-Voltage

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Abstract - The objective of this paper is to improve the quality of the energy transfer from the power supply to the load, and to reduce the harmful effects of the harmonic generated by non-linear loads. In this paper, the problem of the degradation of the current in the installations electric is imposed, which ensues directly from the proliferation of the non-linear loads, to resolve it; a five levels inverter with Neutral Point Clamping (NPC) structure is used as Active Power Filter shunt (APFs). The compensation process is based on concept of P-Q Algorithm. it provides effective compensation for harmonics.

Keywords - NPC topology; SPWM four carriers; Active Power Filter Shunt (APFs); THD

1. INTRODUCTION

The increasing use of control systems based on power electronics in industry involves more and more disturbance problems in the level of the electrical power supply networks [1-2].

Non-linear electronic components such as diode/thyristor rectifiers, switched mode power supplies, arc furnaces, incandescent lighting and motor drives are widely used in industrial and commercial applications. These non-linear loads create harmonic or distortion current problems in the transmission and distribution network [3]. The harmonics induce malfunctions in sensitive equipment, over voltage by resonance and harmonic voltage drop across the network impedance that affect power quality [4-5].

Traditionally passive LC filters have been used to compensate the harmonic distortion and the reactive power; but passive filters are large in size, have ageing and tuning problems and resonate with the supply impedance [6]. Recently Active Power Line Conditioners (APLC) or Active Power Filters (APF) overcome these problems and are designed for compensating the harmonics and suppressing the reactive power simultaneously [7]. Since basic principles of active filter compensation were proposed by Gyugyi and Strycula in 1976 [8]. In 1984, Hirofumi Akagi introduced a new concept of instantaneous reactive power (p-q theory) compensators [9]. It dealt with three-phase system, being later worked by Watanabe and Aredes for three-phase four wires power systems [10].

The shunt active power filter compensation process is based on the instantaneous real-power theory; it provides good compensation characteristics in steady state as well as transient states [11]. The instantaneous real-power theory generates the reference currents required to compensate the distorted line current harmonics and reactive power. It also tries to maintain the dc-bus voltage across the capacitor constant. Another important characteristic of this real-power theory is the simplicity of the calculations, which involves only algebraic calculation [12].

Multi-level inverters can operate not only with PWM techniques but also with amplitude modulation (AM), improving significantly the quality of the output voltage waveform. With the use of amplitude modulation, low frequency voltage harmonics are perfectly eliminated, generating almost perfect sinusoidal waveforms, with a THD lower than 5 %.

The first part consist on using Three-Phase Inverter a Five-Level NPC Topology, the second, method of instantaneous power where we see instantaneous active and reactive powers then apparent power, reactive power and distortion power, in third part an application of the five-level inverter with NPC structure on an Active Power Filter shunt (APFs) and finally exposing the simulation results using Matlab/Simulink.

2. MULTILEVEL INVERTER ILLUSTRATION

2.1. Schematic Diagram

Fig 1(a) shows a two level inverter. Fig 1(b) shows a three level inverter. Fig 1(c) shows N level inverter.

![Fig. 1. Schematic Diagram of (a) Two Level Inverter, (b) Three Level Inverter and (c) N Level Inverter.](image-url)
2.2. Modeling of Three-Phase Inverter a Five-Level NPC Topology

The topology modeled in this study is the voltage inverter three phase five-level topology NPC (Neutral Point Clamp) [13-14]. Fig. 2 shows the voltage three phase five-level NPC topology inverter. The symmetry of three-phase five-level inverters can model them by arm [15-16-17].

![Three-Phase Inverter a Five-Level NPC Topology](image)

To avoid short-circuit voltage sources by conducting several switches, and the inverter is completely controllable, we adopt an additional control, the optimal control is defined as follows:

\[
\begin{align*}
F_{k4} & = 1 - F_{k2} \\
F_{k5} & = 1 - F_{k1} \\
F_{k6} & = 1 - F_{k3}
\end{align*}
\]

(1)

For the arm k, the connection functions of half arm expressed by means of connection functions of the switches as follows where k = 1, 2, 3:

\[
\begin{align*}
F_{k4}^{m} & = F_{k4}F_{k5}F_{k6} \\
F_{k5}^{m} & = F_{k4}F_{k5}F_{k6} \\
F_{k6}^{m} & = F_{k4}F_{k5}F_{k6}
\end{align*}
\]

(2)

Connect functions for switches in parallel are defined as follows:

\[
\begin{align*}
F_{k5} & = F_{k1}F_{k2}(1 - F_{k3}) \\
F_{k6} & = F_{k4}F_{k5}(1 - F_{k6})
\end{align*}
\]

(3)

Potentials of nodes A, B and C of Three phase five-level inverter relatively to the middle point M in the case \(U_{C1} = U_{C2} = U_{C3} = U_{C4} = U\) are given by the following system:

\[
\begin{align*}
V_{sn} & = \left[ F_{11} + 2F_{13} - F_{12} - 2F_{16} \right] \\
V_{sm} & = \left[ F_{21} + 2F_{23} - F_{22} - 2F_{26} \right] \\
V_{cm} & = \left[ F_{31} + 2F_{33} - F_{32} - 2F_{36} \right]
\end{align*}
\]

(4)

The voltages across the load are given by the following system:

\[
\begin{align*}
V_{A} & = \frac{2 - 1 - 1}{3} \left[ F_{11} + 2F_{13} - F_{12} - 2F_{16} \right] \\
V_{B} & = \frac{2 - 1 - 1}{3} \left[ F_{21} + 2F_{23} - F_{22} - 2F_{26} \right] \\
V_{C} & = \frac{2 - 1 - 1}{3} \left[ F_{31} + 2F_{33} - F_{32} - 2F_{36} \right]
\end{align*}
\]

(5)

2.3. The four carriers sinusoidal pulse width modulation strategy

In this section we will present the strategy triangulo-sinusoidal with four triangular bipolar carriers [18-19] (Fig. 3). Where we use four triangular carriers bipolar \(U_{p1}, U_{p2}, U_{p3}, U_{p4}\) dephased one quarter of the period \(T/4\) one relative to another. As for the triangulo-sinusoidal command at a one carrier, this strategy is characterized by the modulation index \(m\).

\[
m = \frac{f_{m}}{f_{m}}
\]

(6)

\[
r = \frac{V_{m}}{U_{pm}}
\]

(7)

![Different signals for the four carriers sinusoidal pulse width modulation strategy](image)

3. METHOD OF INSTANTANEOUS POWER

3.1. Instantaneous active and reactive powers

This method of identification of harmonic currents, simpler is to eliminate the dc component of instantaneous active and reactive power which is relatively easy to achieve [20]. It operates processing Concordia to get active and reactive power and requires sinusoidal voltages at the fundamental frequency. Respectively denote the vectors of voltages at the connection point \(\{Vs\}\) and load currents \(\{ic\}\) a balanced three-phase system by [20-21-22]:

\[
\begin{align*}
\{Vs\} & = \left[ \begin{array}{c}
V_{va} \\
V_{vb} \\
V_{vc}
\end{array} \right] \\
\{ic\} & = \left[ \begin{array}{c}
i_{va} \\
i_{vb} \\
i_{vc}
\end{array} \right]
\end{align*}
\]

(8)
3.2. Apparent power, reactive power and distortion power [23]

Steady deformed, it must amend the definition of power so that it reflects the current harmonic:

\[ S = \sqrt{P^2 + Q^2 + D^2} \]  \hspace{1cm} (9)

We see that expression (9) a new term appears, it is the distortion power D. The following figure illustrates vectorially these powers:

![Vector representation of apparent power.](image)

In single phase, if the instantaneous voltage and current are expressed as:

\[ v(t) = \sqrt{V_{\text{eff}}} \sin(\omega t) \]
\[ i(t) = \sum_{n=1}^{\infty} \sqrt{I_{\text{neff}}} \sin(n\omega t + \varphi_n) \]  \hspace{1cm} (10)

This is the case for a strong network. Then we have:

\[ P = VI \cos(\varphi) \]  \hspace{1cm} (11)
\[ Q = V_{\text{eff}} I_{\text{eff}} \sin(\varphi) \]  \hspace{1cm} (12)
\[ S = V_{\text{eff}} I_{\text{eff}} \]  \hspace{1cm} (13)
\[ I_{\text{eff}} = \sqrt{I_{1\text{eff}}^2 + I_{2\text{eff}}^2 + I_{3\text{eff}}^2 + \ldots + I_{n\text{eff}}^2} \]  \hspace{1cm} (14)
\[ D = V \sqrt{I_{1\text{eff}}^2 + I_{2\text{eff}}^2 + I_{3\text{eff}}^2 + \ldots + I_{n\text{eff}}^2} \]  \hspace{1cm} (15)

The diagram in F Steady deformed, it must amend the definition of power so that it reflects the current harmonic. 2 illustrates the different steps to obtain the harmonic components of current non-linear load [24].

![‘P-Q’ Algorithm extraction of harmonic currents.](image)

4. ACTIVE POWER FILTERS

There are basically two types of active filters: the shunt type and the series type. It is possible to find active filters combined with passive filters as well as active filters of both types acting together.

Fig. 6 presents the electrical scheme of a shunt active filter for a three-phase power system with neutral wire, which is able to compensate for both current harmonics and power factor. Furthermore, it allows load balancing, eliminating the current in the neutral wire. The power stage is, basically, a voltage-source inverter with only a single capacitor in the DC side (the active filter does not require any internal power supply), controlled in a way that it acts like a current-source. From the measured values of the phase voltages (\(v_a, v_b, v_c\)) and load currents (\(i_a, i_b, i_c\)), the controller calculates the reference currents (\(i_a^*, i_b^*, i_c^*\)) used by the inverter to produce the compensation currents (\(i_{ca}, i_{cb}, i_{cc}\)). This solution requires 6 current sensors and 4 voltage sensors, and the inverter has 4 legs (8 power semiconductor switches). For balanced loads without 3rd order current harmonics (three-phase motors, three phase adjustable speed drives, three-phase controlled or non-controlled rectifiers, etc) there is no need to compensate for the current in neutral wire. These allow the use of a simpler inverter (with only three legs) and only 4 current sensors. It also eases the controller calculations [25].

![Active Power Filter shunt in a Three-Phase Power system.](image)

5. SIMULATION RESULTS

The performance of the proposed instantaneous real-power compensator cascaded multilevel inverter based active power filter is evaluated through Matlab/Simulink tools.

The model of Active Power Filter shunt (APFs) is developed using the block Matlab/Simulink. Simulation studies are performed for the parameters of the system shown Table.1.

<table>
<thead>
<tr>
<th>TABLE. 1. Simulation parameters without active filter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameters</strong></td>
</tr>
<tr>
<td><strong>Network Power</strong></td>
</tr>
<tr>
<td>Effective voltage (E_s)</td>
</tr>
<tr>
<td>Frequency (f)</td>
</tr>
<tr>
<td>Line Resistance (R_s)</td>
</tr>
<tr>
<td>Line Inductance (L_s)</td>
</tr>
<tr>
<td><strong>Non-Linear Load</strong> (Graetz bridge to 6 thyristors)</td>
</tr>
<tr>
<td>Apparente Power (S)</td>
</tr>
<tr>
<td>Delay angle (\alpha)</td>
</tr>
<tr>
<td><strong>Linear Load</strong> (below to the non-linear load)</td>
</tr>
<tr>
<td>DC load resistance (R_L)</td>
</tr>
<tr>
<td>DC load Inductance (L_L)</td>
</tr>
</tbody>
</table>
The non-linear diode rectifier R-L load is connected with ac mains and cascaded active filter is connected in parallel at the PCC for injecting the anti-harmonics and eliminating the reactive power. Simulation of the six-pulse rectifier load current or source current before compensation is presented in Fig. 7. This indicates the load current contains the fundamental and harmonic components.

In fact, a good power factor is that having value near unity. This occurs when the source voltage and current are in phase each other. When a harmonic distortion appears, the current and voltage are not in phase. Consequently, the power factor is degraded.

The simulation of source current after compensation is shown in Fig. 10. That indicates the current is sinusoidal.

For the simulation model of the Active Power Filter shunt with five levels established under Matlab/Simulink, we used the parameters in Table. 2.

TABLE. 2. Simulation parameters with active filter

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Numerical values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{dc}$</td>
<td>840 V</td>
</tr>
<tr>
<td>$L_{fa}$</td>
<td>1.5 mH</td>
</tr>
<tr>
<td>$H$ (Window width of hysteresis)</td>
<td>2 A</td>
</tr>
<tr>
<td>$T_s$</td>
<td>0.2 ms</td>
</tr>
<tr>
<td>$L_f$</td>
<td>1.5 mH</td>
</tr>
</tbody>
</table>

The delay between this current and the supply voltage, as shown in Fig. 9, informs us about the degradation occurring in the utility power factor. This means the necessity of a harmonics damping solution.

Fig. 12 proves that utility power factor was corrected by the fact that current and voltage are approximately in phase each other. As a result, power factor is near unity, and consequently reactive power consumed by the non-linear load devices is compensated.
current harmonic spectrum of the source shown in Fig. 11, shows that the THD down to 1.44%.

It is found that the order P-Q has good voltage regulation. Indeed, the response time is less than 0.02s with a zero static error in steady state.

6. CONCLUSION

The work presented in this paper provides a synthesis of active power filters, leading palliative to the problems created by harmonic pollution in distribution systems. An application of active power filter has been processed, it is a parallel active filter powered by a voltage source whose switching orders were sent by the PWM intersective which is based on a two-level voltage inverter, which the reference harmonic currents have been detected by the method of low pass filter.

REFERENCES


