Eliminating The Power System's Harmonics Using Comparative Filter Based Instantaneous Power Theory

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Abstract

In this paper, a new hybrid filter is proposed for eliminating the power system's harmonics. The characteristics of this filter have high efficiency as compared with conventional filters in diminishing the linear and nonlinear loads' disturbances. In the implemented hybrid filter, passive and active filters have been designed to eliminate the high-frequency harmonics (17, 19 and 23) and low-frequency harmonics (5, 7, 11 and 13), respectively. Instantaneous reactive power theory has been applied in the active filter to investigate the harmonic distortion of current in spite of the occurrence of the nonlinear load changes. The produced harmonics investigate the compensation currents which are generated by inverters via the definition of the hysteresis's bands. The results of MATLAB simulation reveal the good efficiency of the proposed hybrid filter in eliminating the different harmonic currents

Keywords: Instantaneous Reactive Power Theory, Current's Harmonics, Hybrid Filters, Hysteresis.

1. Introduction

The presence of the high nonlinear loads leads to unbalancing of the power systems, dropping of the harmonic voltage and losses of active and reactive powers. Utilizing the passive filters has been usually applied as an effective approach to compensate the reactive powers and enhance the power factors in nonlinear loads. The passive filters have been connected in shunt with the power system and indicate low impedance against the especial harmonic [6]. Thus, the aforementioned harmonics trail the low impedance path in the transmission line. Spite of economical profit of active filters, they have no acceptable response against the dynamical changes in nonlinear loads and intense harmonics caused by series and shunt oscillations between source impedance and source filter. Likewise, one of the other deficiencies of passive filters is increasing voltage due to sudden interruption of the passive filter and lack of good designing the passive filters [4, 11]. In recent years, with high progressing of the fast power switches such as GTO and IGBT, active filters have been replaced instead on passive filters which have good efficiency in eliminating the load voltage’s and current’s harmonics [5].

2. Hybrid filter

For utilizing befits of both the active and passive filters, they have been composed with together that is called a hybrid filter. Furthermore, these filters have no any deficiency of both active and passive filters [14]. Different configurations and structures have been introduced for hybrid filters. In this study, shunt structure of hybrid filter has been engaged which is shown in Fig.1.
In fact, the active filter injects a required harmonic current to the Point of Common Coupling (PCC) which is shown in Fig. 2. In this paper, a new approach based on instantaneous reactive power theory is proposed to investigate the harmonic currents.

3. Detection of the reference current via instantaneous reactive power theory

In three-phase circuits, instantaneous voltages and currents can be presented by instantaneous spatial vectors which are given as follows [12]:

\[
\begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix} = \sqrt{3} \begin{bmatrix}
\frac{1}{2} & -\frac{1}{2} & 0 \\
\frac{1}{2} \sqrt{3} & -\frac{1}{2} \sqrt{3} & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
v_a \\
v_b \\
v_c
\end{bmatrix} (1)
\]

\[
\begin{bmatrix}
i_a \\
i_b \\
i_c
\end{bmatrix} = \sqrt{3} \begin{bmatrix}
\frac{1}{2} & -\frac{1}{2} & 0 \\
\frac{1}{2} \sqrt{3} & -\frac{1}{2} \sqrt{3} & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
i_a \\
i_b \\
i_c
\end{bmatrix} (2)
\]

These spatial vectors can be converted in α-β domain. The three-phase currents are presented with positive, negative and zero sequence currents. The instantaneous active power in a-b-c domain is shown by following equation:

\[
P = V_a I_a + V_b I_b + V_c I_c (3)
\]

With calculating the above equation according to the Eq. (1) and (2), the instantaneous active power in α-β domain is obtained:

\[
P = V_a I_a + V_b I_b (4)
\]

Also, active and reactive powers can be presented by following equation:

\[
\begin{bmatrix}
p \\
q
\end{bmatrix} = \begin{bmatrix}
v_a & v_b & i_a \\
v_b & v_a & i_b
\end{bmatrix} (5)
\]
In the above equation, p and q are active power and reactive power, respectively. With performing the calculation of active and reactive powers in d-q domain, these powers do not depend on time and phase, and they are permanent powers [10]. Aforementioned powers can be presented by following scales:

- The average value of instantaneous active power obtained via consummation of energy between load and source.
- The oscillatory value of instantaneous active power obtained via consummation of energy between load and source.
- The average value of instantaneous imaginary power relevant to power changes between phases. In fact, this term of power hasn’t changed the energy between load and source.
- The oscillatory value of instantaneous imaginary power.

The instantaneous active and reactive powers can be given by:

\[ p = \tilde{p} + \bar{p} \]  
\[ q = \tilde{q} + \bar{q} \]  

And indicate the average power or DC power, and also present the oscillatory values of power. The Eq. (6) and (7) can be presented as:

\[ \begin{bmatrix} i_a \\ i_b \end{bmatrix} = \begin{bmatrix} v_a & v_\beta \\ -v_\beta & v_a \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \]  
\[ \begin{bmatrix} i_{a_0} \\ i_{b_0} \end{bmatrix} = \begin{bmatrix} v_a & v_\beta \\ -v_\beta & v_a \end{bmatrix} \begin{bmatrix} -\tilde{p} \\ -\tilde{q} \end{bmatrix} \]  

In order to compensate the reactive power and eliminate the harmonics, the above-mentioned equation in a-b-c domain can be given [1]; and will be generated by inverters to inject the power system.

\[ \begin{bmatrix} i_{a_0}^* \\ i_{b_0}^* \end{bmatrix} = \begin{bmatrix} 2 \sqrt{3} & 0 \\ 2 \sqrt{3} & 2 \sqrt{3} \\ 2 \sqrt{3} & 2 \end{bmatrix} \begin{bmatrix} i_{a_0} \\ i_{b_0} \end{bmatrix} \]  

4. Hysteresis band current control strategy

After definition of the reference currents, inverter injects the required currents to the system to compensate the reactive power and eliminate the harmonics. One of the methods in controlling the current is applying the hysteresis bands to provide a proper pulse width to the inverter’s gates. The salient points of this method are: control of current, satisfied stability, fast response, high accuracy, feasibility employment, limitation of current and insensitivity against the changing of the load parameters [13]. Increase of losses in high power and variable switching frequency which cause the voiceful noises and switching harmonics are disadvantages of this method [3]. Advantages of this method overcome to their defects, thus, it has become majored voltage converter for controlling the inverter’s current [3]. In this strategy, the produced signal will be obtained via comparing the reference current and converter’s current, and also can be presented by following equation:
\[ e = i^* - i_{\text{apf}} \text{ (actual) } \] (11)

Fig. 3 portrait and verify the above equation.

The value of hysteresis band, inductance between network and converter as well as DC voltage capacitor have defined the switching frequency. Maximum switching frequency is:

\[ f_{\text{sw (max)}} = \frac{V}{9HB \cdot L} \] (12)

HB is hysteresis limit and L is the value of inductance that current is injected by it. As shown in Fig. 4, the uprising and decliner slope of error signal will be generated by \(-V_o\) and \(+V_o\).

\[ \frac{di_c}{dt} = \frac{1}{L} \left( |V| + V_o \right) \] (13)

\[ \frac{di_c}{dt} = \frac{1}{L} \left( |V| - V_o \right) \] (14)

The voltage difference is \(2V_o\) which have a direct relation with switching frequency.

\[ \Delta V_{\text{bipolar}} = \left| V_o \right| + V_o - \left( \left| V_o \right| - V_o \right) = 2V_o \] (15)

By decreasing the hysteresis band, the value of error will increase but the switching frequency of inverters will increase. The PWM command circuit for generating the inverter’s pulse is shown in Fig. 5.

5. Simulation results

According to the structure of the power system and excised harmonics, the hybrid filter’s values can be selected. Thus, the proposed values in table 1 will eliminate the 17th, 19th and 23th harmonics and 5th, 7th, 11th and 13th harmonics by passive and active filters, respectively. The current’s value
depends on the good measuring the load voltage and current, computing the compensator current and
switching strategy [7]. Also, the parameters of active filter are given in the following table.

**Table 1:** The best value of passive filters for eliminating the different harmonics

<table>
<thead>
<tr>
<th>Num harmonics</th>
<th>C(µf)</th>
<th>L(mH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>0.65</td>
<td>53.34</td>
</tr>
<tr>
<td>19</td>
<td>0.52</td>
<td>53.34</td>
</tr>
<tr>
<td>23</td>
<td>0.35</td>
<td>53.34</td>
</tr>
</tbody>
</table>

**Table 2:** Active filter’s parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator line voltage</td>
<td>200rms</td>
</tr>
<tr>
<td>Generator frequency</td>
<td>50Hz</td>
</tr>
<tr>
<td>Source inductance</td>
<td>0.1mH</td>
</tr>
<tr>
<td>Filter inductance, (L_f)</td>
<td>4.5mH</td>
</tr>
<tr>
<td>Filter DC capacitor, (C_{DC})</td>
<td>30 µf</td>
</tr>
<tr>
<td>DC reference voltage, (V_{dcr})</td>
<td>700V</td>
</tr>
</tbody>
</table>

To verify and investigate the proposed approach, a system which is consist of harmonic load and
active filter has been simulated in MATLAB environment. This system is equipped with diode three
phase controlled rectifier and resistance load. In the first time, \(R_{Load}=10\Omega\) and \(L_{Load}=2\text{mH}\) and after
0.25s, these values will become twice to deal with the performance of the hybrid filter. An inverter
bank which is composed of six voltage source single-phase converters controlled by IGBT injects the
required current to compensate the reactive power and eliminate the harmonics. According to the
acquired responses which are depicted in Figs. 6 and 7 show the compensation of reactive power and
correction of power factor by active filter.

![Figure 6: The required active power of the load](image1.png)

![Figure 7: The required reactive power of the load](image2.png)

Figs 8, 9, 10, 11 and 12 show the load current, the investigated compensation current by active
filter, compensated current by active filter, absorbed current by passive filter and absorbed current
from source after compensating by hybrid filter, respectively.
With compensating the load current frequency spectrum and source current, the value of THD skips from %22.26 to %2.57 after compensation, and portrait in Figs. 13 and 14.
The capacitor voltage and performance of its regulator can be seen in Fig. 15. As shown in Fig. 16, difference of reference curve and generated curve by filter active is very trivial.

6. Conclusion

In this paper, shunt hybrid filter has been applied to eliminate the harmonics. Due to utilizing the passive filter to eliminate the high-frequency harmonics, size of this filter dramatically decreased. Also,
due to applying the active filter for diminishing the low-frequency harmonics, switching losses well dwindled. By employing the hysteresis control method and using the instantaneous power theory for investigating the harmonic currents in active filter as well as applying the passive filters, the current quality has been praised. The proposed filter has high efficiency in discrimination of the harmonic indexes and good performance in clearing the disturbances of nonlinear loads. The obtained results of simulations are according to the IEEE519 that declare %3 and %5 for harmonic voltage and THD, respectively that they have been approved in this paper.

7. References


