Adjustable Speed Drives are extensively used in Processes Industries. To achieve optimum performance parameters and high production output, it is necessary to operate the drive systems at different speeds. Variable speed operation is realized by supplying the drive motor with variable frequency supply through DC link inverter. When the drive system is operated at varying speeds, it injects current harmonics into the DC link which are multiples of the operating fundamental frequency. These harmonics are passed on to the grid lines with frequencies which are non-integer multiples of the fundamental frequency of the Grid supply. These are called as injected inter harmonics. This paper presents a methodology to estimate energy transfer to active DC link capacitor due to inter-harmonics. It is necessary to calculate the amount of energy stored in active capacitor, when the ripple energy is positive. The principle of mitigating the inter-harmonic is transferring energy to the capacitor when the ripple energy is positive and during the negative half cycle of the inter-harmonic the energy is fed back to the DC link. The work involves simulation and analytical methods for the calculation of instantaneous voltage and current of capacitor and inductor respectively.

Key words: Active DC-link capacitor, Adjustable Speed Drive (ASD), energy transfer mechanism, interharmonics.

INTRODUCTION

Due to large number of non-linear loads and generators in the grid, the voltages and currents have become very irregular in modern power systems. In such manner, control electronic based frameworks, for example, flexible speed drives, control supplies for IT-hardware and high effectiveness lighting and inverters in frameworks producing power from dispersed sustainable power sources are vital sources to make aggravations. Contortions experienced are, for instance, signals which are integer multiples of fundamental frequencies, inter-harmonics, transients and flickering which are all components of 'energy quality' issues.

The frequencies which are not integer multiples of fundamental frequency are called injected inter-harmonics in to the grid which occurs due to nonlinear loads such as adjustable speed drives.

Flexible speed drives are one among the potential wellsprings of inter-harmonics in the grid (H. Soltani et al., 2014), where a diode-connect rectifier and a PWM inverter are normally associated consecutive sharing a typical dc interface having a LC-channel. Till now, a few examinations have been started to know the sources which creates the inter-harmonics, recognizable pieces of proof and their negative impacts on the power supplies (D. Basic, 2010). These reviews are truly helpful to recognize the inter-harmonic components, regardless more trials are required for inter-harmonics reduction. Active DC link capacitor compensation circuit is one of the effective method of reducing these non-integer multiples of ripple components.

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ACTIVE DC-LINK CAPACITOR COMPENSATION CIRCUIT FOR INTERHARMONIC REDUCTION

The active dc link capacitor compensation circuit which have become more popular in several power electronic applications, for example reduction of the dc link capacitance for single phase and three phase rectifiers is one of the method for reducing the grid current inter-harmonic components caused by the unbalanced currents in motors (H. Soltani et al., 2015). Fig 1 demonstrates an adjustable speed drive with an active capacitor compensation circuit. The dc link active capacitor methodology is consist two IGBT Switches S1 and S2, an inductor La which is energy transferring element and also a capacitor Ca working as an energy storage element.

Fig.1. Adjustable speed drive with an active dc link compensator

OPERATION PRINCIPLE FOR AN ACTIVE DC-LINK CAPACITOR CIRCUIT

The proposed active capacitor circuit consists of two IGBT switches, an inductor La and furthermore a capacitor Ca. Here inductor is energy transferring element and capacitor works as an energy storage element. The main aim is to compensate the inverter side ripple energy initiated due to load current imbalance. When the ripple energy (current) is positive, switch S1 is made on and off to sink the ripple energy to the active capacitor of compensation circuit. During the switch on time of S1, the ripple energy charges the inductor and capacitor. Here, the capacitor is the main storage component whereas the inductor only transfers the ripple energy. During the off time of the switch S1, the ripple energy the inductor transfers its energy to capacitor. This operating condition of compensation circuit is same as a DC-DC step-down converter.

When the ripple energy component is negative, switch S2 is operated to release the stored ripple energy in active capacitor back to the dc bus. During the on time of the switch S2 capacitor charges the inductor, during the switch off time energy from both the active elements (La and Ca) are transferred back to dc bus. This operating condition of the circuit is same as a DC-DC step-up converter.

ESTIMATION OF ENERGY TRANSFER IN COMPENSATION CIRCUIT

The compensation of harmonic current calculated is depends on charging of the capacitor i.e. amount of ripple energy stored in the active capacitor. This depends on the calculated ripple current at the load. The ripple component charges both the inductors and capacitor during switch on time and the inductor releases its energy to capacitor during switch off time. Hence the energy in the active capacitor will be the sum of energy stored in the capacitor and energy transferred from inductor. Figure 2 gives the simulated circuit to estimate the charging of the capacitor during each sampling period.

Fig. 2. Simulation circuit to estimate the charging of the capacitor

The above circuit was simulated using PSPICE. The graphs plotted from the simulated results for capacitor voltage and inductor current validates the correctness of the formulae discussed below.

The change in inductor current I is calculated from the below formulae:

\[ \Delta I_1 = I_m \sin(\omega t_1) - I_m \sin(\omega t_0) \]
\[ \Delta I_2 = I_m \sin(\omega t_2) - I_m \sin(\omega t_1) \]
\[ \Delta I_n = I_m \sin(\omega t_{n-1}) - I_m \sin(\omega t_n) \]

Change in capacitor voltage V at each sampling period is calculated as shown below.
\[
\Delta V_1 = \left( \frac{\Delta I_1}{2} + I_m \sin \omega t_0 \right) \times t_{on} \times C \\
\Delta V_2 = \left( \frac{\Delta I_2}{2} + I_m \sin \omega t_2 \right) \times t_{on} \times C \\
\Delta V_n = \left( \frac{\Delta I_n}{2} + I_m \sin \omega t_{n-1} \right) \times t_{on} \times C
\]

The amount of energy transferred to the capacitor from inductor during switch off time can be calculated using below formula

\[
\Delta V_L = I_m \sqrt{\frac{L}{C}}
\]

By considering the \( \Delta I \) and \( \Delta V \) the energy stored in capacitor and inductor can be calculated.

Energy stored in inductor is

\[
E_L = \frac{1}{2} \times L \times \Delta I^2
\]

Energy stored in capacitor is

\[
E_C = \frac{1}{2} \times C \times \Delta V^2
\]

**EXPERIMENTAL RESULTS**

From the below simulation results, it is evident that the capacitor voltage gradually increases during the switch ON time. The inductor transfers its stored energy to the capacitor during the switch OFF time.

**Table 1. Theoretical values**

<table>
<thead>
<tr>
<th>( t_0 )</th>
<th>( t_1 )</th>
<th>( t_1(\text{deg}) )</th>
<th>( t_1(\text{deg}) )</th>
<th>( \text{delta_i} )</th>
<th>( \text{delta_vc} )</th>
<th>( \text{delta VL} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
<td>0</td>
<td>2.88</td>
<td>0.251222</td>
<td>0.031403</td>
<td>0.251222</td>
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<tr>
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<td>300</td>
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<td>8.64</td>
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<td>0.156617</td>
<td>0.249319</td>
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<tr>
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<td>500</td>
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<td>14.4</td>
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<td>0.28005</td>
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<tr>
<td>600</td>
<td>700</td>
<td>17.28</td>
<td>20.16</td>
<td>0.238007</td>
<td>0.401053</td>
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</tr>
<tr>
<td>800</td>
<td>900</td>
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<td>25.92</td>
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<td>0.517806</td>
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<tr>
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<td>31.68</td>
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<td>0.62933</td>
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<tr>
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<td>1300</td>
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<tr>
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<td>1500</td>
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<tr>
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<tr>
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<td>95.04</td>
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<td>1.247138</td>
<td>-0.01578</td>
</tr>
<tr>
<td>3400</td>
<td>3500</td>
<td>97.92</td>
<td>100.8</td>
<td>-0.01578</td>
<td>1.247138</td>
<td>-0.01578</td>
</tr>
</tbody>
</table>

The values calculated are for quarter cycle, and for other quarter cycle the value is multiplied by two. These calculated values are compared with simulation results and the results are verified.

**CONCLUSIONS**

Using P-spice simulation software the energy transfer mechanism between the active capacitor and inductor is established. The energy stored in the capacitor and inductor are estimated analytically and are compared with the simulation results. It has been established that during one switching cycle of the ripple current, a comparison between \( \Delta V \) and \( \Delta I \) by analytical method and simulation method are matching.

**REFERENCES**


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