Investigation and Elimination of Resonances Caused by Chaotic Harmonics of Power Converters in a Sample Network

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***Abstract*— Parallel resonance caused by fourth harmonic of chaotic current of a voltage converter in a power network is studied while fifth and seventh harmonics are filter has been used. Equivalent circuit is used in order to study the resonance in the network. A control method is, then, introduced for elimination of chaotic harmonics caused by the converter which can improve converter stability and removal of parallel resonance.**

Keywords: Chaos, Parallel Resonance, Passive Filter,Time Delay Feedback Control Method, Chaotic Harmonic

Introduction

Although there are many advantages in employing electronic power converters, but these nonlinear devices may lead to generation of harmonics. The harmonics, in turn, not only introduce contamination and reduce power factor of system equipment, but also can result in parallel and series resonances in power network which cause high currents and distortion in voltage waveform [1]. Odd harmonics generated by these devices have been occasionally studied [2]. Since even harmonics are often ignored due to their small amplitude, high-amplitude odd harmonics, e.g. 3, 5, and 7, have initiated more researchers compared to other harmonics. Several methods have been suggested for elimination of these harmonics such as employment of passive and active filters. While reducing the abovementioned harmonics, however, passive filters displace natural frequencies of system and cause resonance at new frequencies [3],[4].

Harmonic generation by theses converters depend on the behavior and performance condition. Even harmonics are often presented due to asymmetrical working condition or unstable control methods. An instability often observed in power converters is the presence of chaos and chaotic oscillations. Chaotic performance of power converters can be attributed to bifurcation and periodic-like behavior of DC-DC and DC-AC converters[5-9]. These undesirable oscillations impose a wide range of harmonics on the principle component which, in turn, introduce high impurity to load current and make these devices generate currents containing odd and even harmonics. Nearly high-amplitude even harmonics result in harmonic resonance caused by harmonic current components. The rest of this paper analyzes a network containing 5^{th} and 7^{th} harmonics leading to harmonic resonance in 4^{th} harmonic. [10]

The source of chaotic harmonic

An inverter used for current control is employed here as harmonic generator for investigation of resonance. The converter behavior is fully described in [11],[12]. Governing equations of the converter are as follows.

$$i_{n+1} = i_n e^{-(RT/L)} + \frac{2E}{R} e^{-(RT/2L)} \left[2\mathrm{Sinh}\left(D_n\left(\frac{RT}{2L}\right)\right) - \mathrm{Sinh}(RT/(2L))\right] \quad (1)$$

$$D_n = .5 + \frac{\mathrm{Sat}(I_{ref} - i_n)}{2} \quad (2)$$

Figure (1) shows bifurcation diagram for different current controller factors. Here, for showing chaotic oscillation in a switching period, the reference current assumed to be constant.

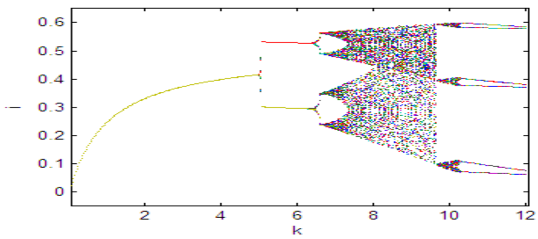

Fig.1 Bifurcation diagram for Converter

Figure (2) illustrates the behavior of load current in low feedback gain. It can be seen that the current signals contains no harmonic components.

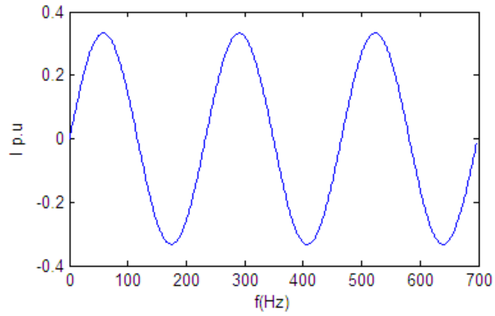

Fig.2 Curren Wave Without Chaotic harmonic

The feedback gain is increased and set at 10 in figure (3). Chaotic oscillation under these circumstances is inevitable and a continuous spectrum of harmonics is imposed on the principle components.

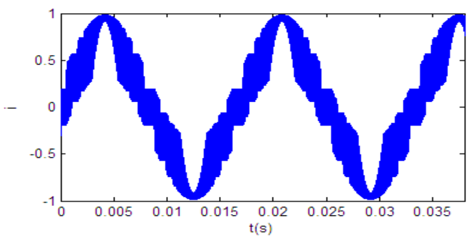

Fig 3. Curren Wave With Chaotic harmonics

Figure (4) shows harmonic spectrum for the current shown on figure (2). Even harmonics are quiet observable in current spectrum. Note that the amplitude of 4^{th} harmonic in this spectrum reaches nearly 6% of that of principle component.

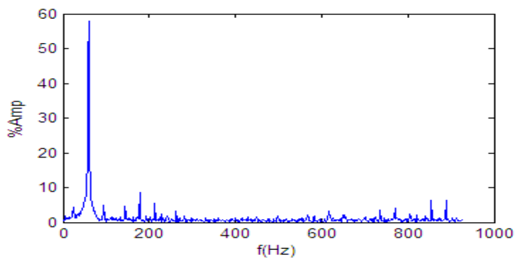

Fig 4. spectrum Curren Wave in Chaotic region

The principle component is omitted in figure (5) in order to highlight harmonic components of the converter current.

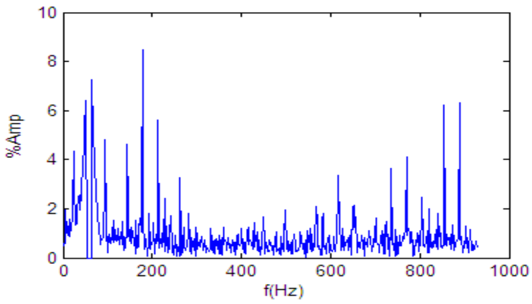

Fig.4 spectrum Curren Wave Without Basic frequency in Chaotic region

Investigation of parallel resonance caused by chaotic harmonics

Figure (6) was employed in order to investigate generate and investigate resonance in a network due to chaotic harmonics of power converters.

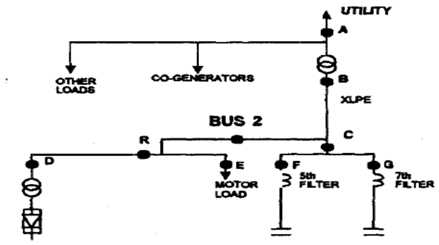

Fig.5 sample Network

The system impedance can take six values depending on working condition. These values are shown in table (1).

Table.1 Impedance System

Impedance	1.39 %	1.73 %	3.05 %	4.5 %	5.52 %	7.62 %
Resistance(mili ohm)	2.24	2.79	4.92	7.26	8.91	12.2 9
inductance(mili hanry)	0.17 85	.222	.391 6	.577 7	.708 7	.978 3

The equivalent circuit for the system is shown in figure (7). Presence of 5th and 7th harmonic filters in the bus B may lead to displacement of natural frequencies of system.

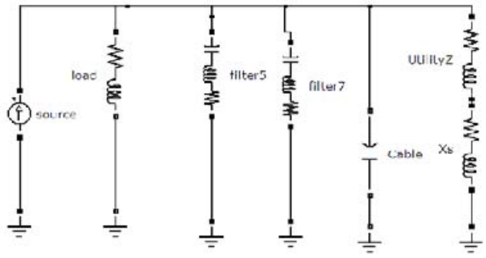

Fig.8 equivalent circuit for the system

Table (2) presents natural frequency of network impedance in the presence of 7th and 5th filters both individually and simultaneously.

Table.2 Neutral frequency in Network

Mod el		Natural frequency				
		1.39 %	1.73 %	3.05 %	5.59 %	7.62 %
1	With 5thfilte r	269	267	266	261	251
2	With 5th and 7th filter	259	257	254	247	241
3	With 7thfilte r	347	345	340	330	322

The table suggests that simultaneous presence of 5th and 7th filters makes it more likely for resonance at 4th harmonic to occur. The natural frequency of the system is 241 Hz under this circumstance which is only 1 Hz away from the forth harmonic. 4th harmonic resonance may be generated under this condition.

Table (3) provides current harmonics in the network for different values of impedance and under the condition which reveals the presence of 5th and 7th harmonic filters.

Table.3 Amplitude of 4^{th} harmonic in network

Model		4^{th} harmonic				
		%1.39	%1.73	%3.05	%5.59	%7.62
١	With 5^{th}filter	.075p.u	.074p.u	.078p.u	.079p.u	.085 p.u
٢	With 5^{th} and 7^{th} filter	.16p.u	.17p.u	.225p.u	.48p.u	3.356p.u
٣	With 7^{th}filter	.098p.u	.1p.u	.12p.u	.13p.u	.16p.u

During resonance, the amplitude of the fourth harmonic may be as four times large as the principle components in the converter current. This generates a 30% distortion on the voltage of bus B. harmonic current and distorted voltage waveforms, when parallel resonance exists, are shown in figures (8) and (9).

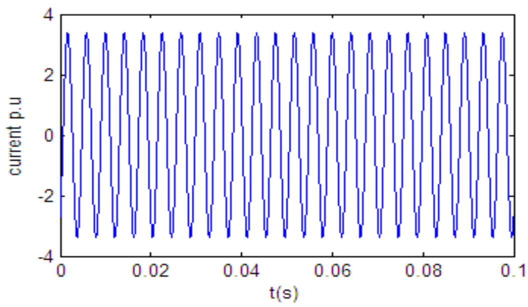

Fig 8 . 4^{th} current harmonic in resonance condition

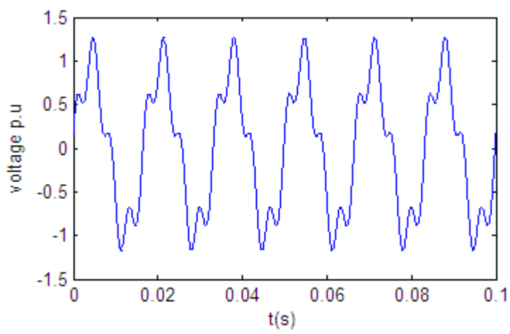

Fig .9 Distorsion voltage effected by 4^{th} current harmonic in resonance condition

Removal of harmonic resonance caused by 4^{th} harmonic of chaotic spectrum of current

A control and stabilizing approach for chaotic behavior of converter is introduced here for the removal of harmonic resonance caused by chaotic current. To be more specific, TDFC chaotic control method is employed along with a delay in the control feedback path of the converter current in order to have delayed range of chaos in the inverter. To do this, the following control function is added to the feedback control of the inverter current. The new equation governing the circuit may be represented as (3).

$\eta(i_n - i_{n-1})$

$$d_n = .5 + .5\text{sat}\big(k(I_{ref} - i_n) + \eta(i_n - i_{n-1})\big) \qquad (3)$$

Chaotic behavior of the circuit for different values of x can be observed in figures (10), (11), and (12). As η increases, up to the determined value of 2.7, the chaotic behavior will be suppressed. But, as it can be seen in figure (13), the chaotic behavior grows dramatically at 3.7 The current waveform at k=10 and in new circumstances for converter is shown in figure (12). The previous chaotic behavior is eliminated and hence, 4^{th} harmonic may no longer exist in the network and, by inference, the parallel resonance caused by this harmonic is removed as well.

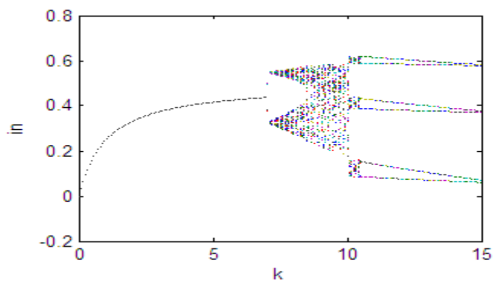

Fig 10. Bifurcation Diagram for η = 1

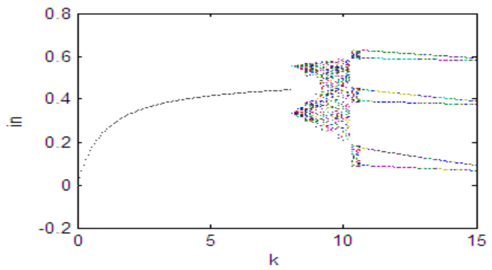

Fig 11. Bifurcation Diagram for $\eta = 2$

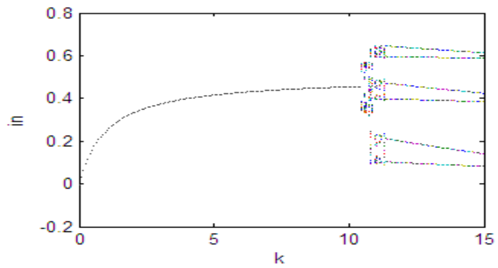

Fig 12 . Bifurcation Diagram for $\eta = 2.7$

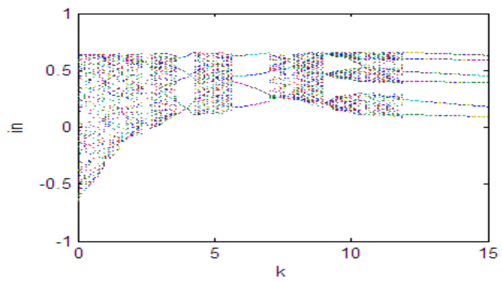

Fig 13. Bifurcation Diagram for $\eta = 3.6$

Conclusion

We studied resonances caused by chaotic harmonics of power converters in networks. The presence of even harmonics, often disregarded in the normal condition of networks, will appear in high amplitude in converter current during the resonance and may lead to parallel resonance under particular conditions. A chaotic control method approach based on stabilizing chaotic behavior and introducing delays in chaotic intervals was used in order to prevent resonance in network. The method was proved to improve the behavior of the system regarding resonance and chaos.

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