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Analysis and Simulation of Possible Bifurcation and Subharmonic Oscillation in Transformer Coupled TCR System.

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Abstract **– thyristor controlled reactor (TCR), which is typically linked by a coupling transformer to the gird, is widely used as a continuously variable reactive power compensator in electric power systems. This paper focuses on anomalous nonlinear phenomena in a TCR system, called switching time bifurcation, and is showed the possibility of subharmonic and interharmonic oscillations accompanied with the switching time bifurcation and synchronous resonances. Also Impact of capacitor Banks on occurrence of bifurcation phenomenon has been considered. It has been shown that the correct selection of the shunt capacitor may prevent or reduce bifurcation phenomenon.**

Keywords **- subharmonic; switching time bifurcation; TCR; shunt capacitor**

I. Introduction

Static VAR compensators (SVCs) are widely used in electric power system. A thyristor controlled reactor (TCR) along with capacitor banks is common configuration, which provides VAR control in both inductive and capacitive regions. These devices, which are used for stable and reliable operation of system, may themselves cause fluctuations due to switching bifurcation [1-7]. Studies show the possible occurrence of subharmonic and interharmonic oscillations accompanied with the bifurcations and resonance in TCR. In practice the shunt capacitor, used commonly in SVC is totally or partially replaced by a filter which is capacitive in the fundamental frequency. This filter exhibits low impedance in high frequencies to eliminate generated harmonics by TCR. Correct selection of the shunt capacitor may prevent or reduce bifurcation phenomenon. However, this mater is not usually considered in shunt capacitor design and selection stage.

II. TCR Circuit configuration

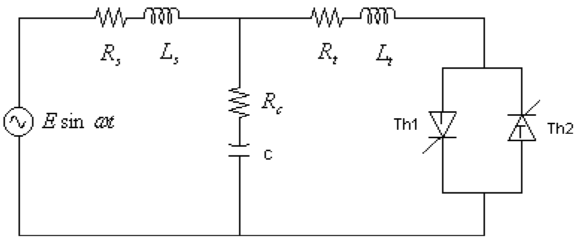

Fig.1. Schematic diagram of single phase TCR

Fig.1 depicts single phase diagram of TCR. Results, then, will be valid for three phase system. This simplification is valid for the phenomenon which is free from inter-phase interaction. Transmission line, which transfers power between the generation and load in a power system, has been represented by lumped inductance L_s and resistance R_s. The power station is assumed as an infinite bus and is expressed by the voltage source $E\sin\omega t$. A TCR consists of a shunt capacitor (SC) and a thyristor controlled reactor (TCR). The SC modeled by a capacitance C and an equivalent series resistance R_c and supplies leading reactive power to the power system. The TCR comprises an inductance L_t with winding resistance R_t and a back-to-back connected thyristor. It regulates the lagging reactive power flow, in accordance with current flowing through the reactor, which is controlled by the thyristor firing angle α . The ideal valve current I_{TCR} due to sinusoidal ac voltage $V(t)=E\sin\omega t$, imposed on the TCR can be obtained by:

$$\begin{cases} I_{TCR}=0 & (0\le t\le\frac{\alpha}{\omega},\ \frac{2\pi-\alpha}{\omega}\le\frac{2\pi}{\omega}), \\ I_{TCR}=\frac{1}{L}\int_{\alpha/\omega}^{t}V(t)dt=\frac{E}{X_t}(\cos\alpha-\cos\omega t) & (\frac{\alpha}{\omega}\le t\le\frac{2\pi-\alpha}{\omega}) \end{cases} \tag{1}$$

Where E and ω denote the amplitude and the angular frequency of the ac voltage, respectively, $X_t=\omega L$ and the firing angle α is ranging from $\pi/2$ to π in normally

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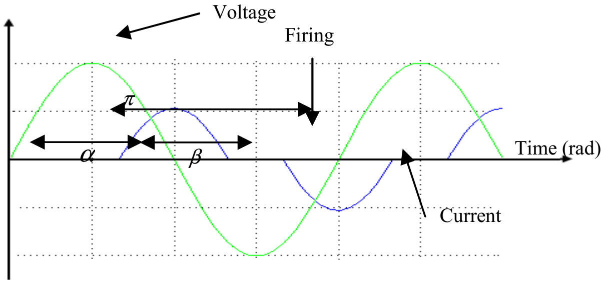

Fig.2. Ideal voltage and current waveforms of TCR

The typical voltage and current in TCR are drawn in Fig.2. The thyristor valve turns off when current reaches to zero. Then the conduction interval expressed by angle β which is obtained by $\beta=2(\pi-\alpha)$ from Eq. (1) as it becomes $\cos\alpha-\cos(\alpha+\beta)=0$. This implies that the relation between firing angle α and conduction angle β of TCR are uniquely derived in ideal conduction, and β changes smoothly due to the continuous variation of α. The valve current I_{TCR} can be decomposed into fundamental and harmonic components [8-9] which by applying Fourier transform them can be expressed as functions of α:

$$\begin{cases} I_1(\alpha)=\frac{E}{X_t}(\frac{2}{\pi}\alpha-\frac{1}{\pi}\sin 2\alpha-2), \\ I_n(\alpha)=\frac{E}{X_t}\frac{4}{\pi}\frac{\cos\alpha\sin n\alpha-n\sin\alpha\cos n\alpha}{n(n^2-1)}, \\ \quad n=2k+1(k=1,2,3....). \end{cases} \tag{2}$$

Eq. (2) shows that the TCR generates not only fundamental reactive current in accordance with firing angle α but also produces undesired harmonic component. The consequence due to some capacitor values, in TCR constitutes resonant circuit. This may lead to severe harmonic distortion in power system.

III. Switching time bifurcation

To examine this phenomenon, circuit parameters are shown in table1. Figure 3 shows the current value in TCR obtained in simulations, in which firing angle α is increased from 95^0 to 175^0 by 1^0 step. When α is increased from 112^0 to 113^0, the system is transferred to a new continuous control region with much less conduction angle values and conduction angle experiences discontinuously and jump. Other switching time bifurcations can also be found in different firings angles. Fig.4 shows the phase plane diagram for the condition immediately after conduction angle jumps. The gap between 120^0 and 40^0 is an inaccessible region, which exists due to bifurcation caused by switching time.

TABLE1
CIRCUIT THE PARAMETERS OF THE STUDID TCR SYSTEM

Symbol	Value
E	$24V$
S	$24VA$
Z_{base}	24Ω
X_s	$3.24\Omega(10.3mH)$
R_s	0.1512Ω
X_c	$25.68\Omega(124\mu F)$
X_t	$6.84(21.6mH)$
R_r	0.375Ω

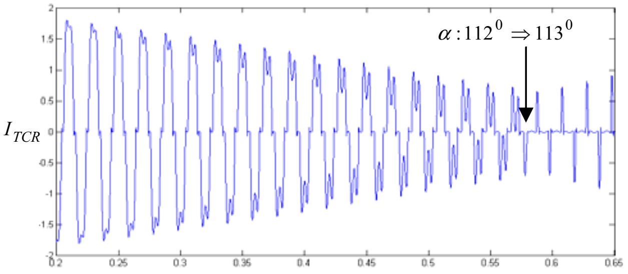

Fig.3 TCR current when α increase from 95^0 to 175^0 at 1^0 step

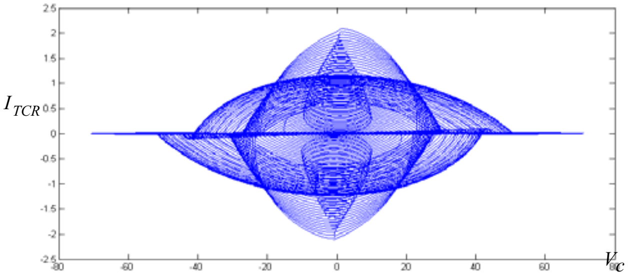

Fig.4 phase plane diagram shows considerable change of trajectory orbits.

IV. Switching time bifurcation and subharmonic and interharmonic oscillation in TCR

This region shows subharmonic [10-11] and interharmonic oscillation which is also observed in simulations. To examine this phenomenon, consider circuit values changes to table2. Figure.5 shows the TCR simulated current value, in which firing angle α is increased from

TABLE2
CIRCUIT PARAMETERS OF THE STUDID TCR SYSTEM

Symbol	Value
E	$10V$
S	$10VA$
Z_{base}	10Ω
X_s	$6.92\Omega(22mH)$
R_s	0.246Ω
X_c	$25.68\Omega(124\mu F)$
X_t	$3.02\Omega(9.6mH)$
R_r	0.375Ω

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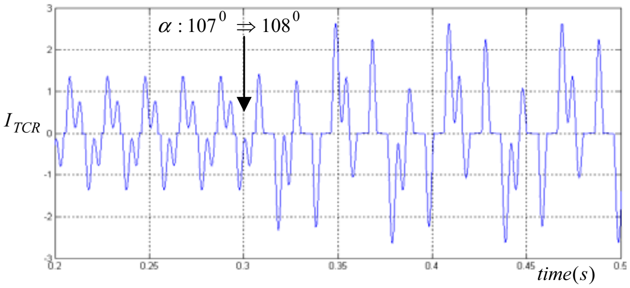

Fig.5. TCR current when α increase from 95^0 to 175^0 at 1^0 step

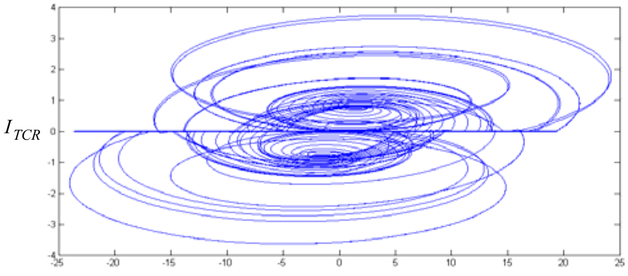

Fig.6. the phase plane diagram related to Fig.6

95^0 to 175^0 by 1^0 step. When α is increased from 107^0 to 108^0 the conduction angle experiences discontinuously and jumps to 81^0 and 54^0. The phase plane diagram related to Fig.5 is shown in Fig.6. If α is increased to 109^0, as depicted in fig.7 and Fig.9 $17\,Hz$ subharmonic and other interharmonics are generated in system. Increasing conduction angle to 110^0 generates more subharmonics and interharmonics (Fig.11 and 12).

Fig.12 shows the simulation for conduction angle more than 112^0, which, completely jumps to 80^0 equivalent subharmonics. Fig.13 shows related phase plain diagram of Fig.12, which shows complete change in shape of trajectories orbits. Fig.14 shows harmonic spectrum of TCR current, which shows interharmonics vanish. Other subharmonic and interharmonic oscillations are also observed in the simulations, which are identified as multiple conduction angles to a firing angle in Fig.15.

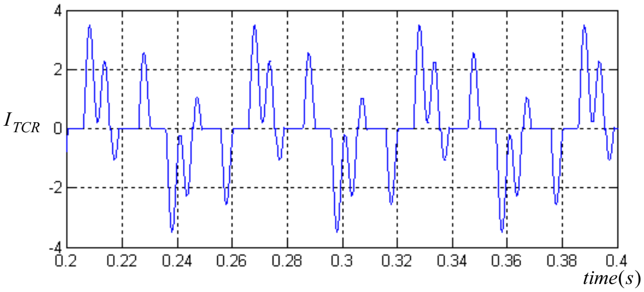

Fig.7. TCR current for $\alpha = 109^0$

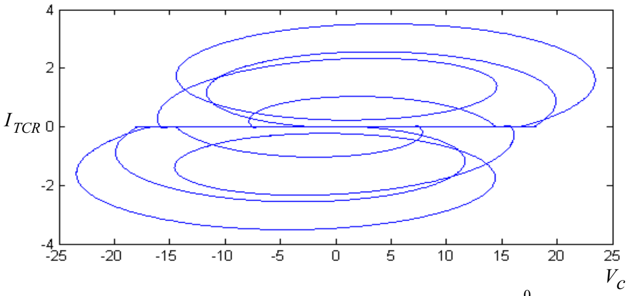

Fig.8. the phase plane diagram for $\alpha = 109^0$

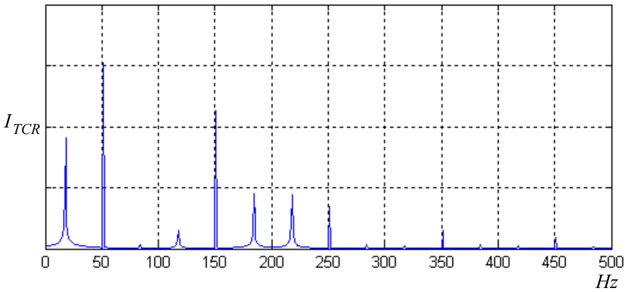

Fig.9. the emergence of $17\,Hz$ subharmonic for $\alpha = 109^0$

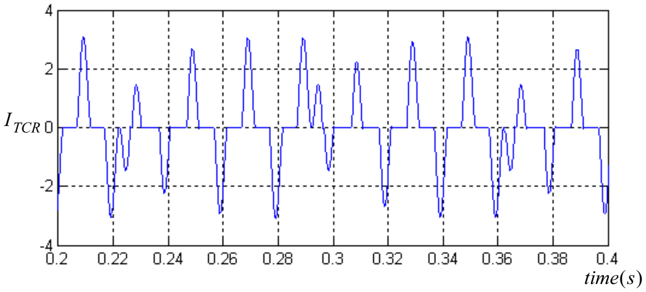

Fig.10 TCR current for $\alpha = 110^0$.

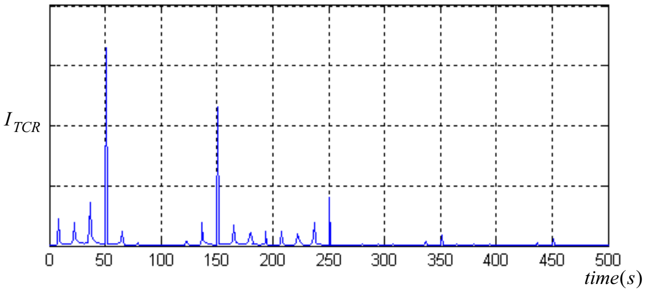

Fig.11. subharmonics and interharmonics generated for 110^0 conduction angle which is more than those for 109^0

V. The effect of shunt capacitor in bifurcation phenomenon

One of the main components in SVC configuration is shunt capacitor. In practice the shunt capacitor is totally or partially replace by a filter which is capacitive in the fundamental frequency. This filter has low impedance in high frequency to eliminate the generated harmonic by TCR. As the shunt capacitor impedance changes, all regions in Figure 15 will change too. The TCR currents are shown in Fig.16 for different capacitor values.

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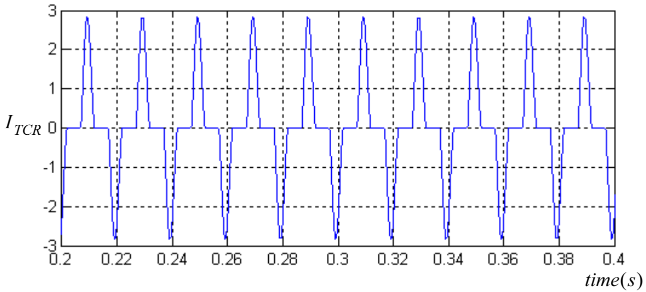

Fig.12. TCR current for $\alpha = 112^0$

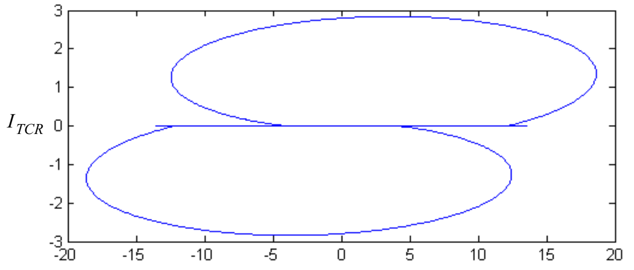

Fig.13. Related phase plane diagram shows considerable change of trajectory orbits.

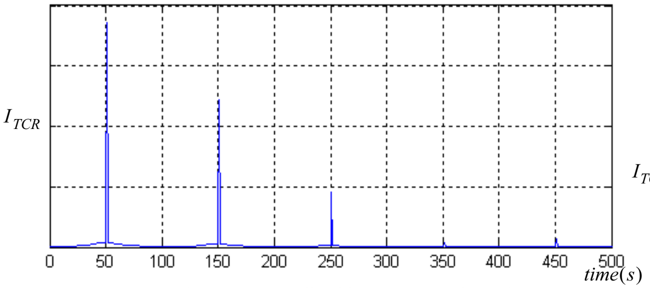

Fig.14 elimination of all subharmonics and interharmonic at

$\alpha = 112$

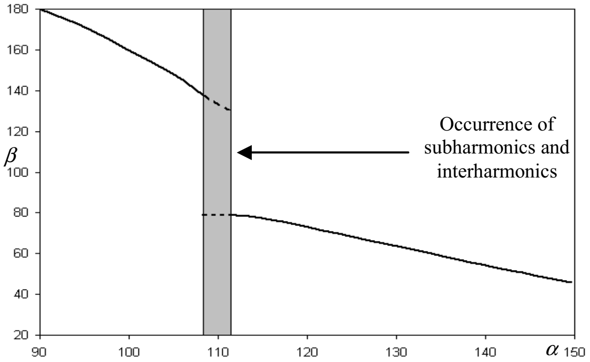

Fig.15. Relationship between conduction angle β and firing angle α

Taking the circuit values given in Table 1 as the base values, some simulations has been performed to show how much, system is sensitive to the variation of shunt capacitor. The results are as shown in Figure 17. The simulation results indicate that, for presented system, shunt capacitor impedance less than 95% of the base value may not cause switching time bifurcation, and continuous control of the TCR conduction angle (β) over the desired region will be achieved. For higher fix capacitor impedances, switching time bifurcation is inevitable and conduction angle control is only possible in two discrete regions I and III, while the great portion of an expected control region remains inaccessible (region II). It is also seen that increasing shunt capacitor shifts inaccessible region II to higher conduction angles, and this causes more limitations to control TCR. However, for a desirable TCR operation and effective participation in power system operation, TCR should operate in all regions, especially in region I. A sudden shedding of a big portion of TCR capacity while working in high conduction angle values will cause the network to face instantaneous surplus of a large reactive power flow. However this problem can be tolerable in lower conduction angles. Therefore, shunt capacitor with lower impedances at least may shift uncontrollable region to lower values, which is much tolerable.

Finally simulation result shows that more increment in shunt capacitor impedance can lead to abnormal behavior, which may be categorized as chaotic oscillations.

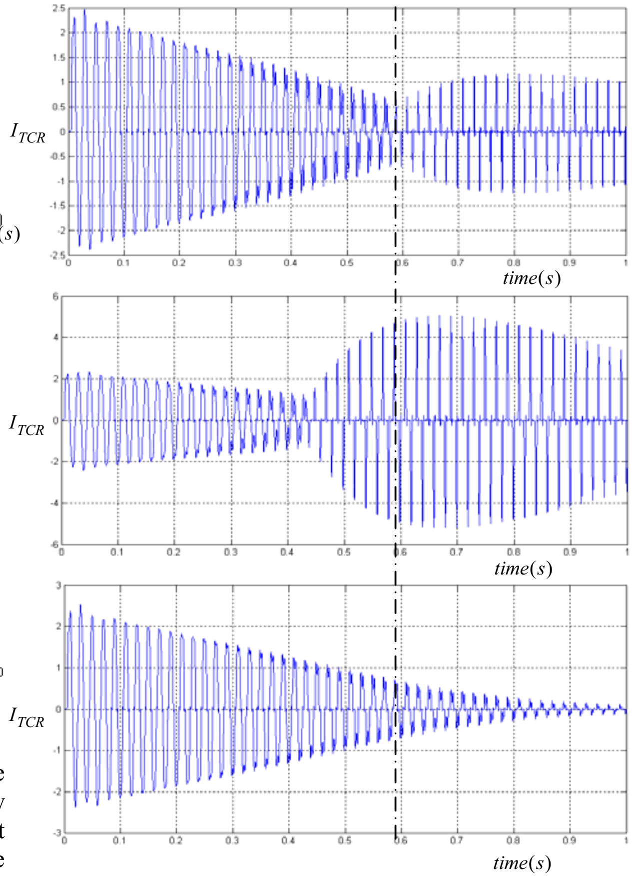

Figure 16: TCR Current for different shunt capacitor impedances; normal, +5% and -5% changes.

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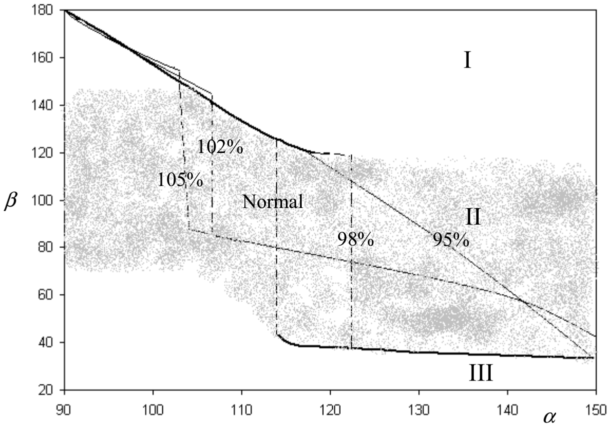

Figure 17: β versus α for different coupling transformer impedances; normal, -/+2% and -/+5% changes.

VI. Conclusion

This paper discussed anomalous nonlinear phenomena in a TCR system, called switching time bifurcation, which increases the possibility of subharmonic and interharmonics oscillations accompanied with the switching time bifurcation. These Phenomena effects normal operation of TCR. Also Impact of capacitor in TCR on occurrence of bifurcation phenomenon has been showed. Cutting TCR VAR supply while working in high conduction angle values will cause the network facing instantaneous surplus of a large reactive power flow. However this problem can be tolerable in lower conduction angles. It has been shown that shunt capacitor with lower impedances may at least shift uncontrollable region to lower values, which is much tolerable.

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REFERENCES

[1] S. Jalali, I. Dobson, R. H.Lasseter, "Instabilities due to bifurcation of switching times in a Thyristor Controlled Reactor", *IEEE 0-7803-0695-3/92,* 1992

[2] S. Jalali, I. Dobson, R. H.Lasseter and G. Venkataramanan, "Switching time bifurcations in a Thyristor Controlled Reactor", *IEEE, Transactions on circuits and systems*, *Fundamental theory and applications,* Vol.43, No.3, March 1996.

[3] R. Rajaraman, I. Dobson, S. Jalali, "Nonlinear dynamics and switching time bifurcations of a thyristor controlled reactor", *IEEE: 0-7803-1254-6/93*, 1993

[4]: I. Dobson, Stability of Ideal Thyristor and Diode Switching Circuits, *IEEE Transactions on Circuits and systems: Fundamental theory and applications,* Vol.42, No.9, And September 1995

[5] R. Toyoshima, T. Funaki, T. Hikihara, "Anomalous Phenomenon of Conduction Angle in TCR-SVC and Its Control" 2004 35th Annual lEEE Power Electronics Specialirrs Conference

[6] M.Rostami, S.H.Fathi, M.Abedi, "Switch time bifurcation elimination analysis in SVC plants" September 2004, ELSIVIER, Electric Power System

[7] T. Funaki, Member, IEEE, Kouto Nakagawa,"The Origin of Nonlinear Phenomena in TCR-SVC Associated With Parametric Excitation of Intrinsic Oscillation and External Excitation" JOURNAL OF LATEX CLASS FILES, VOL. 6, NO. 1, JANUARY 2007

[8] L.J.Bohmann, R.H.Lesseter, "Harmonic interactions in Thyristor Controlled circuits", *IEEE, Trans. On Power delivery*, Vol.4, No.3, July 1989

[9] S. G. Jalali and R. H. Lasseter, "Harmonic interaction of power systems with static switching circuits," Power Electronics Specialists Conj: June 1991, M.I.T., MA, pp. 330-337.

[10] X.Chen, W.Zhang, and W.Zhang,"Chaotic and subharmonic oscillations of a nonlinear power system," IEEE Trans. on Circuits and Systems II, Vol. 52, No. 12, pp.811-815, 2005

[11]: J.H.B.Deane, D.C.Hamill, Instability, subharmonic and chaos in power electronic systems, *IEEE, Trans. On power electronics,* Vol.5, No.3, July 1990

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