# Chaos and Control of Chaos in Current Controlled Power Factor Corrected AC-DC Boost Regulator

Arnab Ghosh[1], Dr. Pradip Kumar Saha[2], Dr. Goutam Kumar Panda[3]
*(Assistant Professor, Electrical Engineering Department, Gargi Memorial Institute of Technology, Kolkata, India)
** (Professor & Head, Department of Electrical Engineering, Jalpaiguri Govt. Engineering College, Jalpaiguri, India)
*** (Professor, Department of Electrical Engineering, Jalpaiguri Govt. Engineering College, Jalpaiguri, India)

***ABSTRACT:*** *In these modern research areas the Non-linear Dynamics is a very popular topic, the researchers study the nonlinear behaviour of every system which can be an industrial machine/instrument or a theoretical aspect. Prior researchers already studied the nonlinear dynamics of Current Controlled DC-DC Boost Converter. But the Power Factor Corrected Boost Converter is a circuit which is used in very practical purpose where the input is AC, the AC is rectified to DC by diode bridge rectifier and the rectified DC is to feed the boost converter i.e. conventional pure DC supply is replaced by the rectifier DC. In this converter the circuit is designed specially as input power factor can maintain unity so it is called Power Factor Corrected (PFC) Boost Converter. This paper aims to develop a circuit for PFC boost converter to observe Phase-Portrait diagrams and also discuss the control of chaos.*

***Keywords:*** *AC-DC PFC Boost Regulator, State Equations, Phase-Portrait Diagrams, Control of Chaos.*

## I. INTRODUCTION

Power factor correction converter (PFC) is an important area of study and research in power electronics motivated by practical applications [1]. This AC-DC converter provides DC voltage at the output with high input power factor. In fact, a low power factor reduces the power available from the utility grid, whiles a high harmonic distortion of the line current causes EMI problems and cross interferences through the line impedance between different systems connected to the same grid. It is usually assumed that the output ripple can be neglected by using a huge output capacitor, which is not acceptable in design due its high cost and size. Thus many efforts are being done to develop interference systems, therefore to ensure a minimum distortion and a power-factor close to the unity. One of the most common circuits used to achieve unity power factor is the boost Power Factor Correction circuit.

In last decade, studies of complex behaviour in switching power converters have gained increasingly more attention from both the academic community and the industry. Various kinds of nonlinear phenomena, such as bifurcation and chaos have been revealed [2][3]. Chaos could be described as noise like, bounded oscillations with an infinite period found in nonlinear, deterministic systems [4]. These complex behaviours implying instability can be observed by changing circuit parameters, or enclosing the accessional control method when the circuit parameters are fixed. The occurrence of bifurcation and chaos in power electronics was first reported in the literature in the late 1980 [5][6]. In [7] the chaotic behaviour in a buck converter with certain parameter range was verified theoretically and experimentally.

Deane [8] first discussed the route to chaos in a current controlled boost converter. Chan and Tse [9], S. Banarjee and K. Chakrabarty [10] studied various types of routes to chaos and their dependence upon the choice of bifurcation parameters.

Recently some nonlinear behaviours in the PFC boost converter have been reported [11].

The possibility of controlling nonlinear chaotic dynamical systems has been subjected to extensive investigation. The prior researchers focused on control of Chaos by means of small, time-dependent parameter or input perturbations [12,13]. Many different strategies to control chaotic dynamics in nonlinear systems have been proposed in recent surveys of some of the available methods for control of chaos can be found in [14], [15], [16] and [17]. *Time-Delayed Auto Synchronization (TDAS)* was proposed by Pyragas in [18]. *Extended Time-Delayed Auto Synchronization (ETDAS)* was proposed by Socolar et al. [19]. Partial differential equations, initial conditions and the domain of control of a given system have been described in [20], [21], [22]. Mostly developed in the area of control engineering which makes use of *State Feedback Controllers (STC), Adaptive Control Schemes* [23] to solve the problem of controlling chaos.

In this thesis, in order to better understand the dynamics of PFC boost regulator, model of CCM is considered to analyze its behaviours. The modelling and simulation aspects of current-mode controlled PFC boost regulator are operating in chaotic regime are addressed. Firstly, the numerical simulation of chaotic and discontinuous system is presented, so that the results reflect the true behaviour, as an extremely challenging task for any simulation tool. Secondly, MATLAB/Simulink is used to compare the results obtained by numerical simulation.

## II. DESIGN CONCEPT OF AC–DC PFC BOOST REGULATOR

DC power supplies are extensively used inside most of electrical and electronic appliances such as in computers, monitors, televisions, audio sets and others. The high power non linear loads (such as static power converter, arc furnace, adjustable speed drives etc) and low power loads (such as fax machine, computer, etc) produce voltage fluctuations, harmonic currents and an imbalance in network system which results into low power factor operation of the power system. There is a need of improved power factor and reduced harmonics content in input line currents as well as voltage regulation during power line over-voltage and under voltage conditions. The mains AC input voltage is rectified and supplied to the Boost converter, which mainly consists of an inductor, a power MOSFET, a power diode and a bulk capacitor. The Error Amplifier 2 with predetermined reference voltage senses the DC output voltage across the capacitor. The error voltage $V_{e2}$ from the amplifier then is fed to the multiplier and multiplied with the template sinusoidal input voltage to get the reference current, $i_L^*(reference)$. The error $I_{e1}$ that is the output of Error Amplifier 1, as the difference of $i_L(actual)$ and $i_L^*(reference)$ provides the correct timing logic for the switching driver circuit to turn on and off the MOSFET in the Boost converter. Hence, this method ensures continuous conduction of current flow for the full cycle of the input voltage.

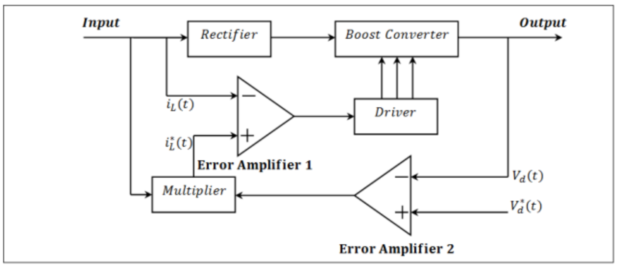


Fig. 1: PFC control strategy block diagram

## III. STATE EQUATIONS FOR MODELING OF BOOST CONVERTER

There are two states[1] of the circuit depending on whether the controlled switch is open or closed. When switch is closed, the current through the inductor rises and any clock pulse arriving during that period is ignored. The switch opens when reaches the reference current. When switch is open, the current falls. The switch closes again upon the arrival of the next clock pulse.

*The State Equations during "ON" period*

$$\frac{di_L}{dt} = \frac{V_{in}}{L} - \frac{r_i * i_L}{L}$$

$$\frac{dv_C}{dt} = \frac{-v_C}{C(R+r_C)}$$

*The State Equations during "OFF" period*

$$\frac{di_L}{dt} = \frac{V_{in}}{L} - \frac{i_L}{L}\left(r_i + \frac{R*r_C}{(R+r_C)}\right) - \frac{v_C*R}{L(R+r_C)}$$

$$\frac{dv_C}{dt} = \frac{R*i_L - v_C}{C(R+r_C)}$$

## IV. PROPOSED MODEL OF AC–DC PFC BOOST REGULATOR

Like many areas of engineering, the PFC converter is motivated by practical applications and it is widespread in many implementations before it is thoroughly analyzed and most of its problems are uncovered. Many prior researchers investigated the boost PFC converter with current-mode control by using linear models. They introduce some assumptions to direct the system toward linear models. They assumed that the output ripple is neglected by using a huge output capacitor, which is not acceptable in design due to its high cost and size. Also, they replaced the input time-varying voltage with its root mean square (rms), ignoring the effect of the time variation. With all these assumptions, they derived the linear system ignoring the effect of nonlinearity, introduce a small-signal equivalent circuit, and discussed the stability problem depending on these linear treatments. The main feature of this PFC circuit is the use of a multiplier that introduces its nonlinearity.

Modelling, simulation and circuit analysis are done by MATLAB 7.8.0 (R2009a) respectively. These not only help in developing a deeper understanding of PFC converters but are also extremely important tools for design verification and performance evaluation. These techniques help in the evaluation of a system without risking the huge cost and effort of developing and testing an actual converter.

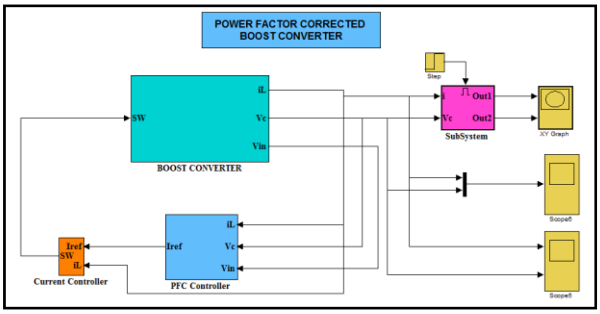


Fig. 2: Boost PFC ac-dc regulator under fixed frequency current mode control.

## V. PHASE-PLANE CURVES

Simulation of PFC Boost Converter is done by MATLAB 7.8.0(R2009a). The model is totally designed by Simulink blocks. The phase-plane trajectory is constructed between the output capacitor voltage $v_C$ and the inductor current $i_L$ to explain the stability from the nonlinear view point as shown below

***Case I(Period I Operation)***

$$v_s = 220\sin\omega t, L = 40\,\text{mH}, C = 100\,\mu\text{F}, R = 40\,\Omega, K_1 = 400$$

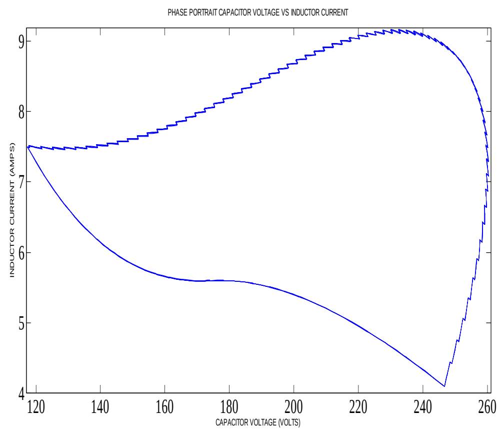


**Fig. 3: Phase Plane Trajectory (Case I) Capacitor Voltage vs. Inductor Current (Period I operation)**

In this operation, all waveforms repeat at the same rate i.e. after an one cycle with the driving clock pulse. It is "Period–I operation". The time domain diagrams of state variables i.e. inductor current and output capacitor voltage repeat after a cycle, so it is a "Period–I operation". The converters have always been designed to operate in only one type of periodic operation. The Phase Plane Trajectory of "Period–I operation" is shown in Fig. 3.

***Case II(Period II Operation)***

$v_s = 220\, sin\, \omega t$ , $L = 40\, mH$ , $C = 100\, \mu F$ , $R = 44\, \Omega$ , $K_1 = 400$

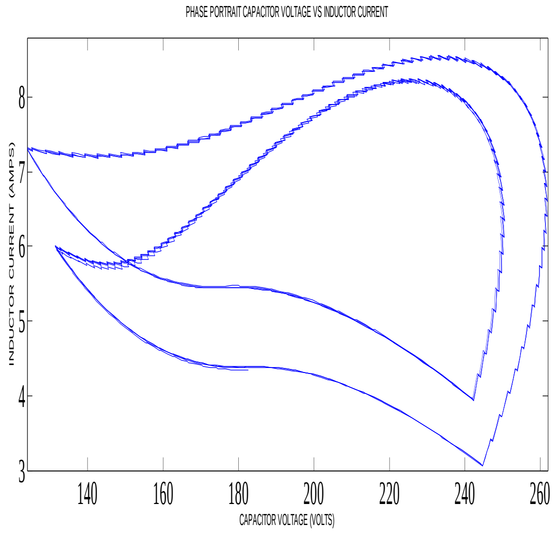


**Fig. 4: Phase Plane Trajectory (Case II) Capacitor Voltage vs. Inductor Current (Period II operation)**

***Case III(Period V Operation)***

$v_s = 220\, sin\, \omega t$ , $L = 40\, mH$ , $C = 100\, \mu F$ , $R = 38\, \Omega$ , $K_1 = 400$

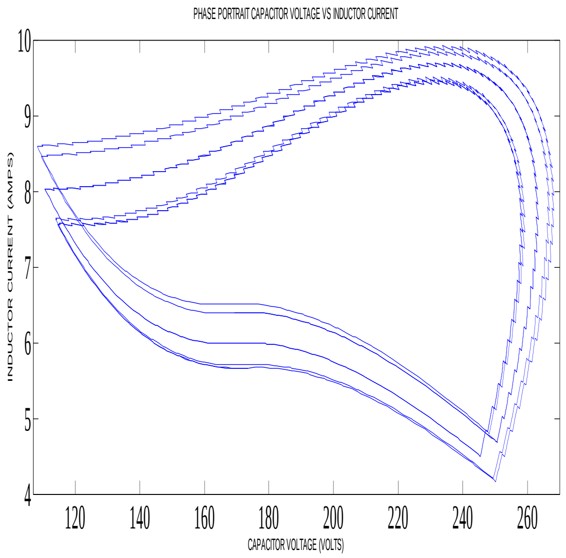


**Fig. 5: Phase Plane Trajectory (Case III) Capacitor Voltage vs. Inductor Current (Period V operation)**

***Case IV(Chaotic Mode Operation)***

$v_s = 220\, sin\, \omega t, L = 40\, mH, C = 100\, \mu F, R = 65\, \Omega, K_1 = 400$

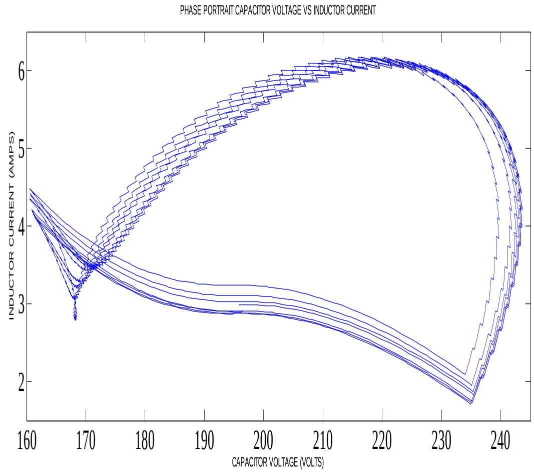


**Fig. 6: Phase Plane Trajectory (Case IV) Capacitor Voltage vs. Inductor Current (Chaotic Mode Operation)**

The time domain diagram of state variables i.e. inductor current and output capacitor voltage repeats after "$n$" times of cycles, so it is a "Chaotic mode operation". Chaos is largely unpredictable long-term evolution occurring in deterministic, nonlinear dynamical system because of sensitivity to initial conditions. The Phase Plane Trajectory of "Chaotic mode operation" is shown in Fig. 6.

## VI. CONTROL OF CHAOS

There are several kinds of methods to controlling chaos (previous discussion), here the TDS method is picked up. Our strategy to stabilize the UPO of the current-mode-controlled boost converter will consist of modifying the reference current with a term proportional to the difference between a linear combination of the present and past states of the system. Precisely, instead of compare it to

$$I_{ref} + \eta(\alpha(v(t) - v(t-1)) + \beta(i(t) - i(t-1)))$$

Where $\eta$ is an overall feedback gain and $\alpha$ and $\beta$ are relative weights. Notice again that, for a period – I solution the feedback signal vanishes. One must bear in mind that, although the mathematical computations to find out the range of parameters that stabilize the orbit can be quite imposing, once those value are known, the actual implementation requires only the knowledge of the period of target orbit in order to form the feedback signal. For the system like PWM – controlled converters the period of any orbit is a multiple of period of the clock used to generate the pulses. More detailed information about the target unstable orbits can be obtained experimentally using, for instance, the techniques exposed in [17], and this can be used to numerically compute the parameter range mentioned above.

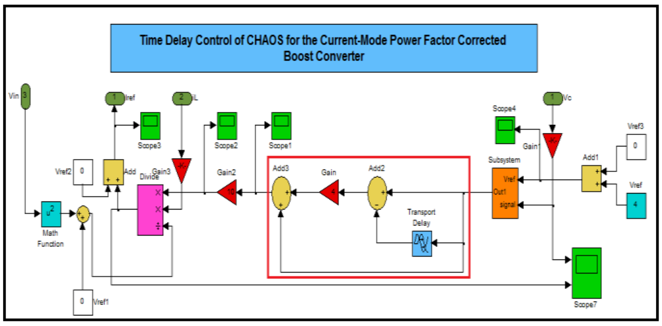


**Fig. 7: MATLAB Model of Time – Delay Feedback Control of Chaos of PFC Boost Converter**

***BEFORE CONTROLLING CHAOS***

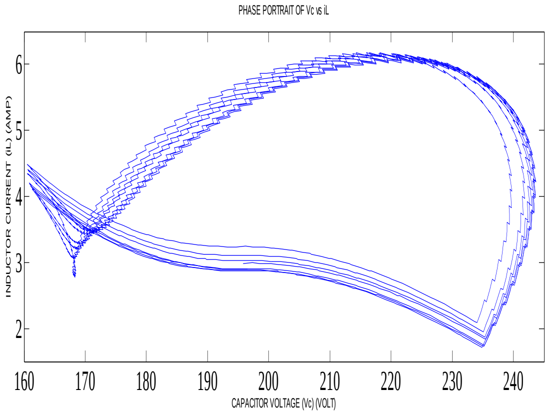


**Fig. 8: Phase Portrait of Capacitor Voltage vs. Inductor Current in Chaotic Mode**

***AFTER CONTROLLING CHAOS***

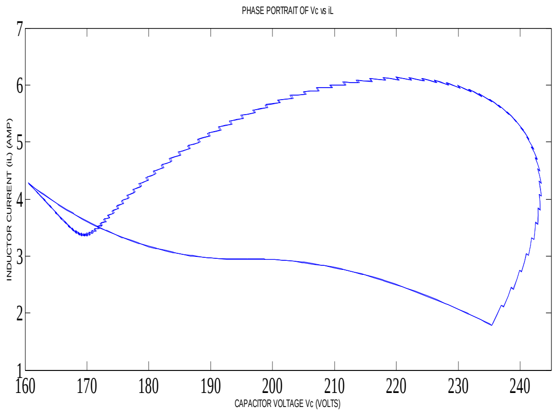


**Fig. 9: Phase Portrait of Capacitor Voltage vs. Inductor Current after Controlling Chaos**

The Chaotic mode phase portrait is shown in Fig. 8, the Time Delay Feedback System is used (Fig. 7) for controlling the chaos. Fig. 9 is shown after controlling the chaos.

## VII. CONCLUSION

The Power Factor Corrected (PFC) AC-DC Boost Regulator with current-mode control has been investigated depending on the nonlinear model. Results highlight that the proposed model of practical PFC regulator, simulation results and phase-portrait diagrams. The phase-plane-trajectory curves are observed by varying value of $resistance$ $(R)$. The value of $load\, resistance$ $(R)$ is increased or decreased; the phase-portrait of output capacitor voltage $(v_C)$ and inductor current $(i_L)$ is going to period I to period II to chaotic-mode. Chaos phenomena are shown by multiple loops on phase-plane diagram. The most important point of all the case studies, if the entire system is operated in chaotic-mode the output capacitor voltage ripples has been minimized by increasing the chaotic-region. The chaos control are also done by time delay feedback system$(TDS)$. We can control entire system in our desired region according to our demand. In a DC-DC converter system, the input voltage is constant and therefore the dynamical behaviour is periodic with the switching frequency . On the other hand, the input voltage of the boost AC-DC PFC regulator system is periodic with the line frequency. The results highlight that the dynamical behaviour is periodic with the line frequency not with the switching frequency and simulation results are also agree with our statements.

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**Arnab Ghosh,** Assistant Professor, Electrical Engineering Department, Gargi Memorial Institute of Technology, Kolkata,WB-700144, B.Tech (Electrical ) from JIS College of Engineering, Kalyani, M.Tech ( Electrical) Specialization: Power Electronics & Drives from Jalpaiguri Govt. Engineering College, Jalpaiguri.

**Pradip Kumar Saha**, Professor and Head, Department of Electrical Engineering, Jalpaiguri Government Engineering College, Jalpaiguri,WB-735102. BE (Electrical) from B.E.College, Shibpore. M.Tech((Electrical) Specialization: Machine Drives & Power Electronics from IIT- Kharagpur. PhD from University of North Bengal. FIE, MISTE, Certified Energy Auditor.

**Goutam Kumar Panda,** Professor, Department of Electrical Engineering, Jalpaiguri Government Engineering College, Jalpaiguri,WB-735102, BE (Electrical ) from J.G.E. College, Jalpaiguri, M.E.E( Electrical) Specialization: Electrical Machines & Drives from Jadavpur University. PhD from University of North Bengal. FIE, MISTE, Certified Energy Auditor.