Study of Chaos and Dynamics of DC-DC Converters

BY

SAI RAKSHIT VINNAKOTA

ANUROOP KAKKIRALA

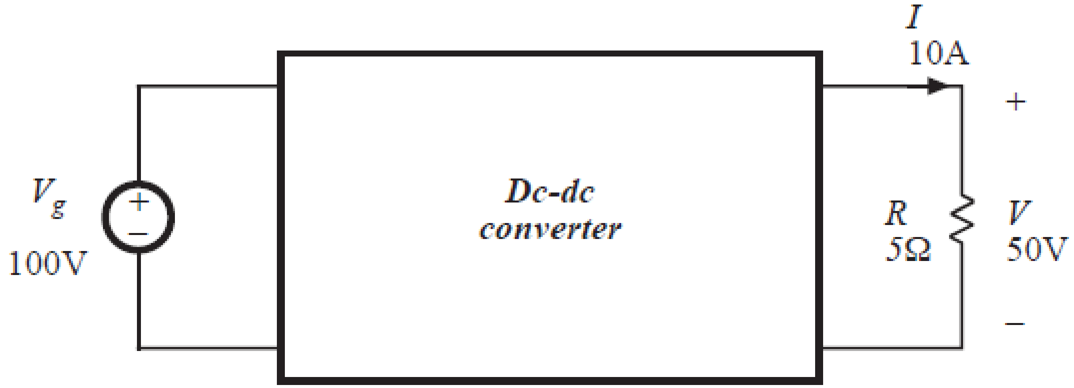
VIVEK PRAYAKARAO

What are DC-DC Converters??

- A **DC-to-DC converter** is an electronic circuit which converts a source of direct current (DC) from one voltage level to another.

Types of DC-DC Convertors:

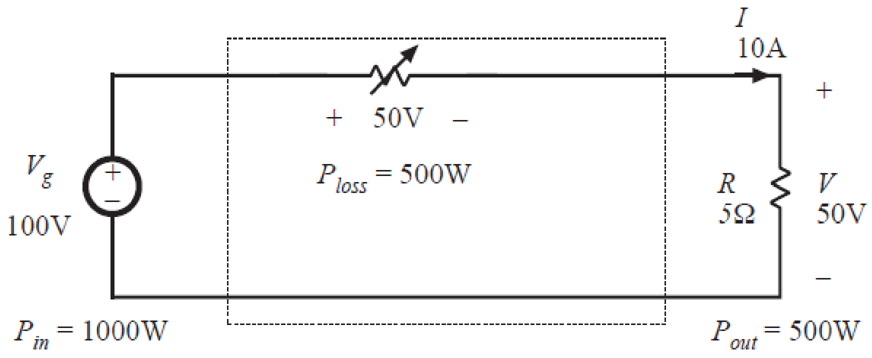
- **Linear (Dissipative)**
- **Switched-mode conversion**
- **Magnetic**



Input source: 100V
Output load: 50V, 10A, 500W
How can this converter be realized?

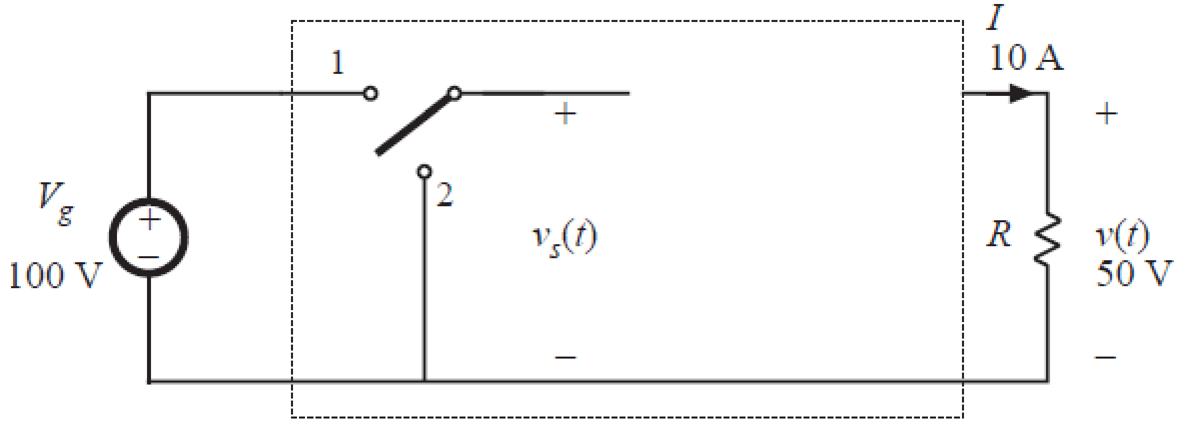
Linear or Dissipative realization

- Linear regulators can only output at lower voltages from the input.
- They are very inefficient when the voltage drop is large and the current is high
- They dissipate heat equal to the product of the output current and the voltage drop.
- The inefficiency wastes power and requires higher-rated and consequently more expensive and larger components.



Switched-mode conversion

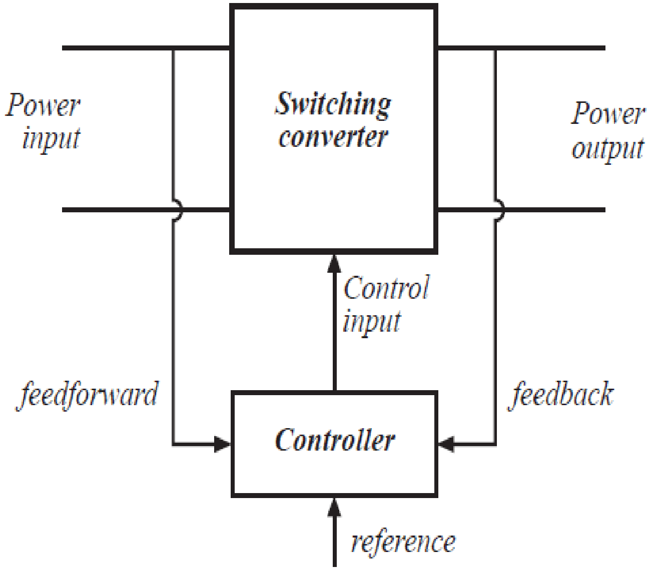
- Electronic switch-mode DC to DC converters convert one DC voltage level to another, by storing the input energy temporarily and then releasing that energy to the output at a different voltage.
- This conversion method is more power efficient and is beneficial to increase the running time of battery operated devices.
- Drawbacks of switching converters include complexity, electronic noise.



Non Linearity !!

Why is it important to study the dynamics??

- The semiconductor switching devices have intrinsically nonlinear DC characteristics: BJTs, MSOFETs, IGBTs, thyristors, diodes.
- They also have nonlinear capacitances, and most suffer from minority carrier charge storage.
- The control circuits usually involve nonlinear components: comparators, pulse-width modulators (PWMs), multipliers etc.



So, study of dynamics and chaos in such circuits help in the design, analysis and control of power converters.

Types of DC-DC Converters

- **Buck Converter**

A **buck converter** (step-down convertor) is a DC -to- DC power converter with an output voltage less than its input voltage.

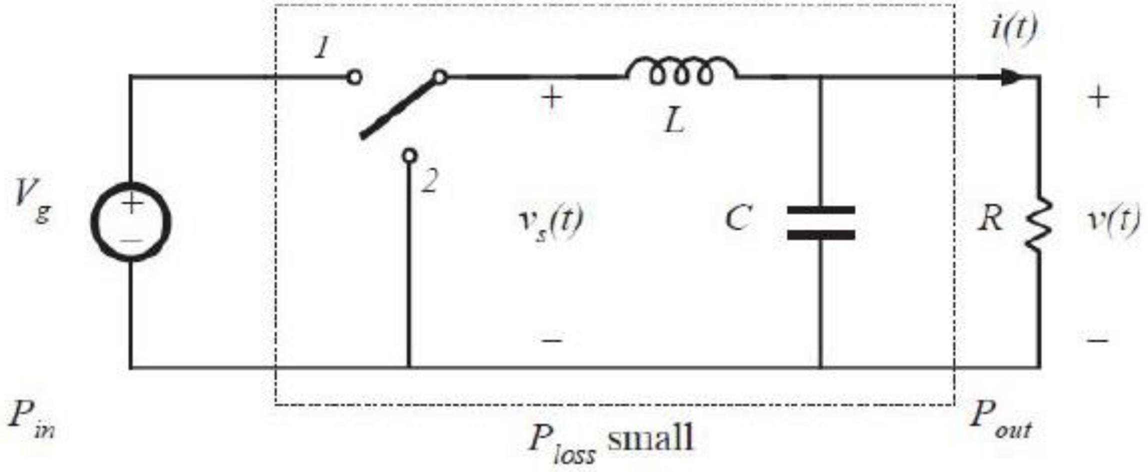
- **Boost Converter**

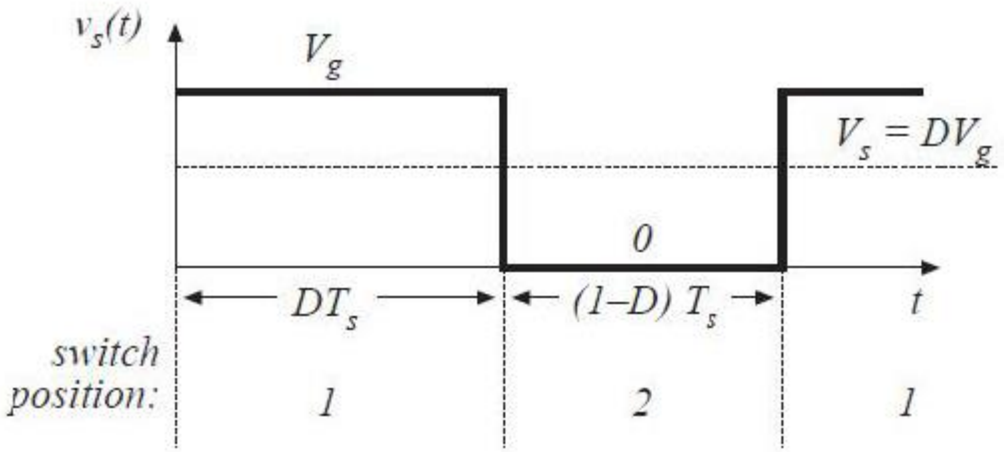
A **boost converter** (**step-up converter**) is a DC-to-DC power converter with an output voltage greater than its input voltage.

- **Buck-Boost Chopper**

A **buck–boost converter** is a DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude.

Buck Converter





The average value of $v_s(t)$, which would then be equal to DVg. Therefore,

Vs = D Vg

Principle of Operation of a Buck Converter

- DC-DC Buck Converter exhibits a wide range of bifurcation and chaos phenomena even for small changes in the parameter values of the device.
- The differential equations governing the circuit are

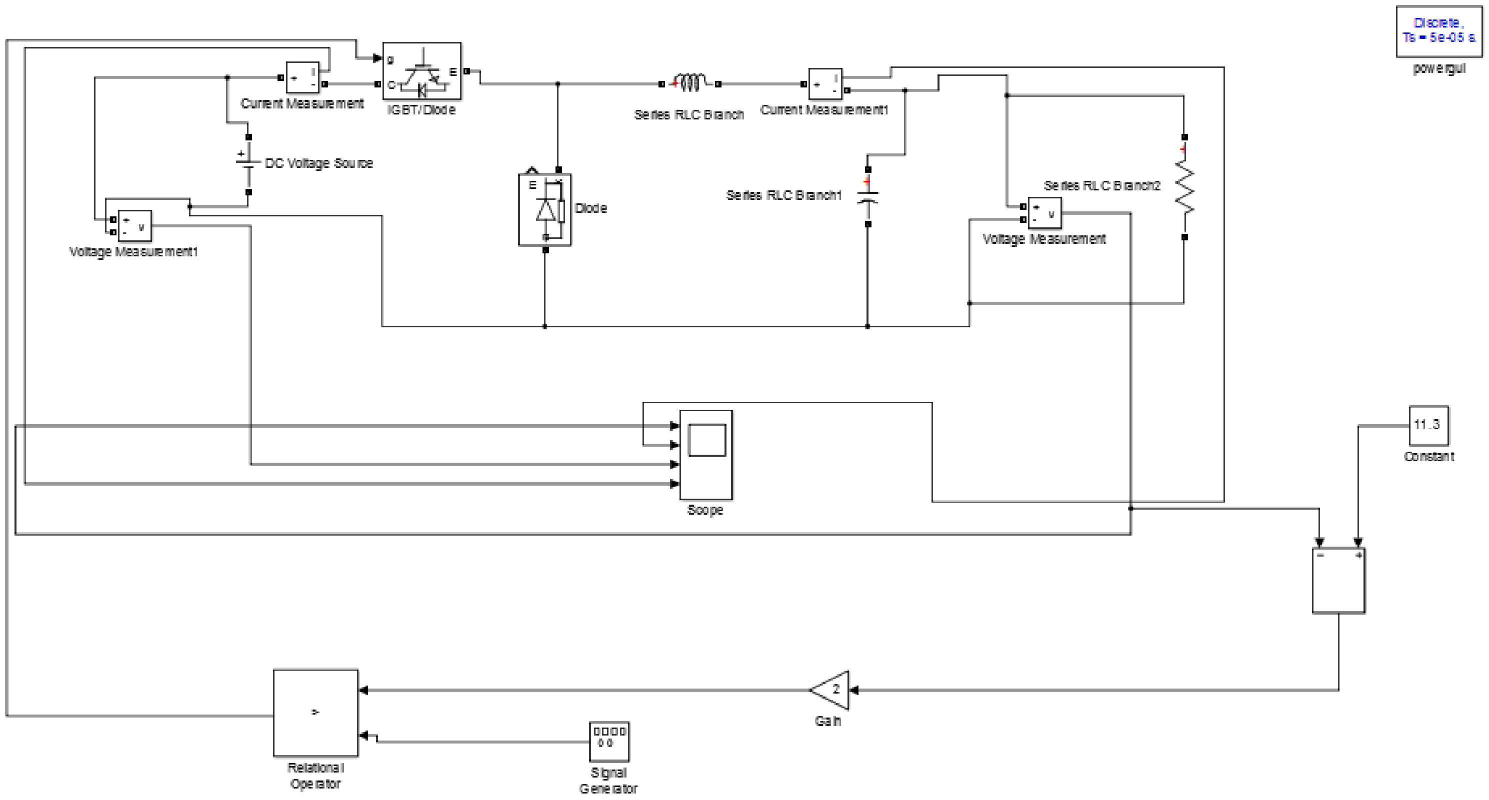
$$\frac{dv}{dt} = \frac{-1}{C} i(t) - \frac{1}{RC} v(t)$$

$$\frac{di}{dt} = -\frac{1}{L} v(t) + \frac{E}{L} \delta(t)$$

$$V_c(t) = a(V(t) - V_{ref})$$

$$V_r(t) = V_L + (V_u - V_L)\frac{t \bmod \cdot T}{T}$$

Simulation of the Circuit

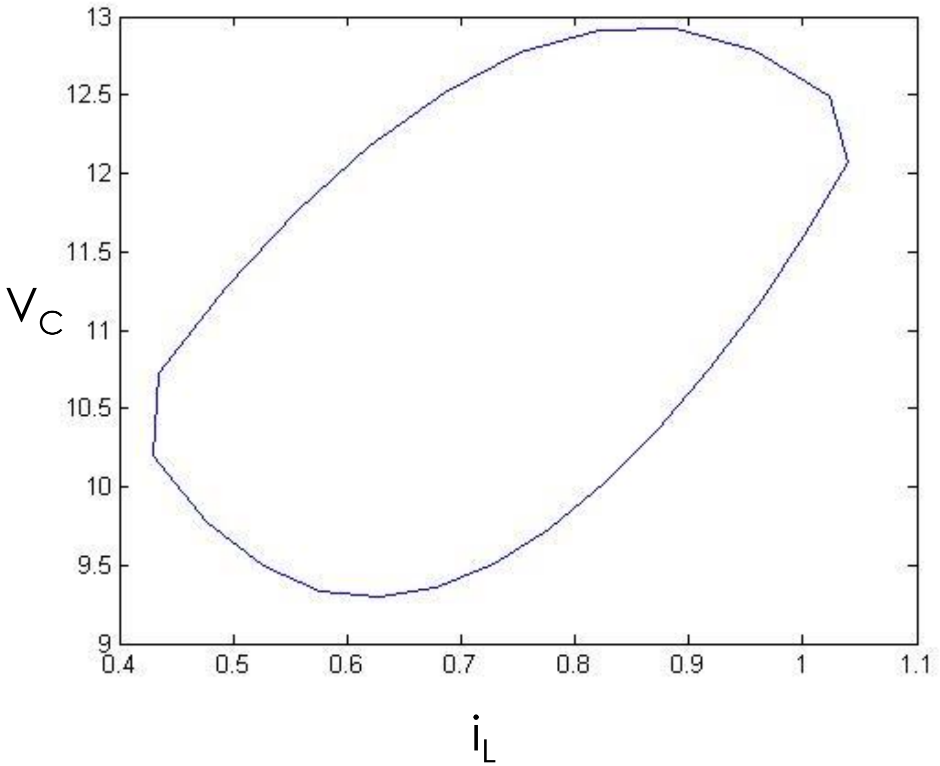


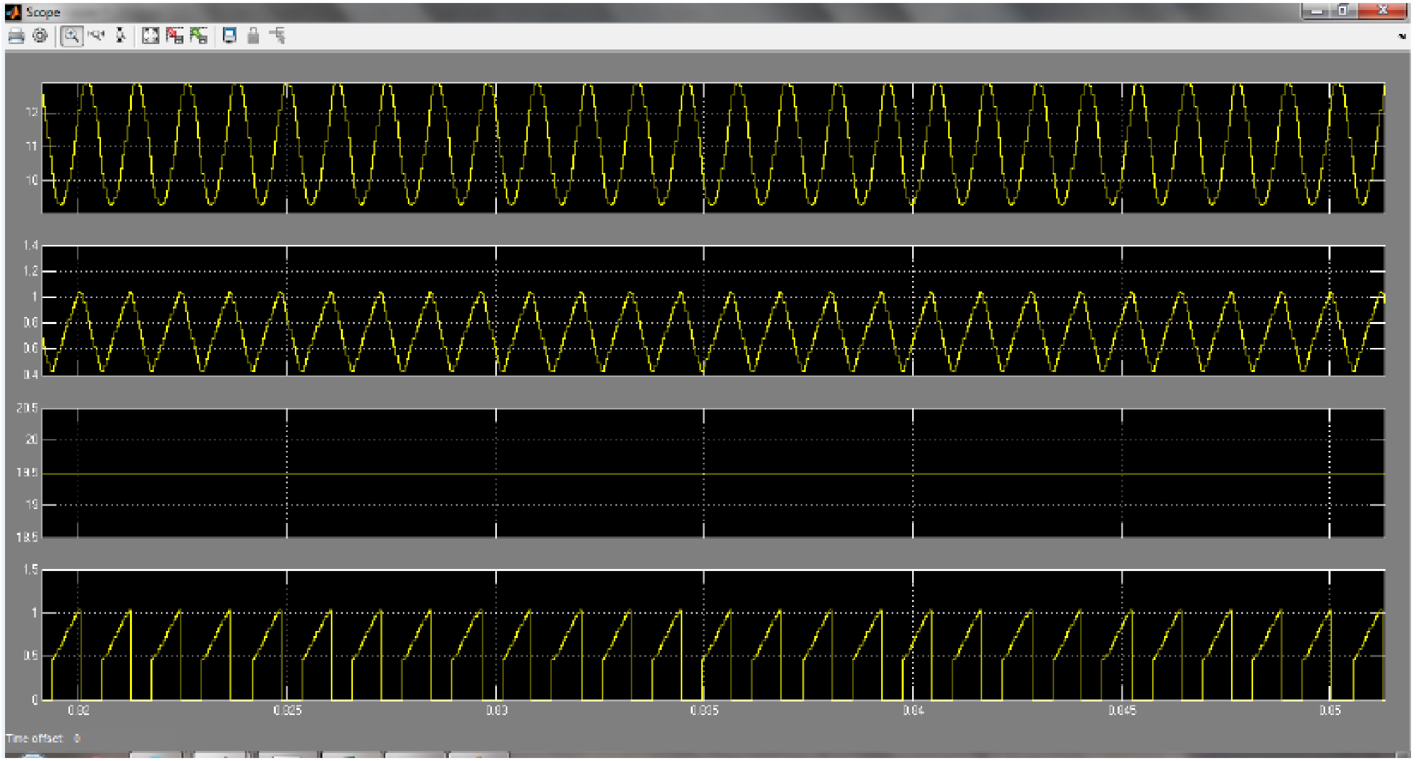
The parameters chosen are V_{in}=I5V - 40V , V_{ref} = I1.3V,

L=10 mH, C=25 μF, R=15 Ω, a=2, V_L=2V, V_U=5V, T=400 μs;

Simulation Results

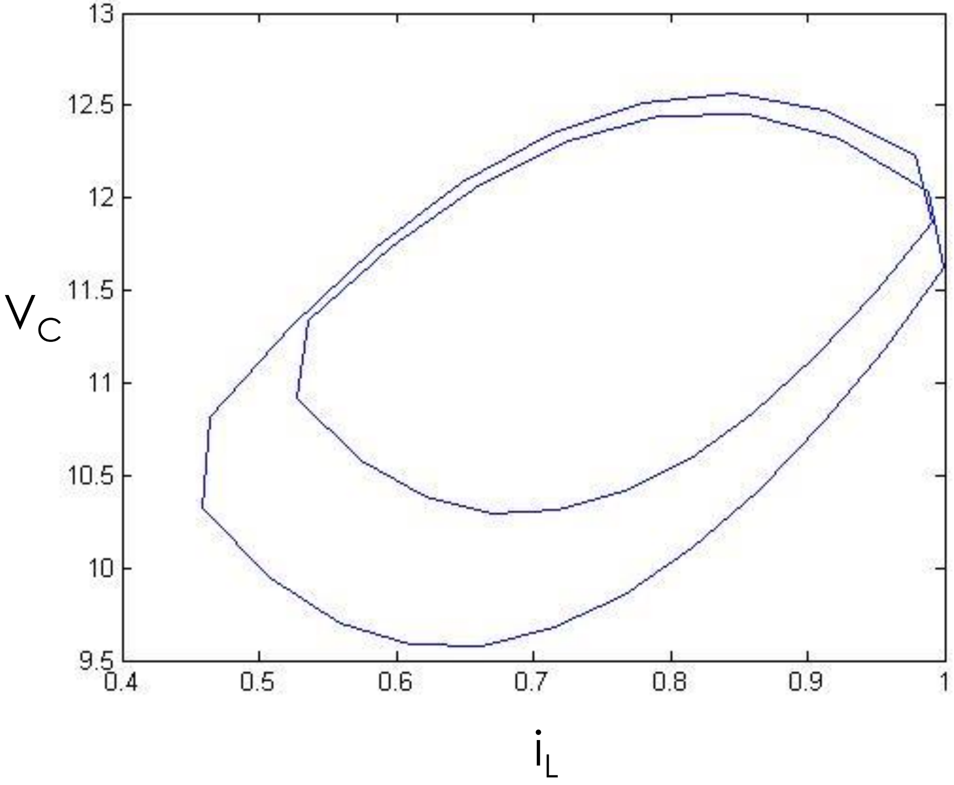
Period 1 at $V_i = 19.5$ V

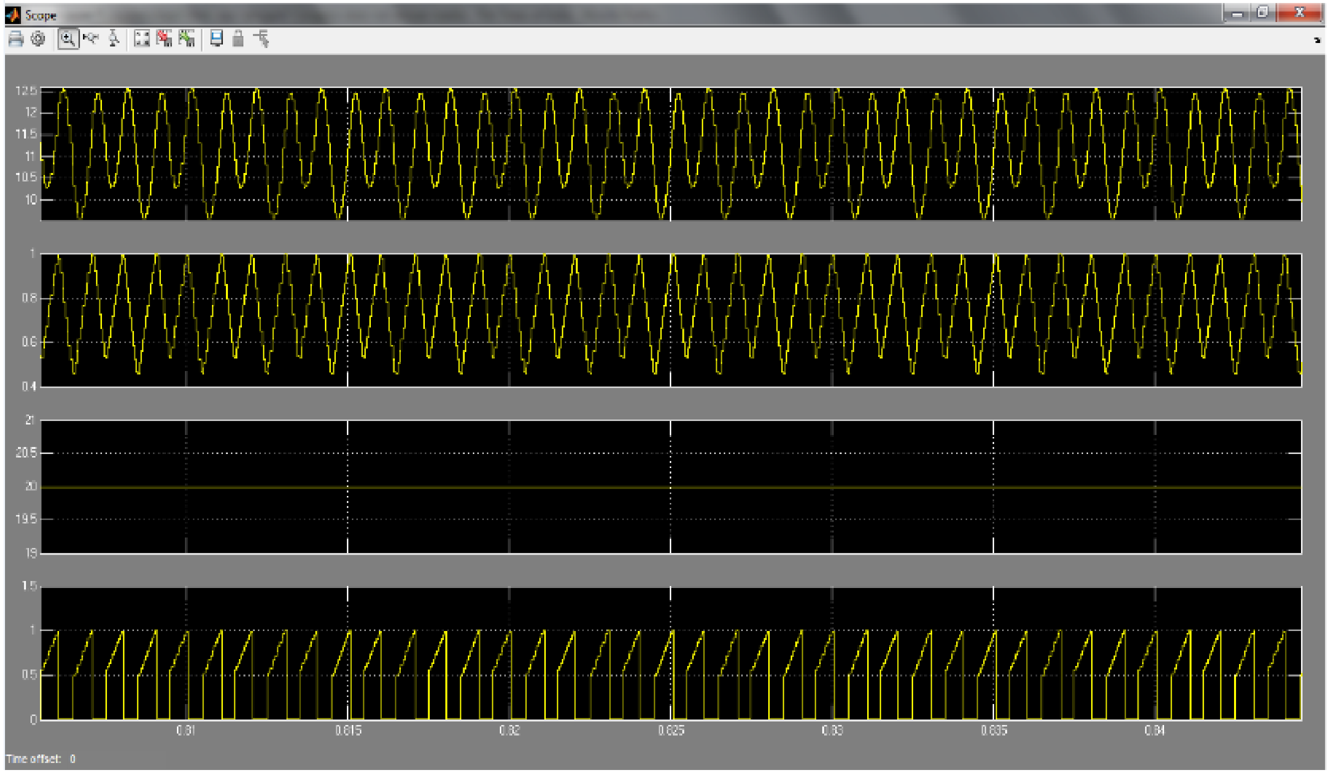




Simulation Results cont…

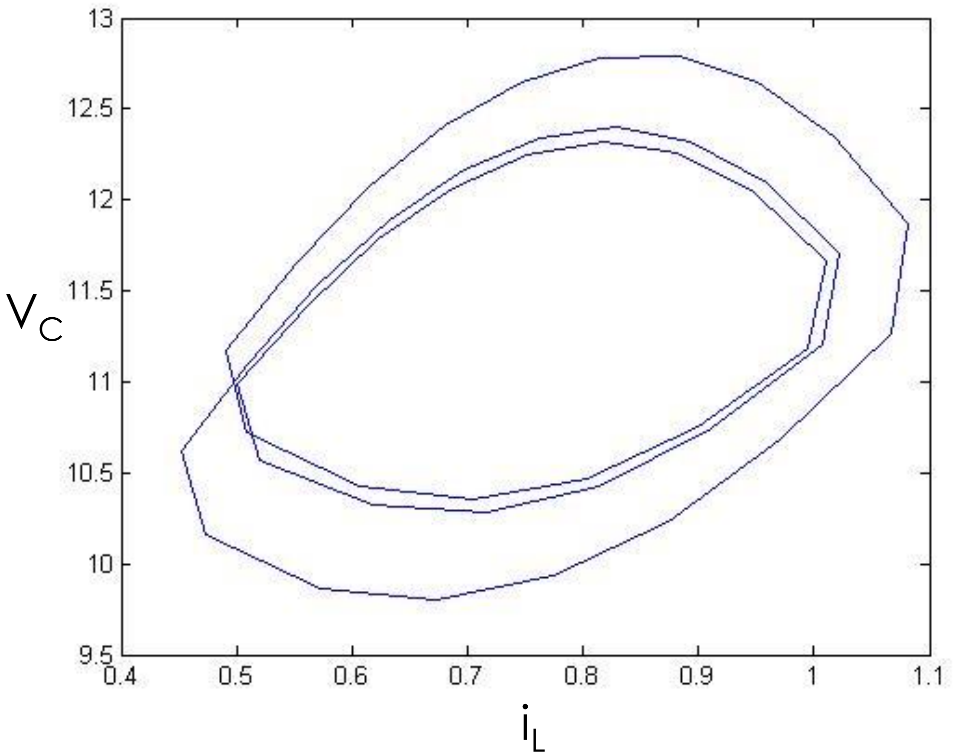
Period 2 at V_i = 20 V

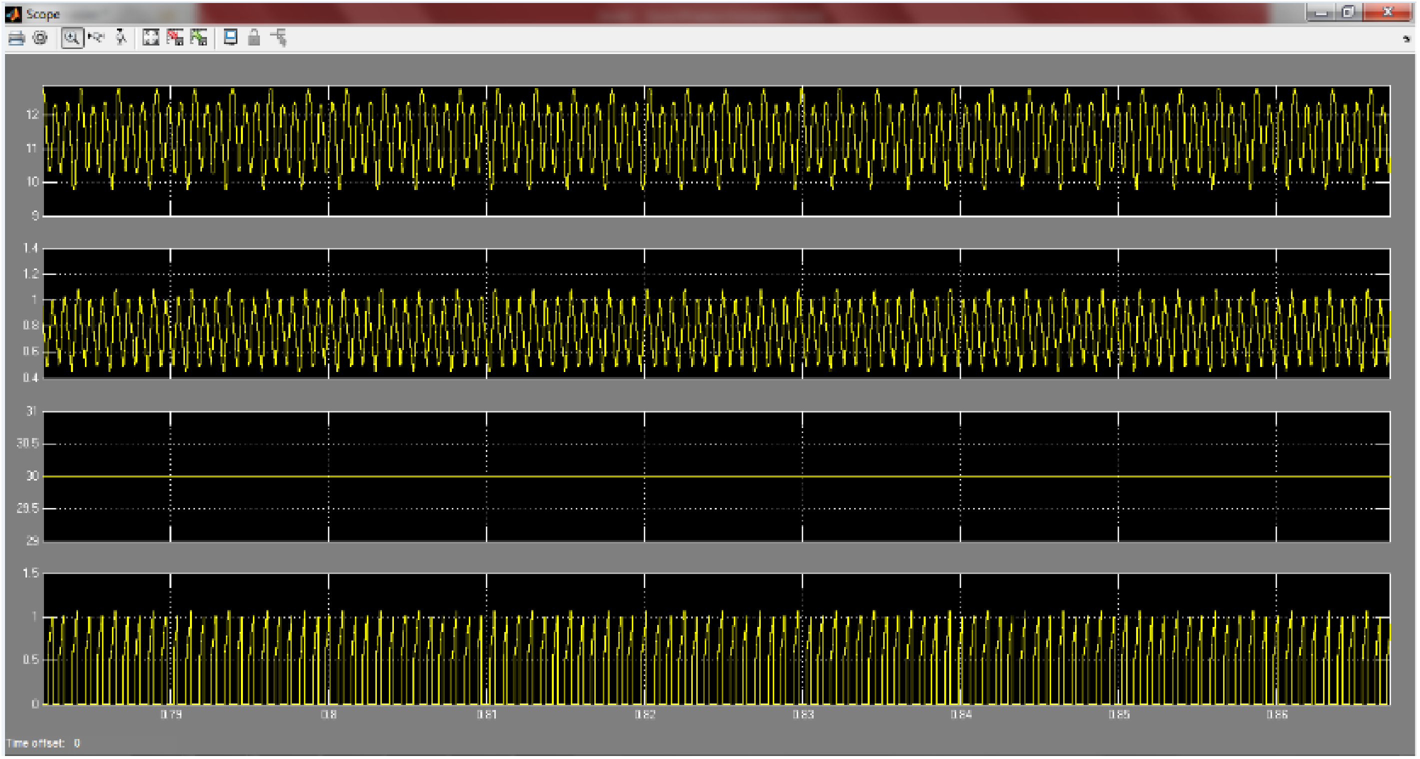




Simulation Results cont…

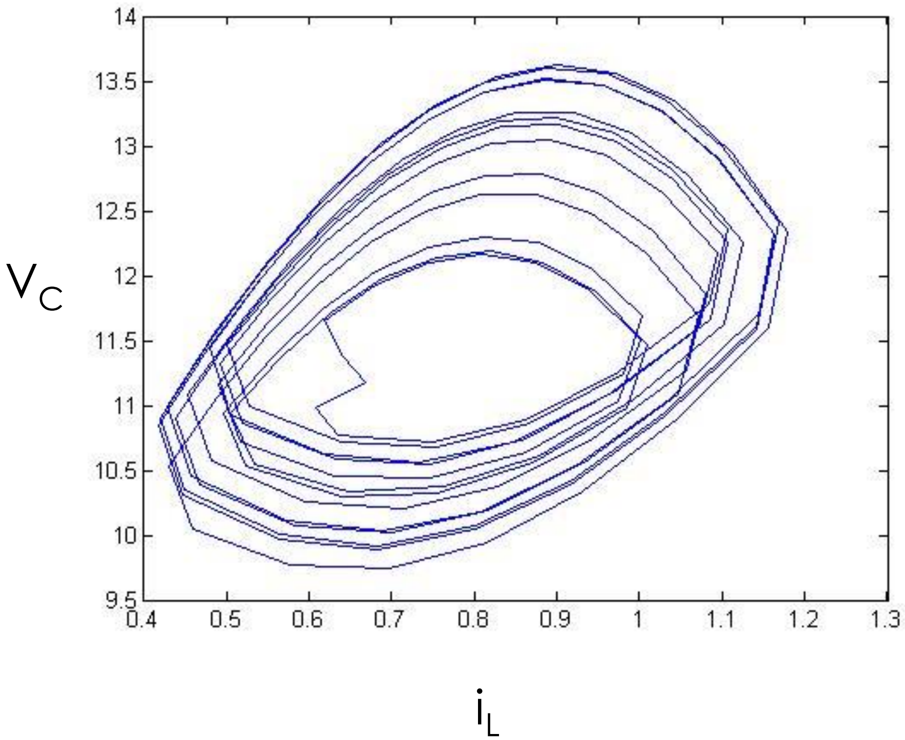
Period 3 at V_i = 30 V

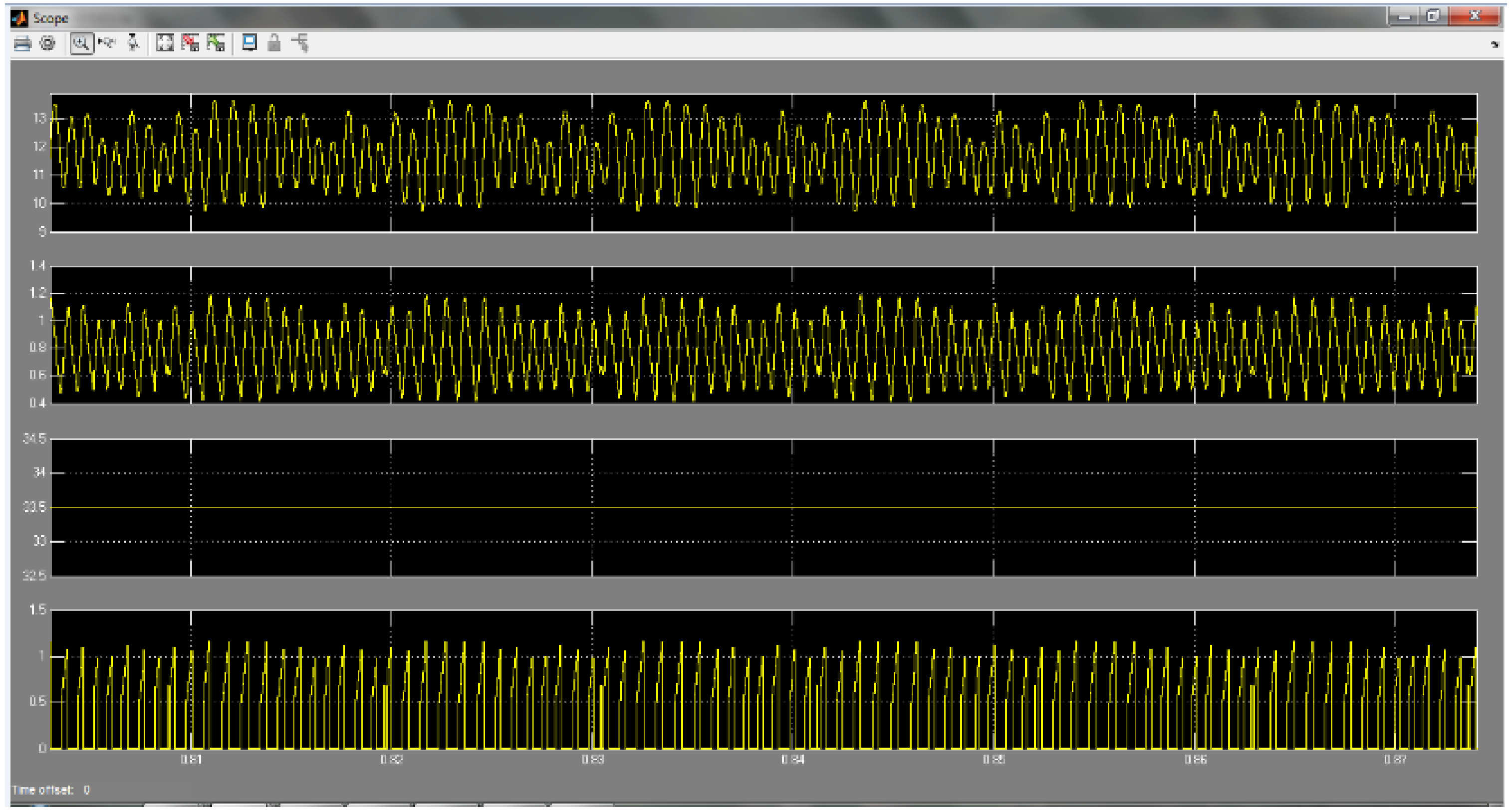




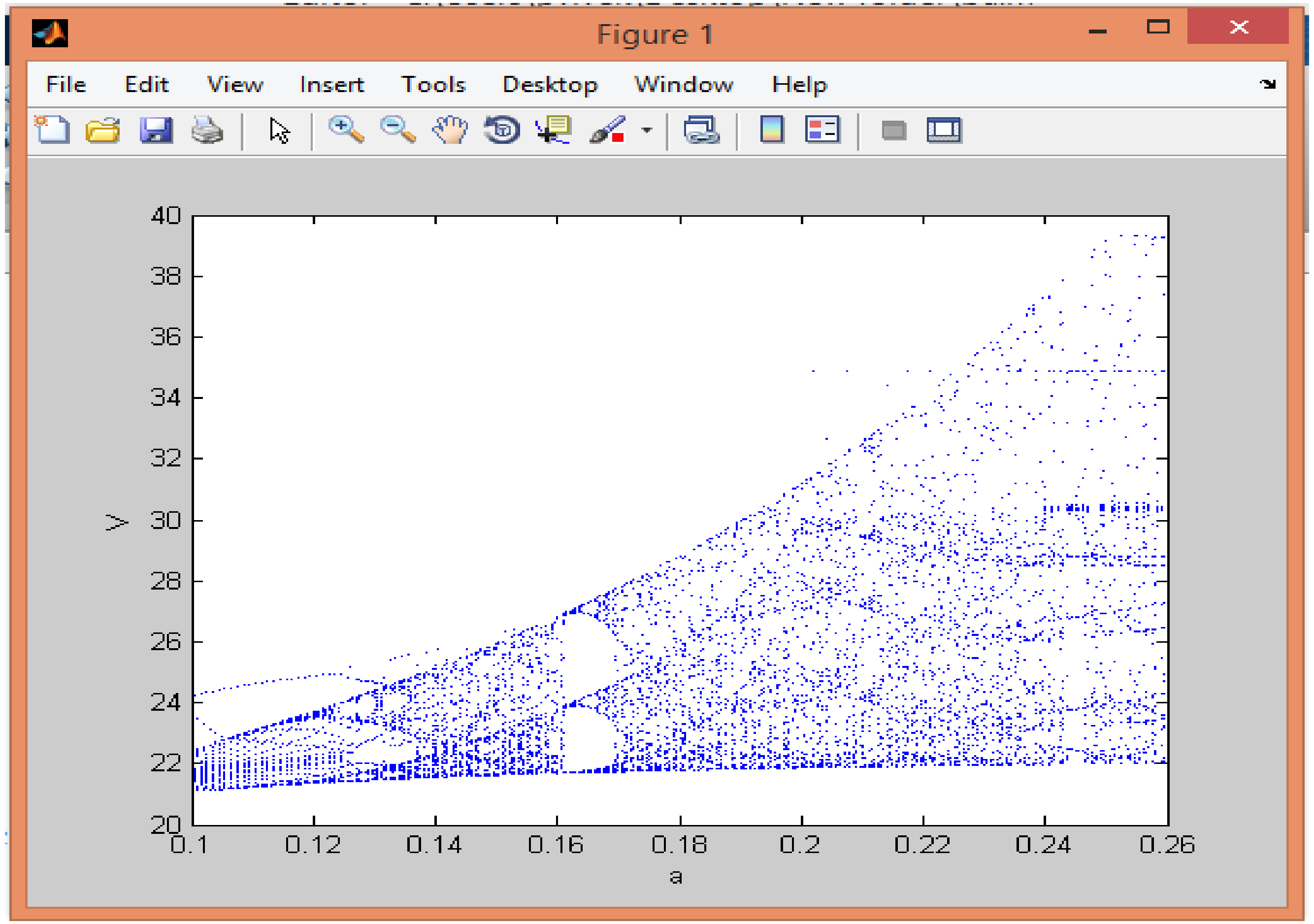
Simulation Results cont…

Chaos at V_i = 33.5 V



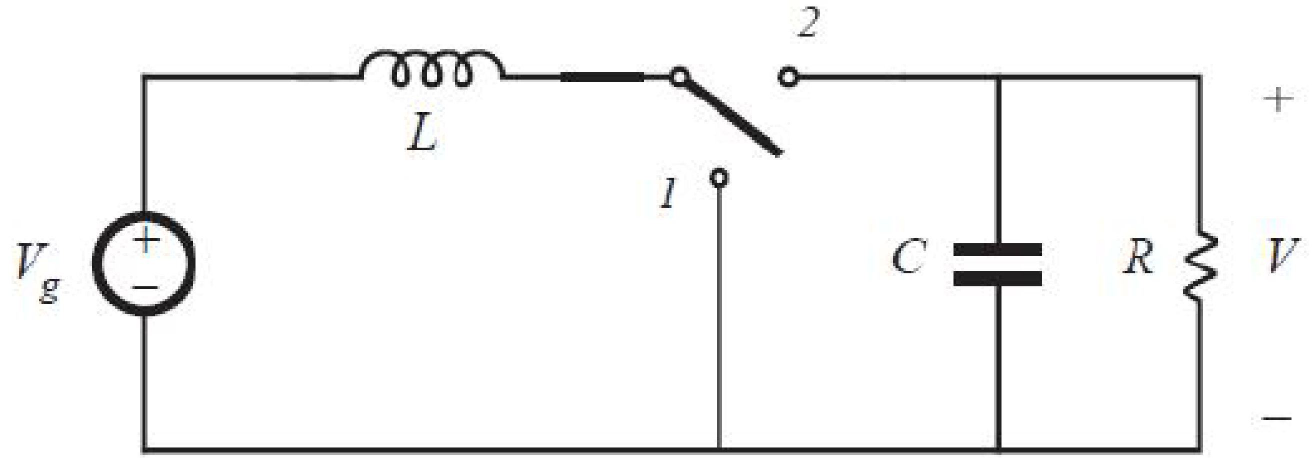


Bifurcation Diagram



Gain 'a' was chosen as the bifurcation parameter. This diagram clearly shows that the period-doubling route to chaos is initiated as a reaches 0.22.

Boost Converter



- The input-output relation for this boost circuit would be:

Vo =Vg/(1 - D)

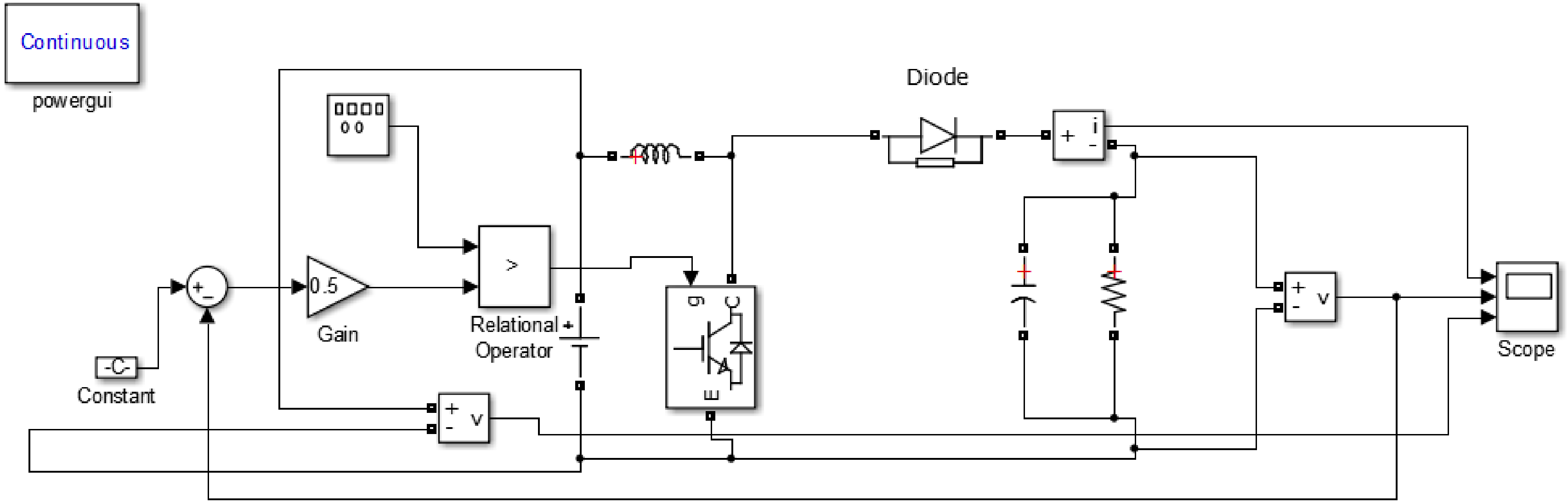
Principle of Operation of a Boost Converter

- DC-DC Boost Converter exhibits a wide range of bifurcation and chaos phenomena even for small changes in the parameter values of the device.
- The differential equations governing the circuit are

$$\frac{d\hat{u}_C}{dt} = \frac{1}{RC}\left(\frac{kV_o^2}{V_{in}} - 1\right)\hat{u}_C + \frac{V_{in}}{V_o C}\hat{i}_L$$

$$\frac{d\hat{i}_L}{dt} = -\frac{1}{L}\left(kV_o + \frac{V_{in}}{V_o}\right)\hat{u}_C$$

Simulation of the Circuit

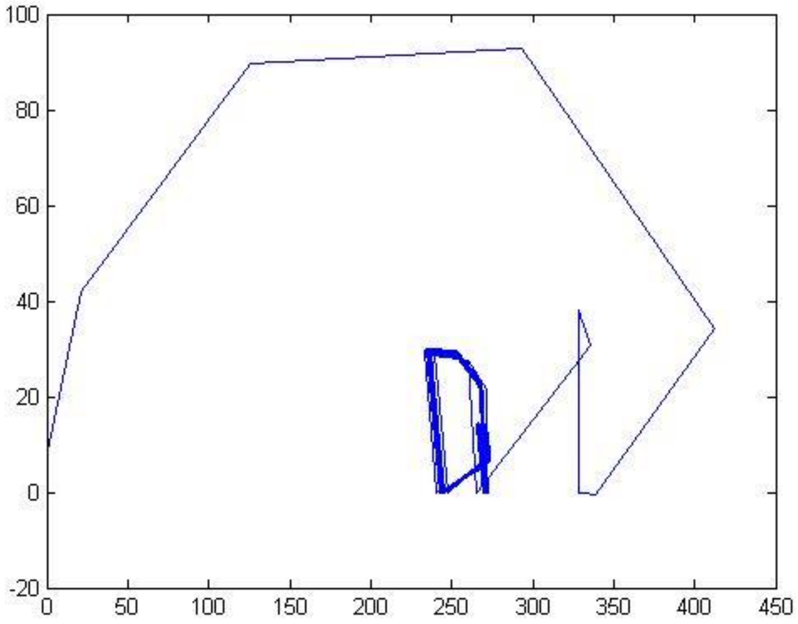


The parameters chosen are
V_{in}=220, V_{ref} = 330V,
L=500 μH, C=100 μF, R=33-45 Ω,
a=2, V_L=2V, V_U=5V, T=50 μs;

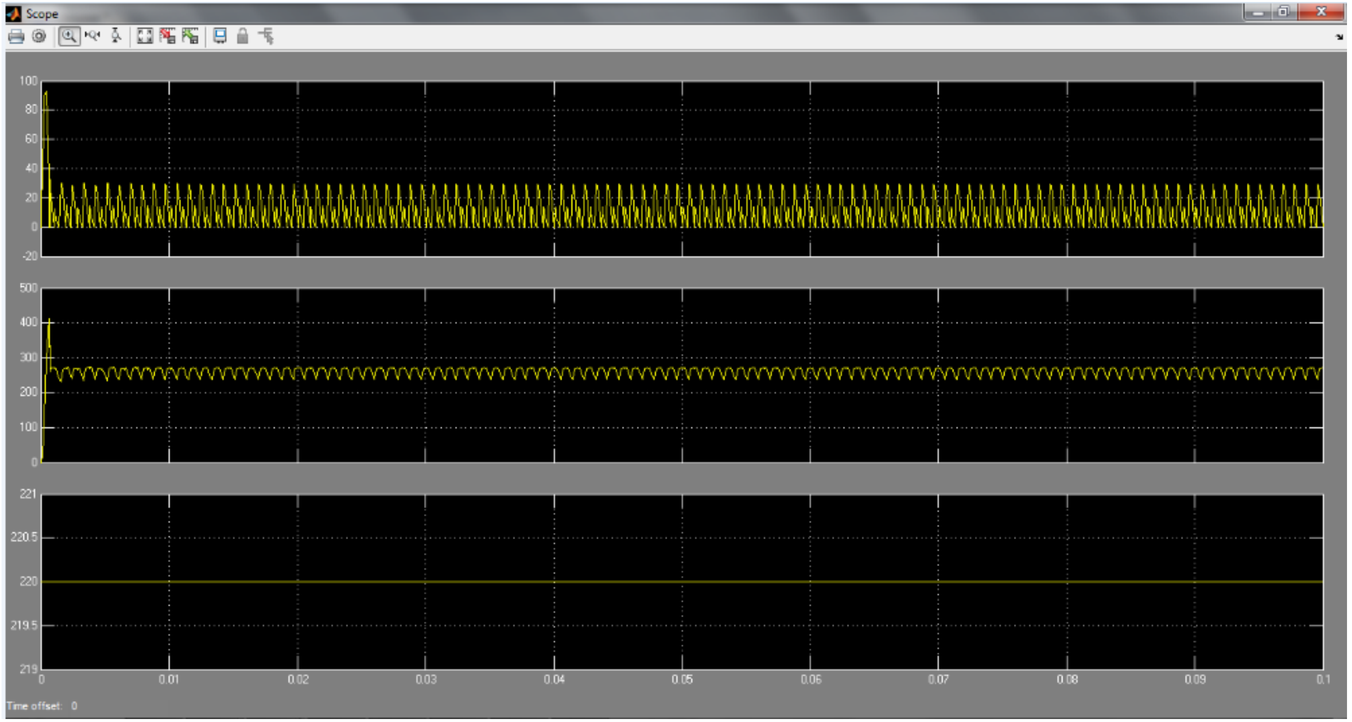
Simulation Results:

Attractor at V_i = 19.5 V

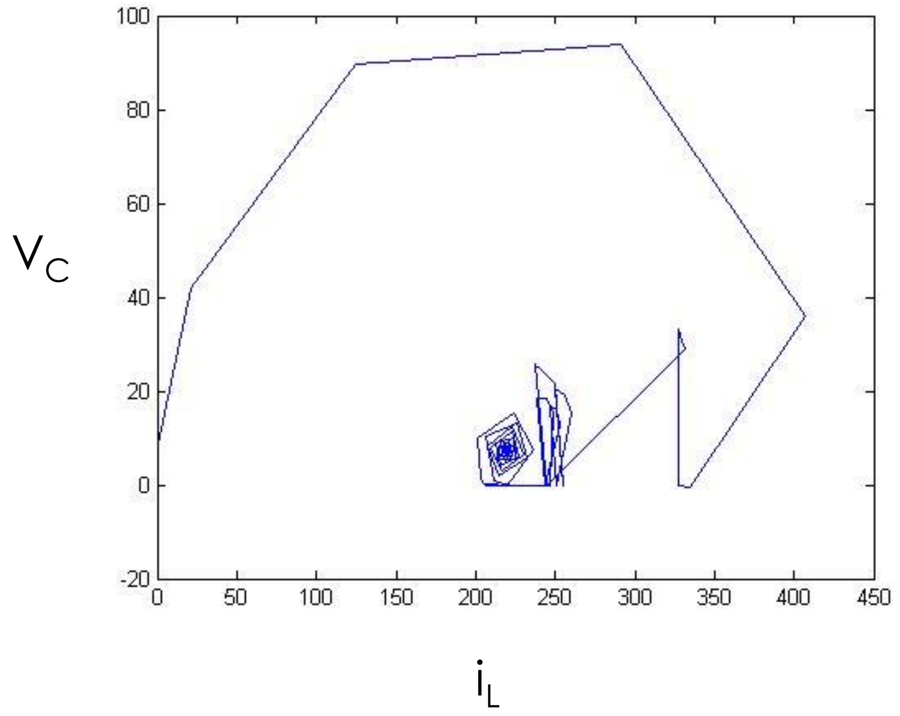
V_C

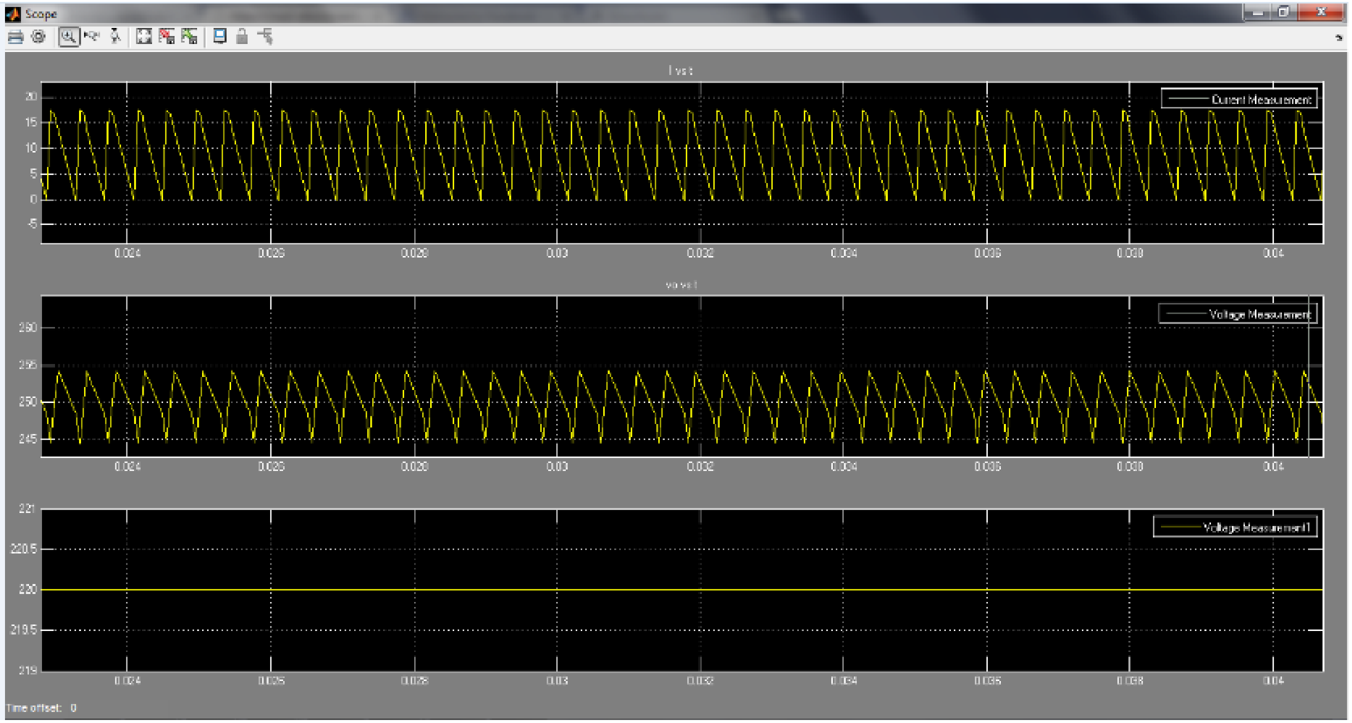


i_L

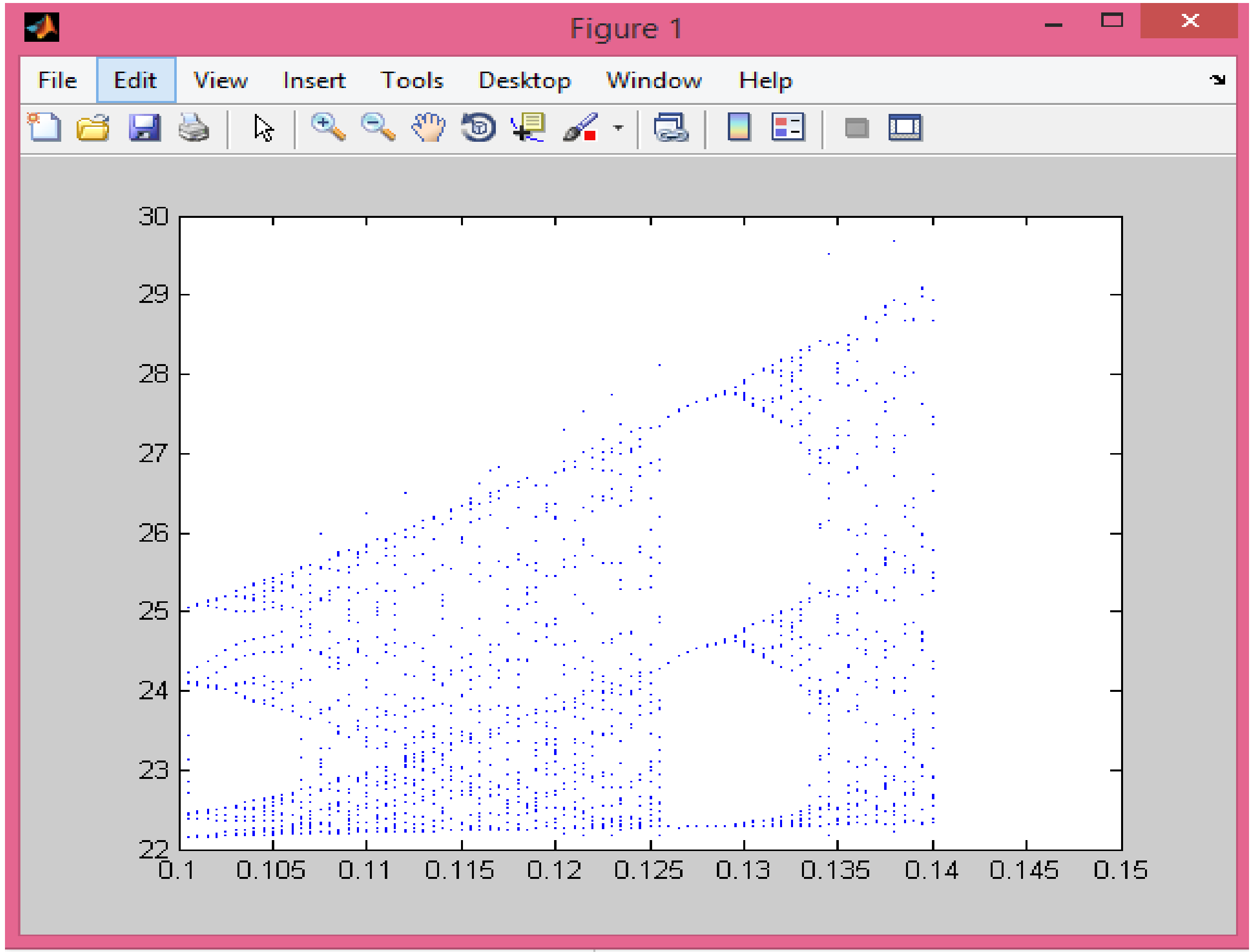


Simulation Results cont….



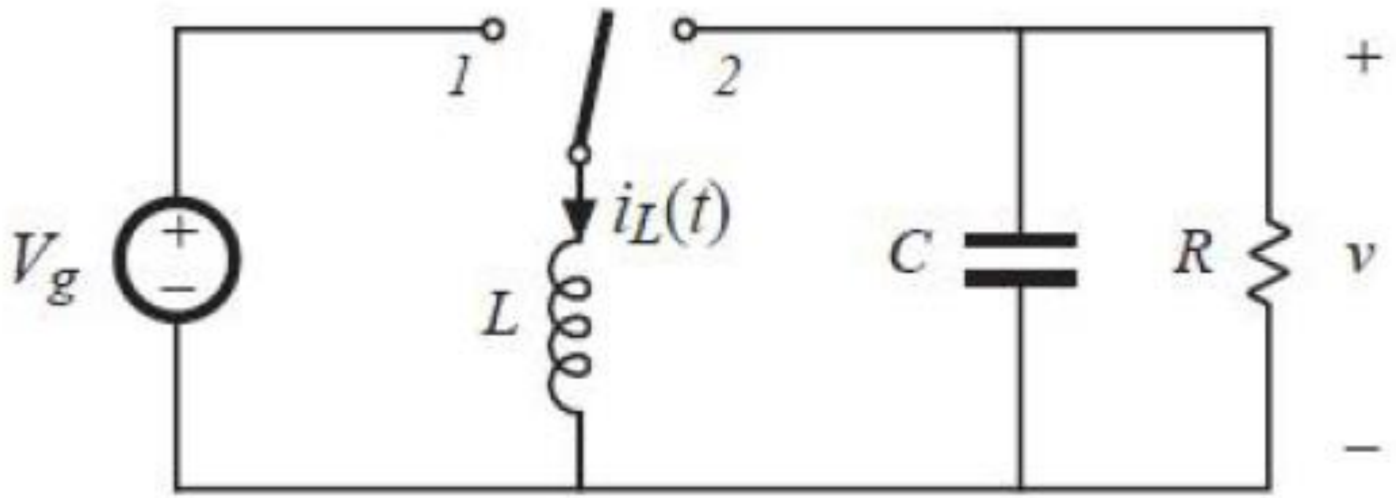


Bifurcation Diagram



Gain ‘a‘ was chosen as the bifurcation parameter. This diagram clearly shows that the period-doubling route to chaos as a reaches 0.14.

Buck-Boost Chopper



- The average value of $v_s(t)$, which would then be equal to DVg. Therefore,

$$\mathbf{V_o = D/(1 - D)*V_g}$$

Principle of Operation of a Buck-Boost Chopper

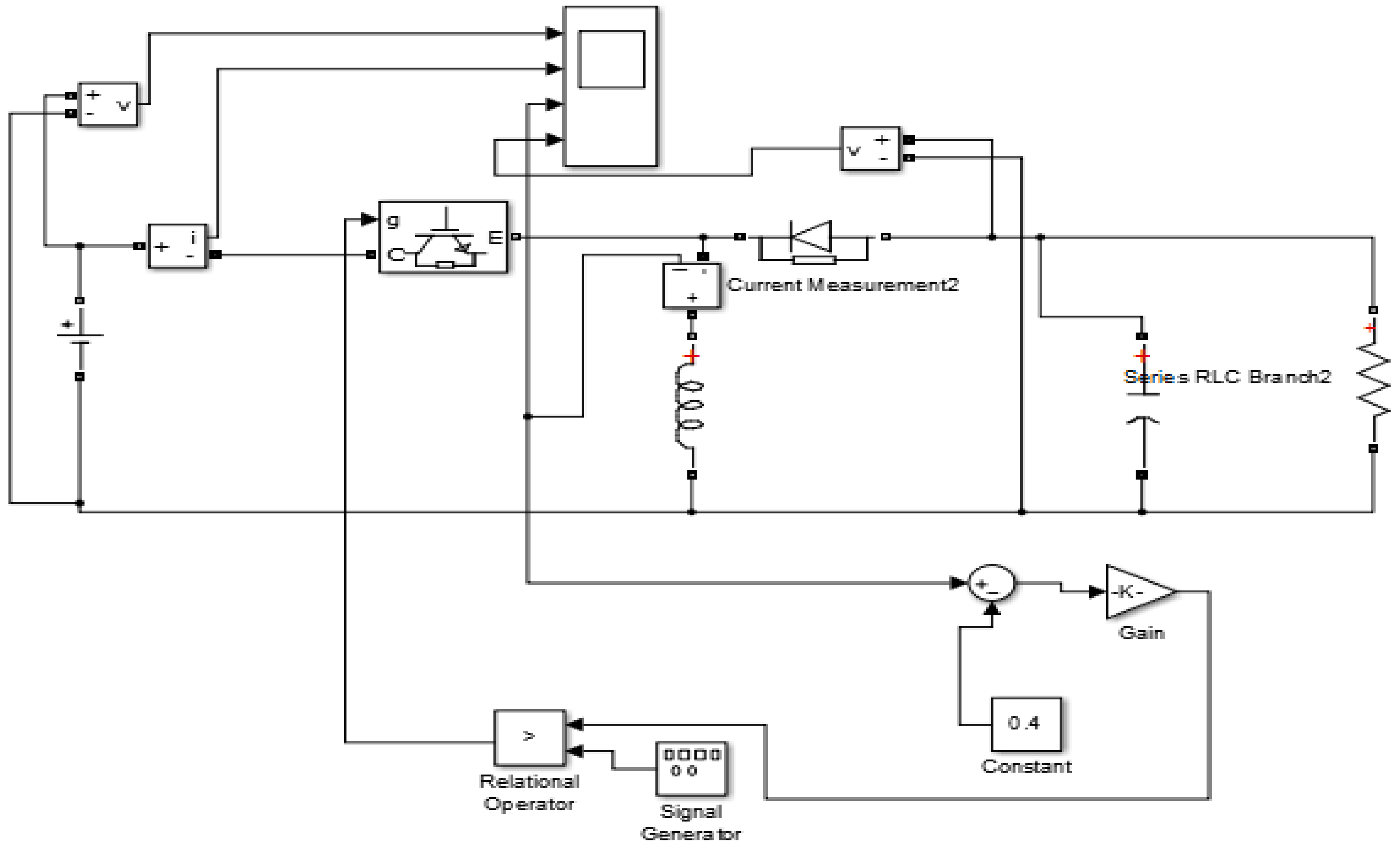
$$\begin{cases} \dfrac{di}{dt} = \dfrac{E}{L} \\ \dfrac{dv_c}{dt} = -\dfrac{1}{RC} v_c \end{cases}$$

When switch is closed

$$\begin{cases} \dfrac{di}{dt} = -\dfrac{1}{L} v_c \\ \dfrac{dv_c}{dt} = \dfrac{1}{C} i - \dfrac{1}{RC} v_c \end{cases}$$

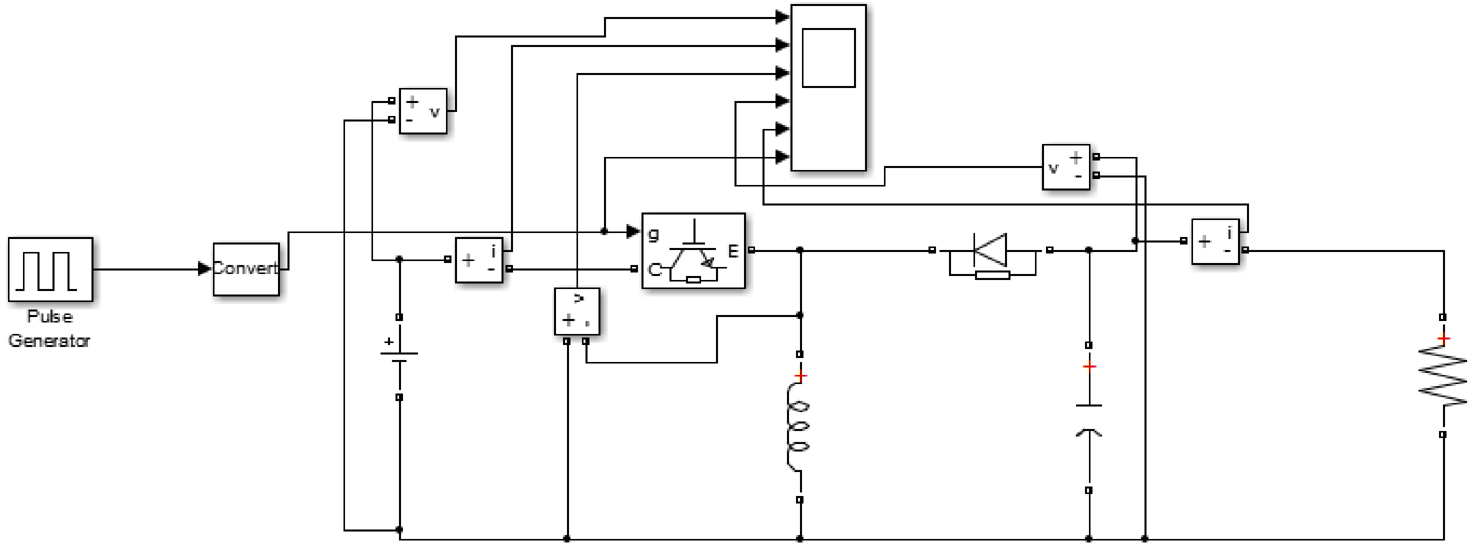
When switch is open

Simulation of the Circuit – Closed Loop



- The parameters chosen are V_{in}=12 V, I_{ref} =4.5 A, L=1.1 mH, C=4.4 μF, R=50 Ω, a=2, V_L=2V, V_U=5V, T=50 μs;

Chopper Open Loop



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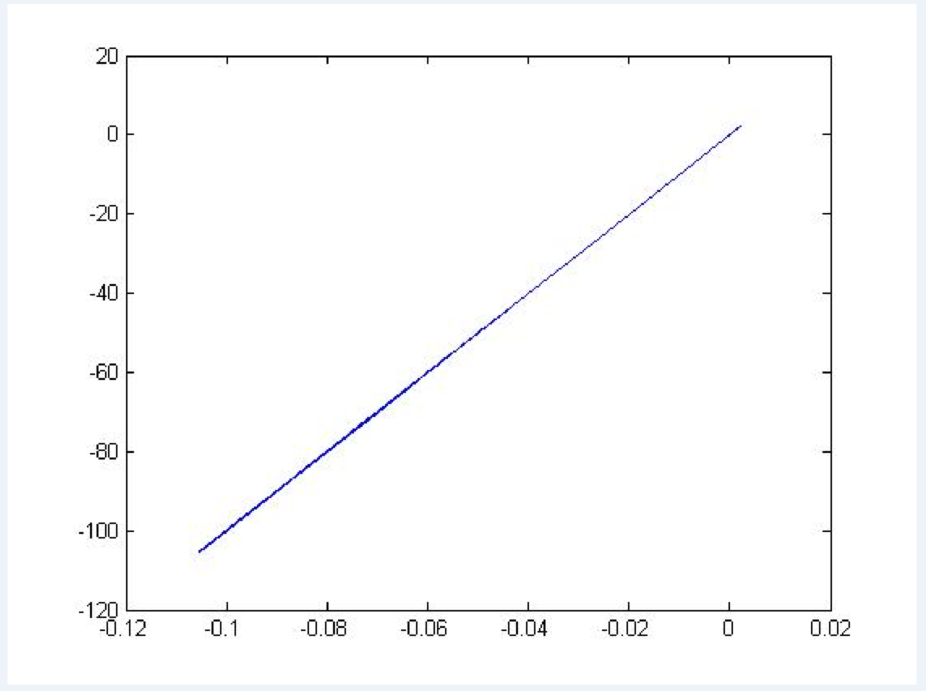
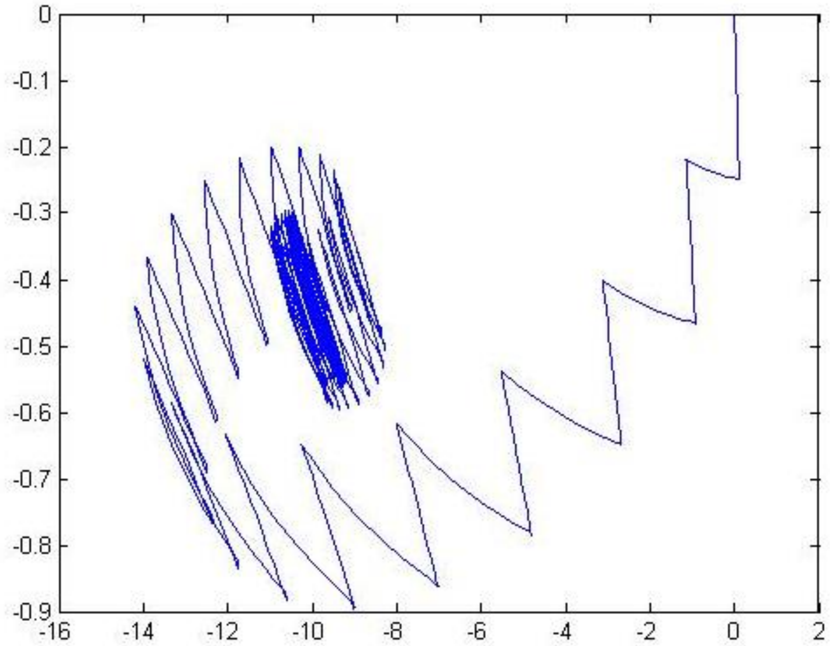
Simulation Results:



V_C

i_L

Open Loop

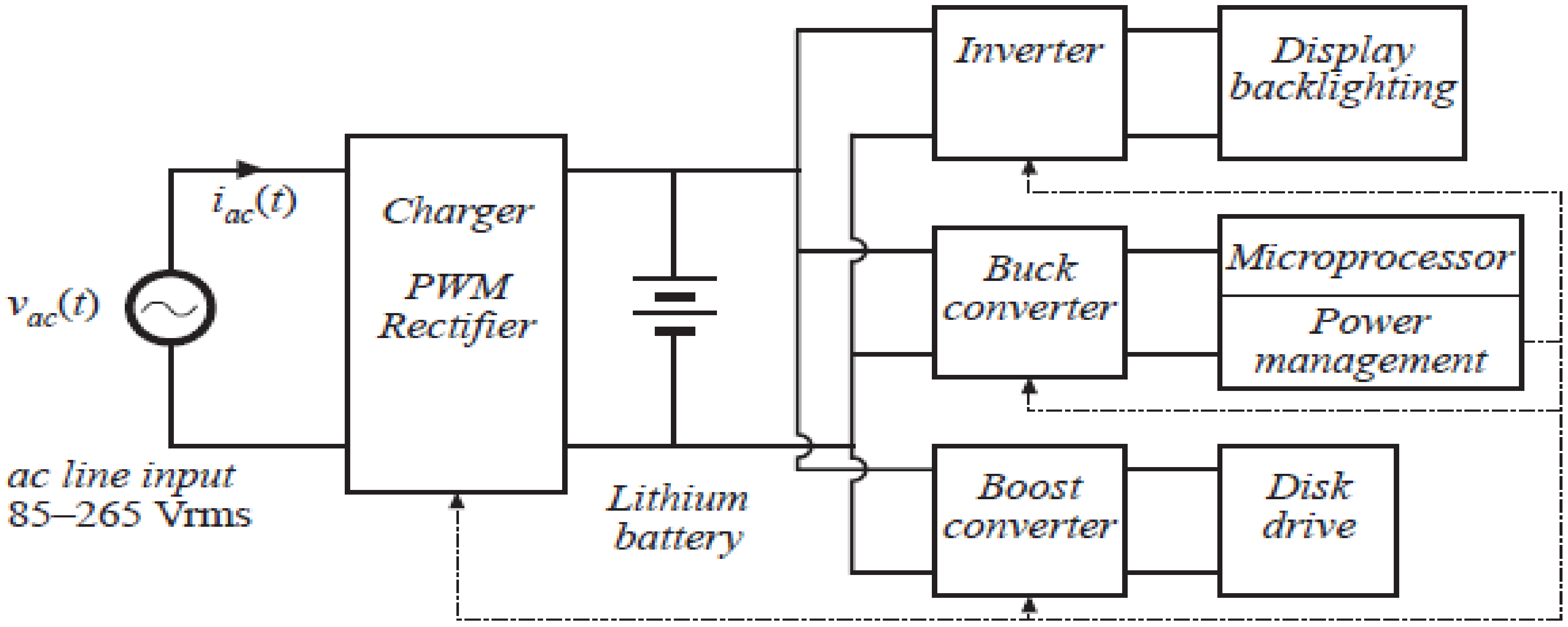


V_C

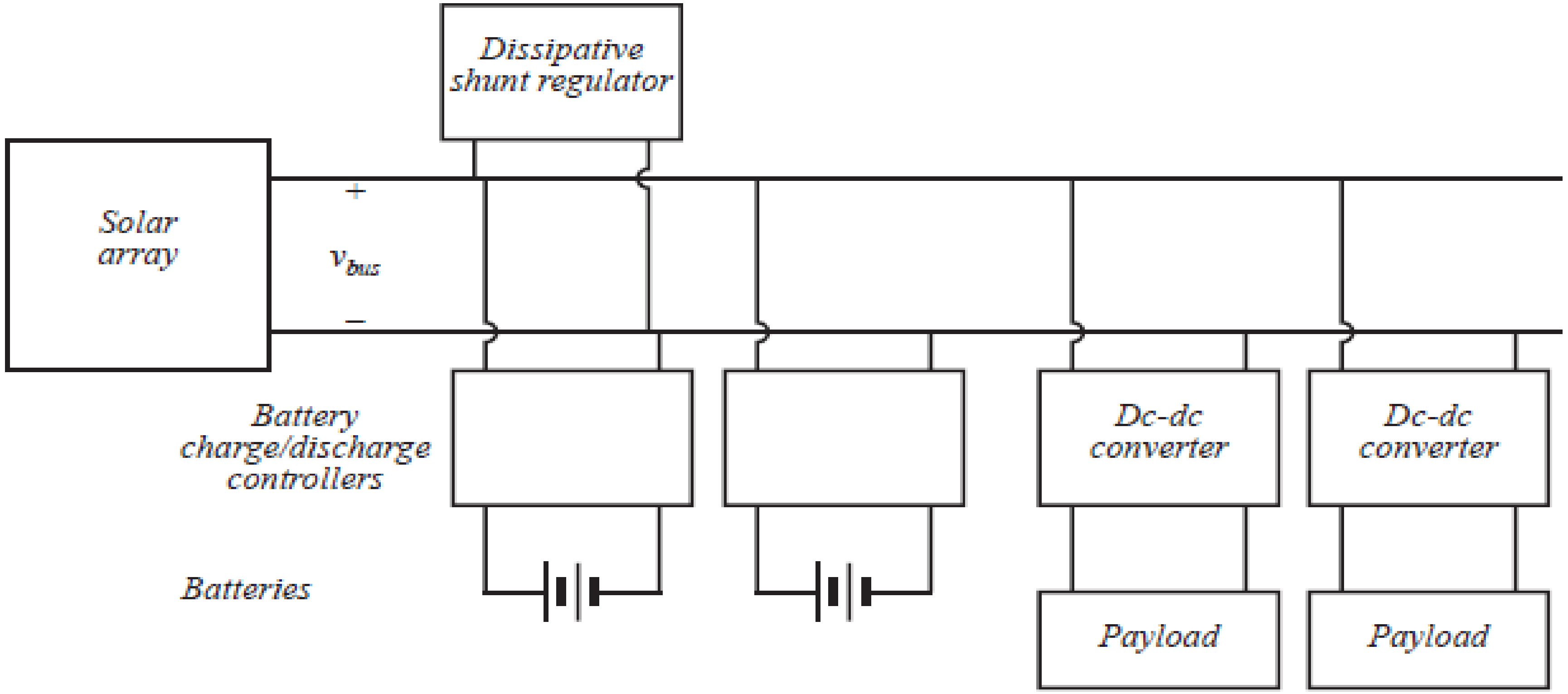
i_L

Closed Loop

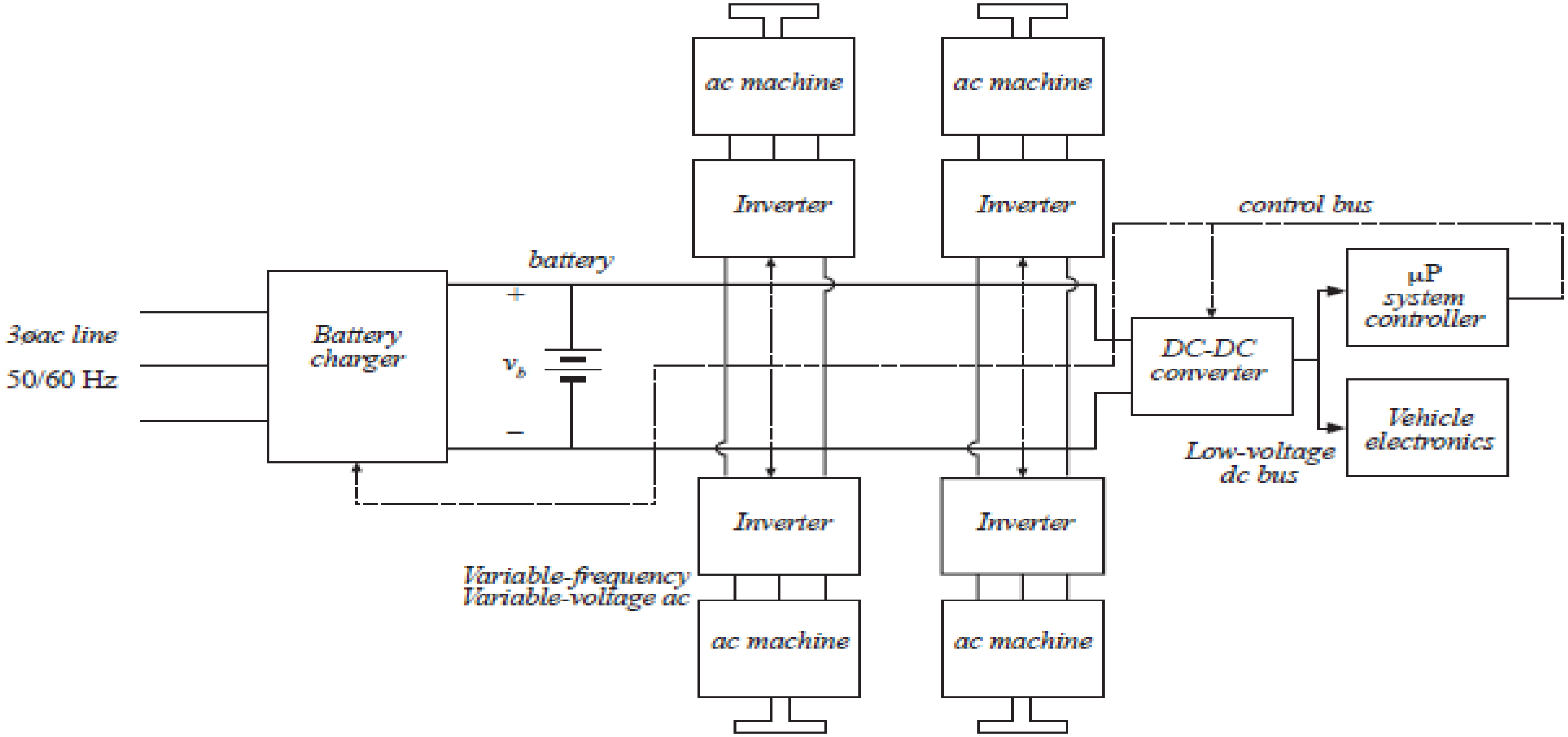
Application 1:
A laptop computer power supply system



Application 2:
Power system of an earth-orbiting spacecraft



Application 3:
An electric vehicle power and drive system



References

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THANK YOU