Training in Electrical Engineering Discipline

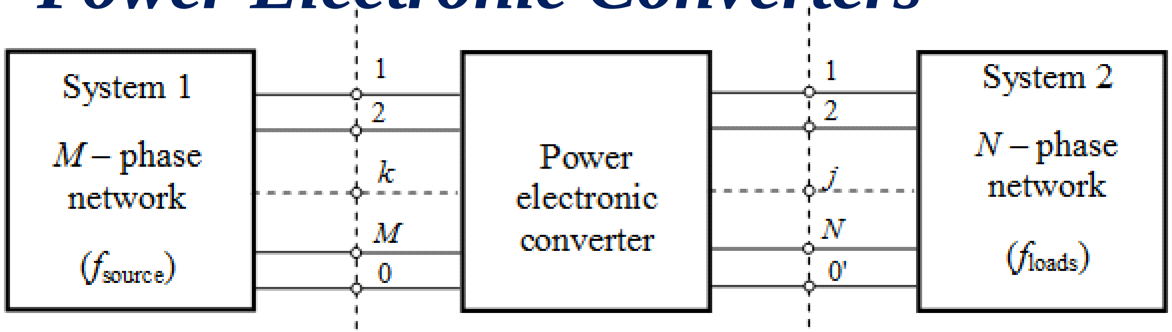
Modelling and Simulation in Electrical Engineering

Day 4
Modelling and Simulation of Power Electronic Converters

Denis Pelin, full proffessor ; P9 FERIT
Andrej Brandis, assistant, P9 FERIT

Osijek; 4th, April 2019

Power Electronic Converters

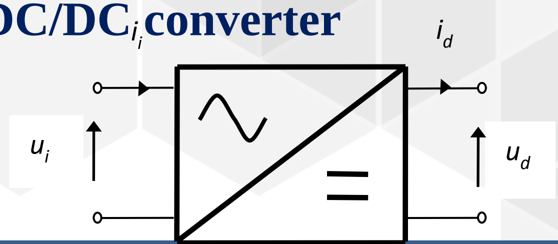


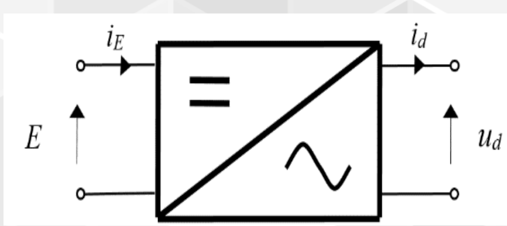
- **System characteristic:**

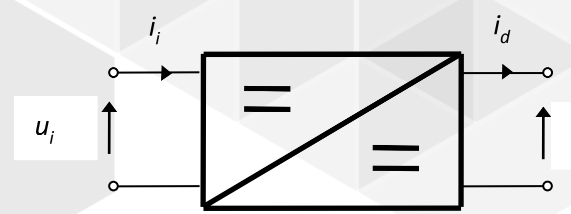
-frequency
- v/i characteristic values
-number of phases
-galvanic isolation

- install device that will allow to connect these two, by some characteristics, different systems.
- these devices are called ***power electronic converters***, and the electrical engineering branch that deals with the design of these devices, and the study of their interaction with both systems, are named as ***converter technique.***

- **Basic converters division regarding frequency as leading characteristic of the systems are:**
  - **rectifier**
  - **invereter**
  - **DC/DC converter**

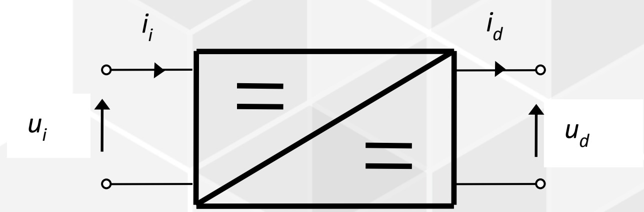


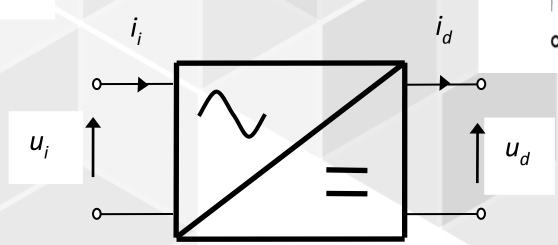


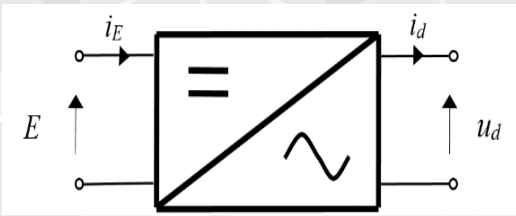


Chosen power converter topologies

- ***DC/DC converter*: Boost converter topology (modeling and steady-state analysis)**
- ***Rectifier*: Single phase diode rectifier in bridge topology with capacitive load (modeling)**
- ***Inverter*: Single-phase autonomous voltage inverter in H-bridge topology with inductive load (modeling)**

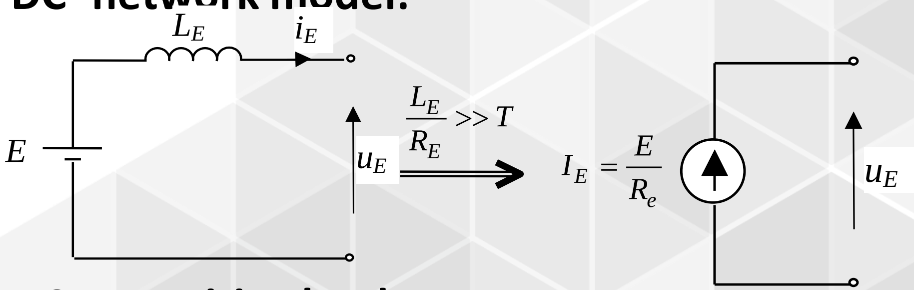




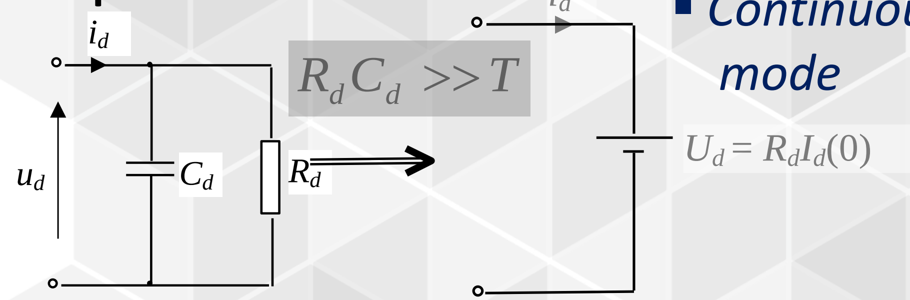


- *Boost converter topology – MODELLING AND STEADY STATE ANALYSIS- Analytical approach*

DC- network model:

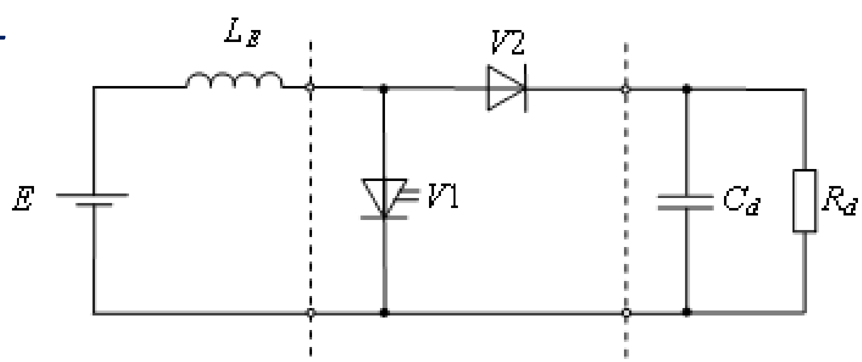


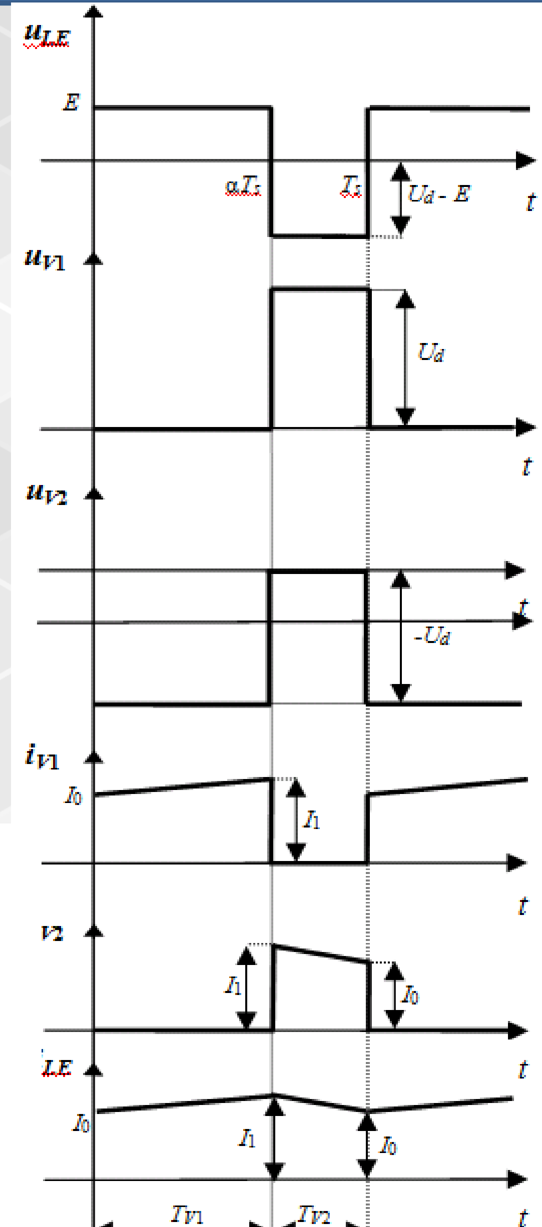
DC- capacitive load:



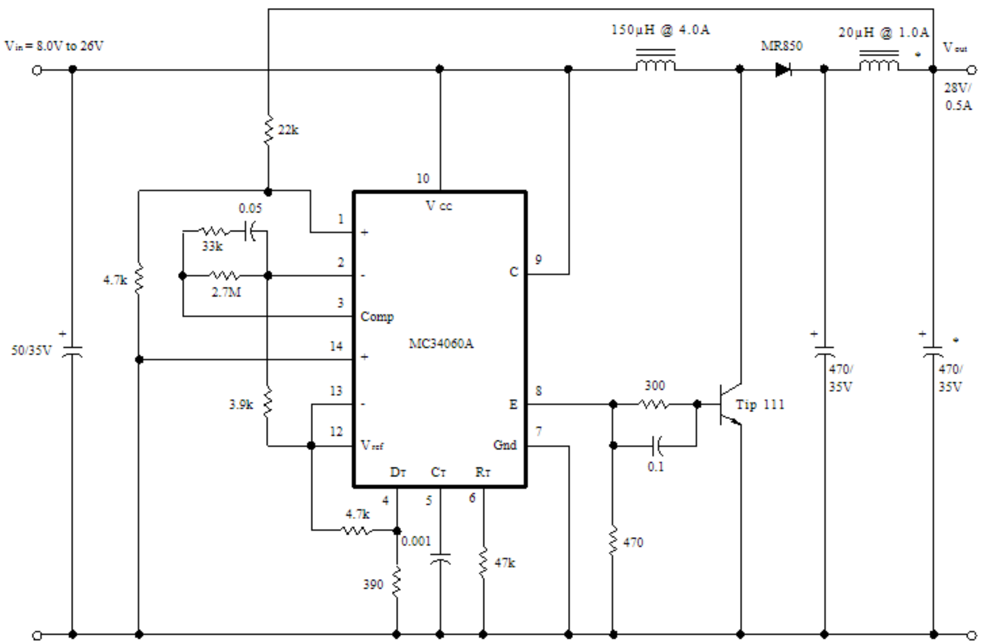
- *Continuous operation mode*

- *2 switches; BT + diode*



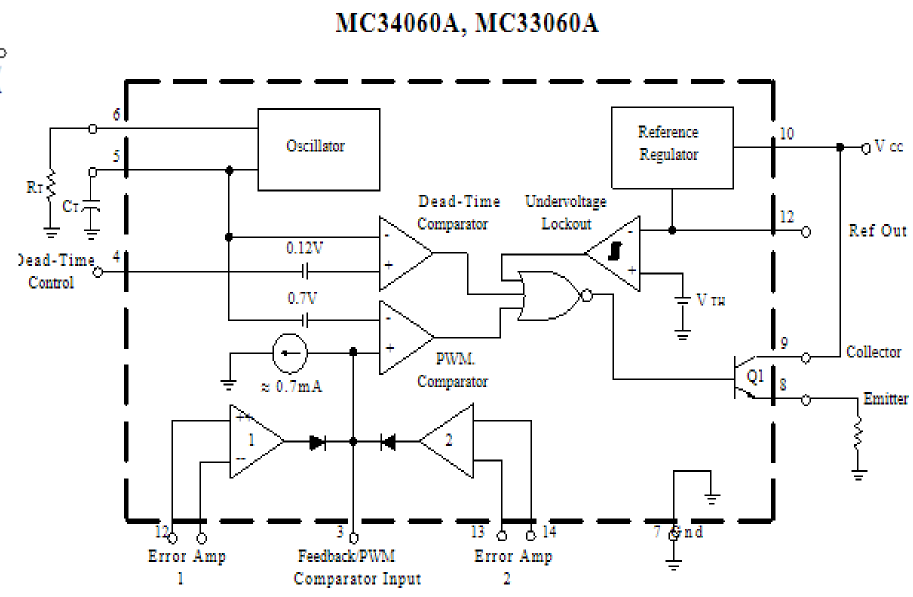


- *Boost converter topology – MODELLING AND STEADY STATE ANALYSIS- Numerical approach*
- *physical realisation of the boost converter*



- *MC34060 is a fixed pulse-width modulation control circuit.*

- *Block diagram of MC34060*

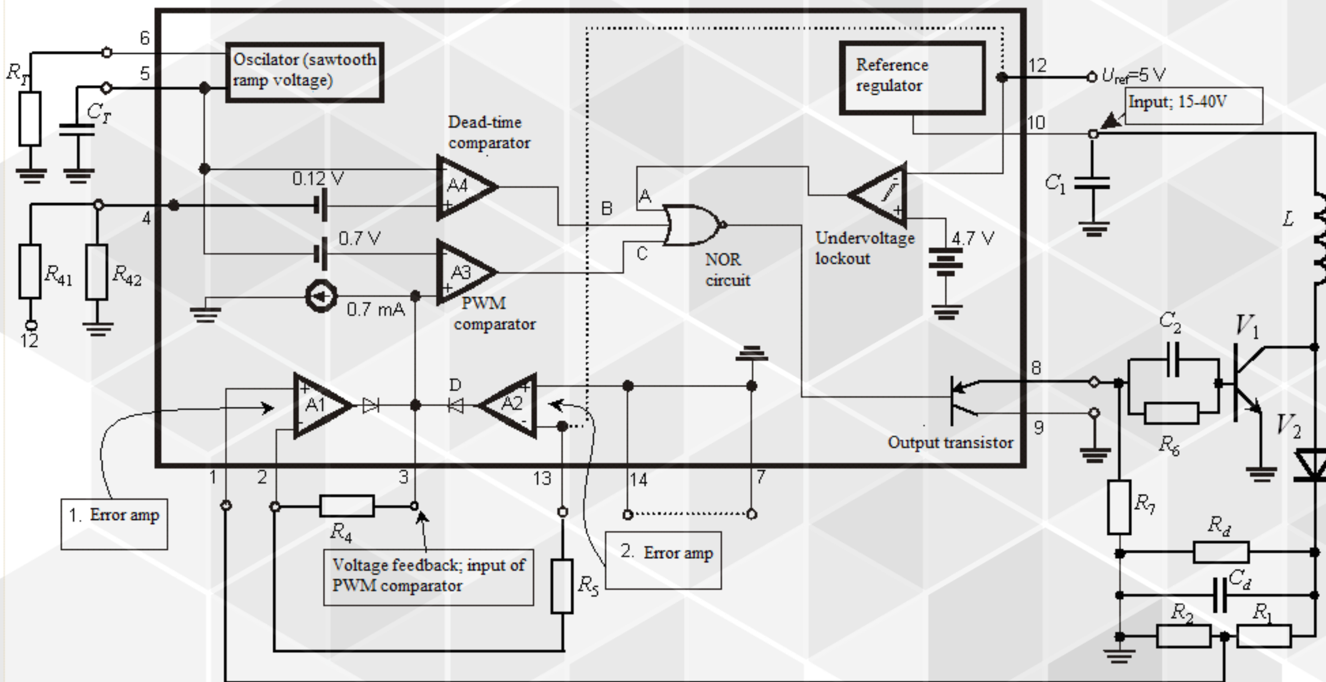


This device contains 46 active transistors

- *MC34060 subsystems : oscillator, 2 error amp, PWM comparator , undervoltage lockout, reference regulator.*

Boost converter topology – MODELLING AND STEADY STATE ANALYSIS- Numerical approach

- *equivalent circuit of the boost converter by taking in consideration MC34060 subsystems*



- *NOR gate condition*

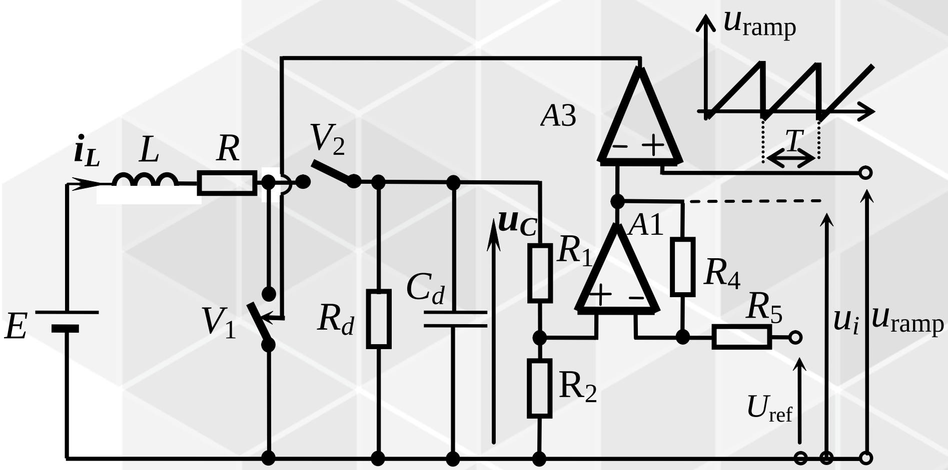
input A	input B	input C	output
0	**0**	**0**	**1**
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	0

- *switching condition*

input C	output
0	**1**
1	**0**

Boost converter topology – MODELLING AND STEADY STATE ANALYSIS- Numerical approach

- *Functional diagram for writing state equation*



- When $u_{ramp} \geq u_i$, the controlled switch V_1 is in the ON-state and the diode V_2 is in the OFF-state. The state equations are:

$$\frac{du_C}{dt} = \frac{1}{CR_d} u_C$$

$$\frac{di_L}{dt} = \frac{1}{L}\left(E - Ri_L\right)$$

- When $u_{ramp} < u_i$, $i_L > 0$, the controlled switch V_1 is in the OFF-state and the diode V_2 is in the ON-state. The state equations are:

$$\frac{du_C}{dt} = \frac{1}{C}\left(i_L - \frac{u_C}{R_d}\right)$$

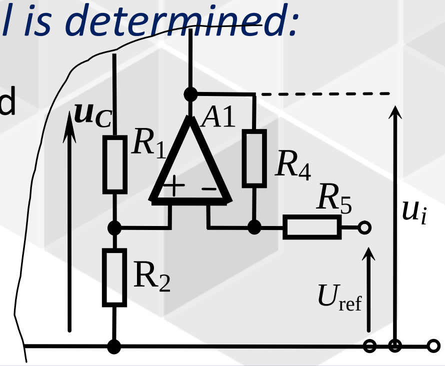
$$\frac{di_L}{dt} = \frac{1}{L}\left(E - Ri_L - u_C\right)$$

- *for discontinuous operation mode 3rd interval is determined:*

  - When $u_{ramp} < u_i$, $i_L = 0$, the controlled switch V_1 and the diode V_2 are in the OFF-state. The state equations are:

$$\frac{du_C}{dt} = \frac{1}{CR_d} u_C$$

$$i_L = 0$$



$$u_i = \frac{-R_4}{R_5} U_{ref} + \left(1 + \frac{R_4}{R_5}\right) \cdot \frac{R_2}{R_1 + R_2} u_C$$

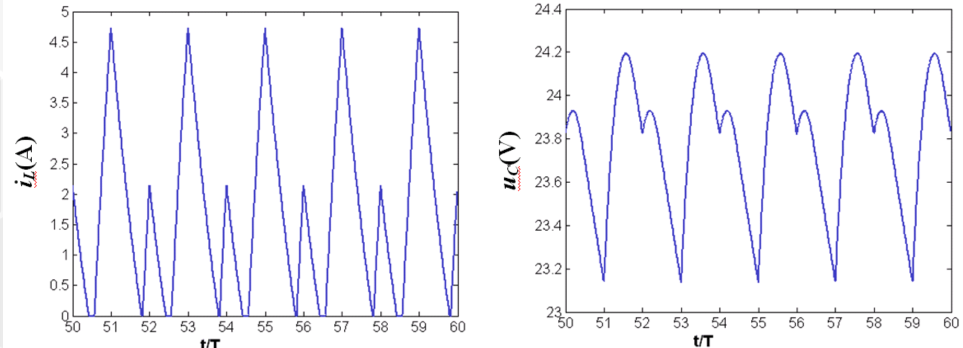
$$u_{ramp} = \frac{3}{T} t + 0{,}7$$

- *Boost converter topology – MODELLING AND STEADY STATE ANALYSIS- Numerical approach*
- *Numerical integration method choose*
- The fourth-order Runge-Kutta method of numerical integration with the fixed step size of integration *h*=20 ns was used.

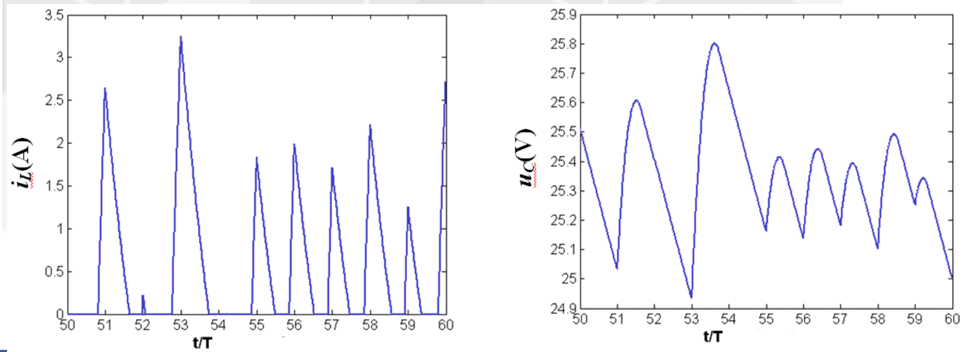
➢ REGIONS OF STEADY-STATE RESPONSES

Steady state responses	*E*,V	
	Measured values	Computed values
Period-one operation	14-17.9	14-18.2
Period-two operation	17.9-19.7	18.2-19.8
Period-four operation	19.7-20	19.8-20.2
Period-eight operation	-	20.2-20.3
Chaos	20-21.8 21.9-24	20.3-21.8 21.9-24
Period-three operation	21.8-21.9	21.8-21.9

- *Period -two operation*



- *Chaos*

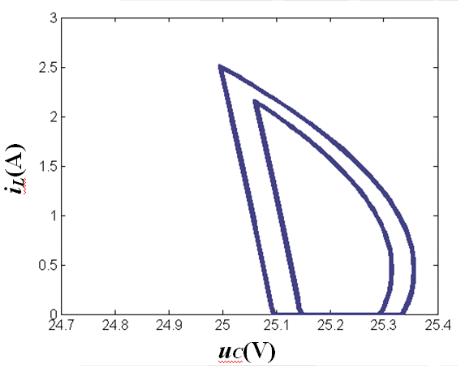


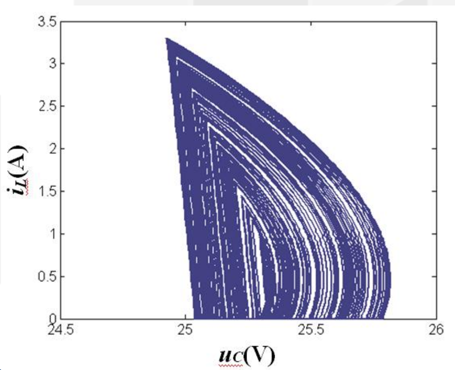
- *Period doubling route to chaos is identified*

- *Boost converter topology – MODELLING AND STEADY STATE ANALYSIS- Numerical approach*

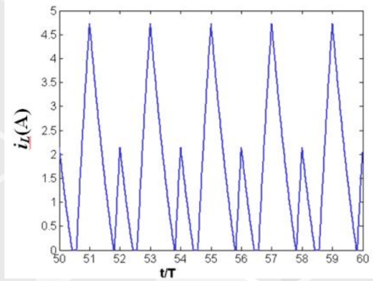
- *Simulation tools for identification different steady-state responses*

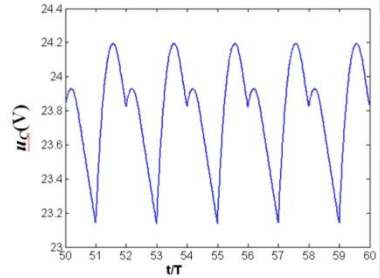
Phase plane – phase portraits



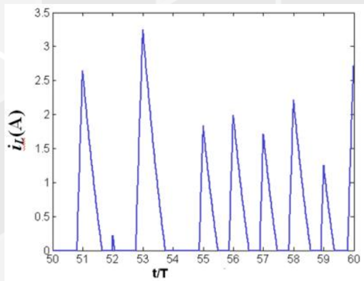


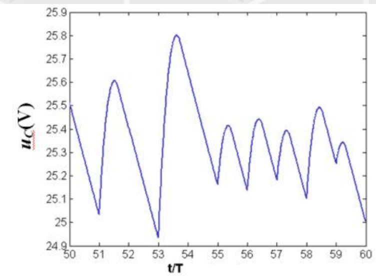
- *Period -two operation*



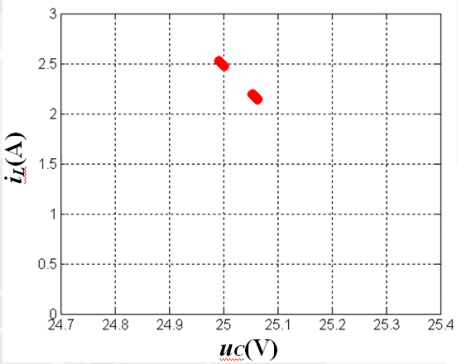


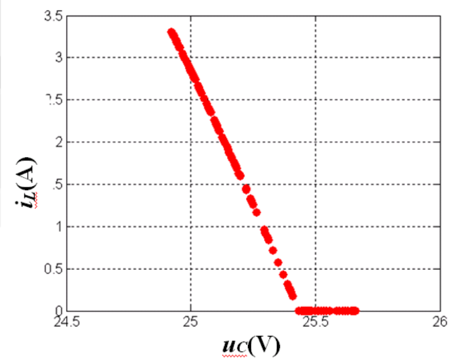
- *Chaos*



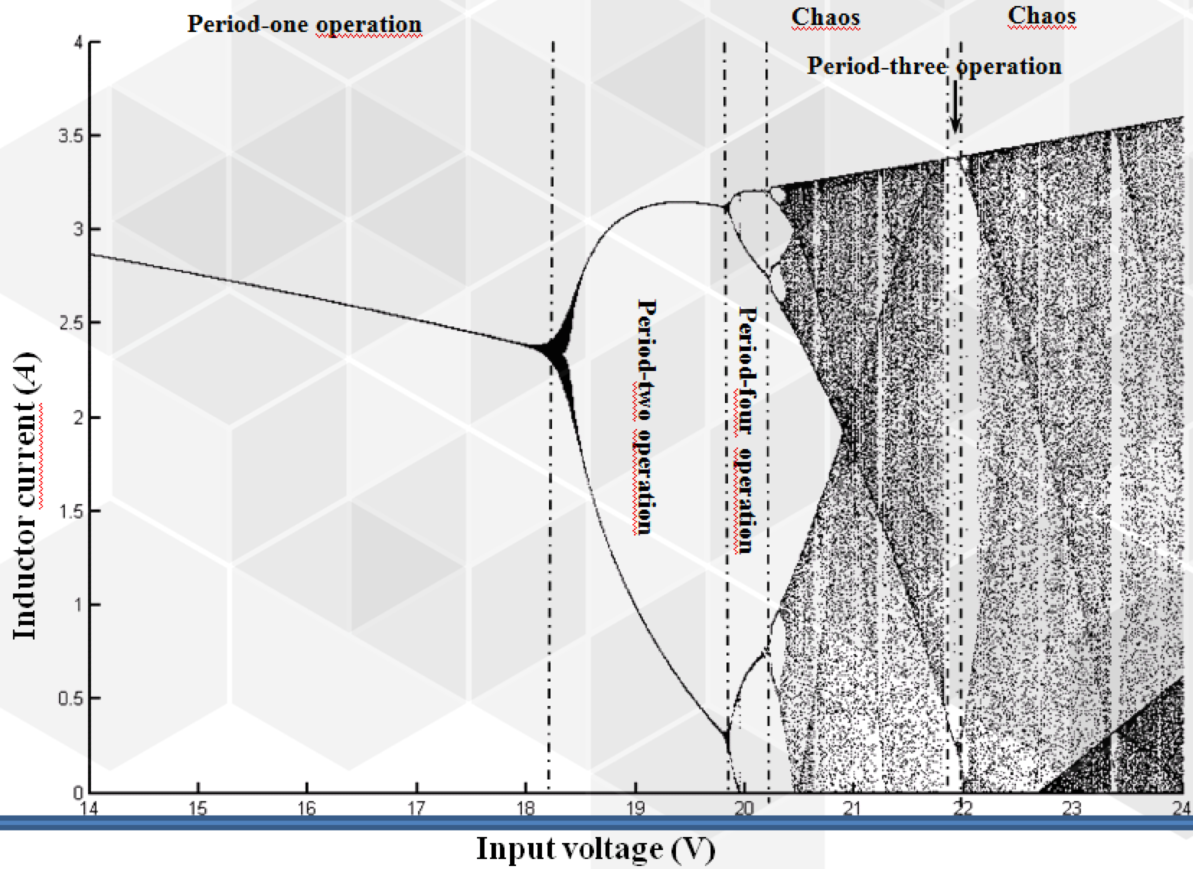


Poincare Map





- *Boost converter topology – MODELLING AND STEADY STATE ANALYSIS- Numerical approach*
  - *Bifurcation diagram- INSIGHT INTO THE STEADY-STATE RESPONSES*



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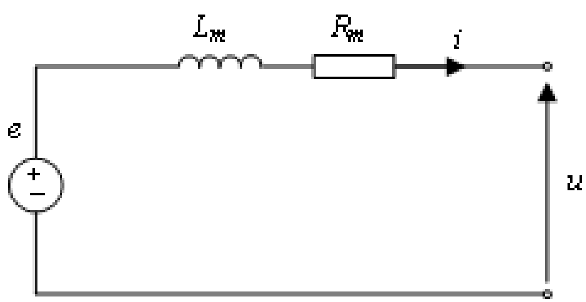
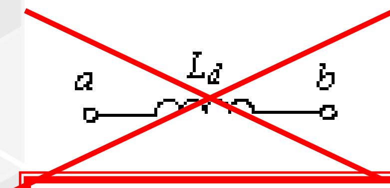
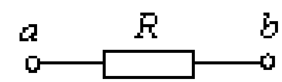
▪*Single phase diode rectifier in bridge topology with capacitive load- MODELLING*

AC- network model:

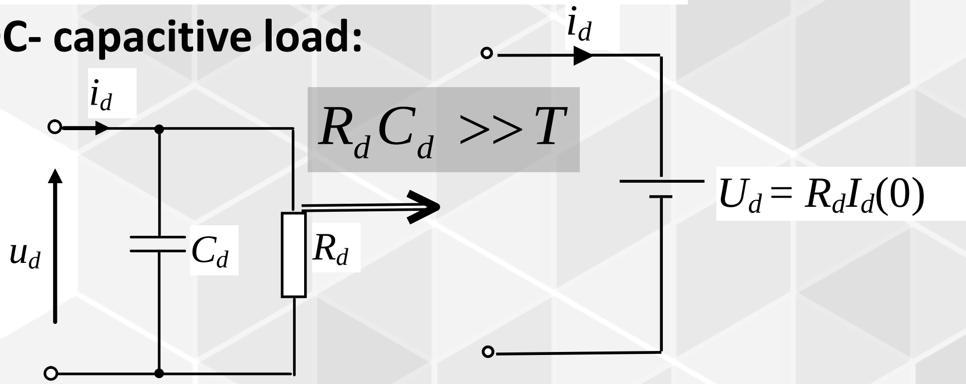


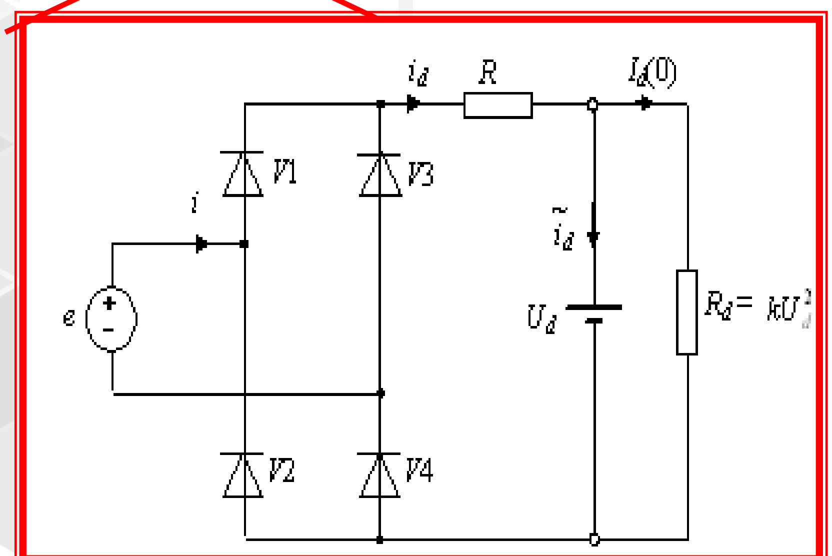
- ✓ L_m and R_m according to IEC 725* – referent parameters of AC grid <16A/phase
- ✓ *e*–sinusoidal voltage source, 230 V, 50 Hz





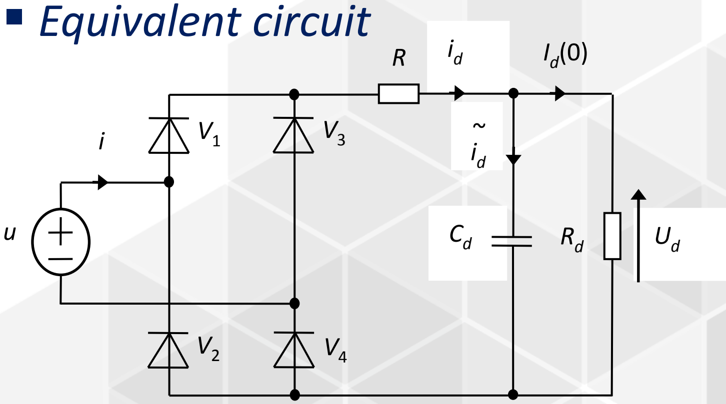
DC- capacitive load:





Single phase diode rectifier in bridge topology with capacitive load- MODELLING

- *Equivalent circuit*

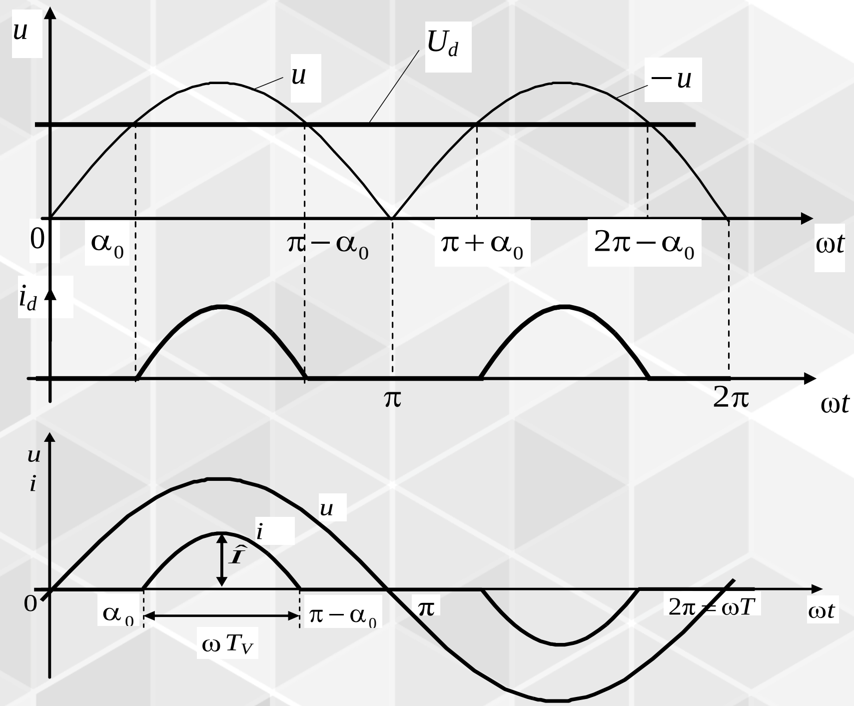


$$i_d = \frac{u - U_d}{R} = \frac{\hat{U}\sin\omega t - U_d}{R}$$

$$\frac{T_V}{T} = \frac{1}{2} - \frac{1}{\pi}\arcsin\frac{U_d}{\hat{U}}$$

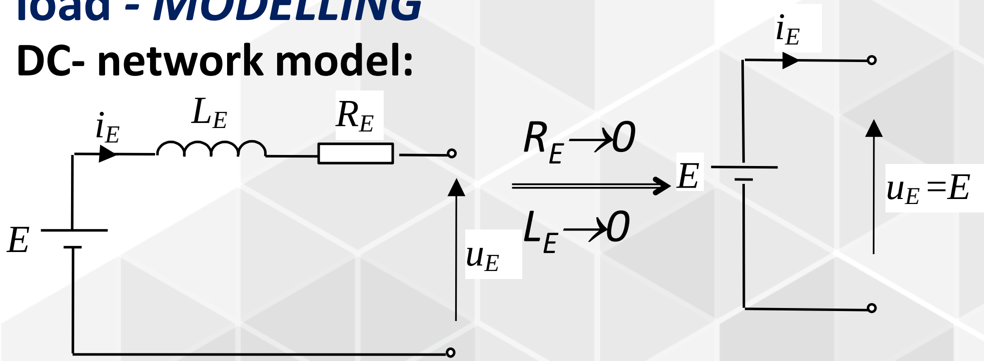
$$U_d = \hat{U}\frac{1}{\sqrt{1 + \frac{\pi^2}{4}\left(2\frac{T_V}{T} + \frac{R}{R_d}\right)}}$$

- *Analysis of the equivalent circuit*

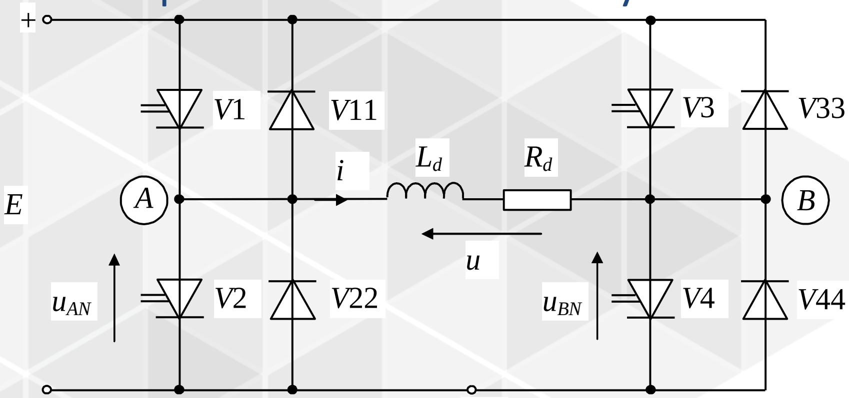


Single-phase autonomous voltage inverter in H-bridge topology with inductive load - *MODELLING*

DC- network model:



Equivalent circuit for analysis

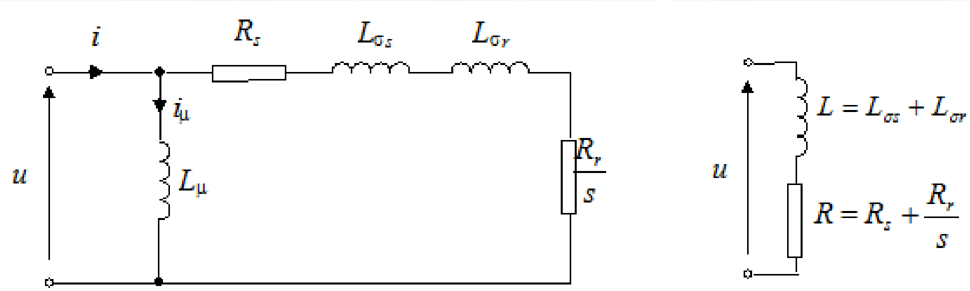


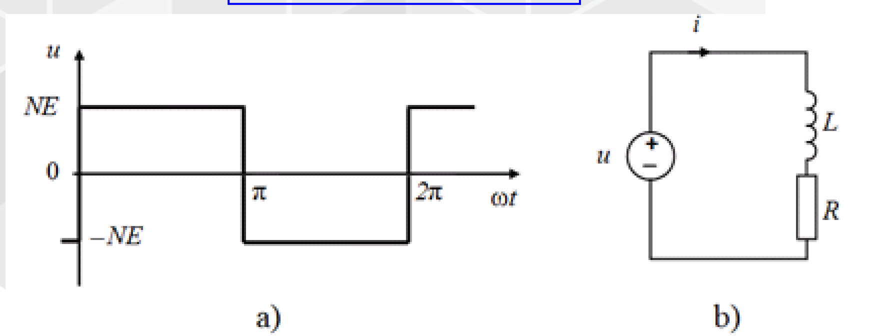
$$x_{V1} + x_{V2} = 1 \quad , \forall t$$

$$x_{V3} + x_{V4} = 1 \quad , \forall t$$

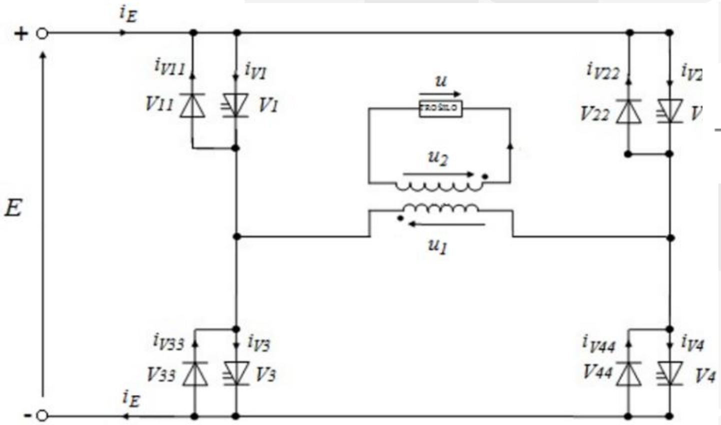
$$u = (x_{V1} - x_{V3})E$$

AC- inductive load:

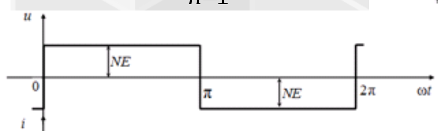


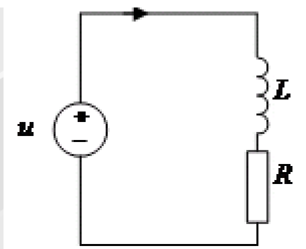


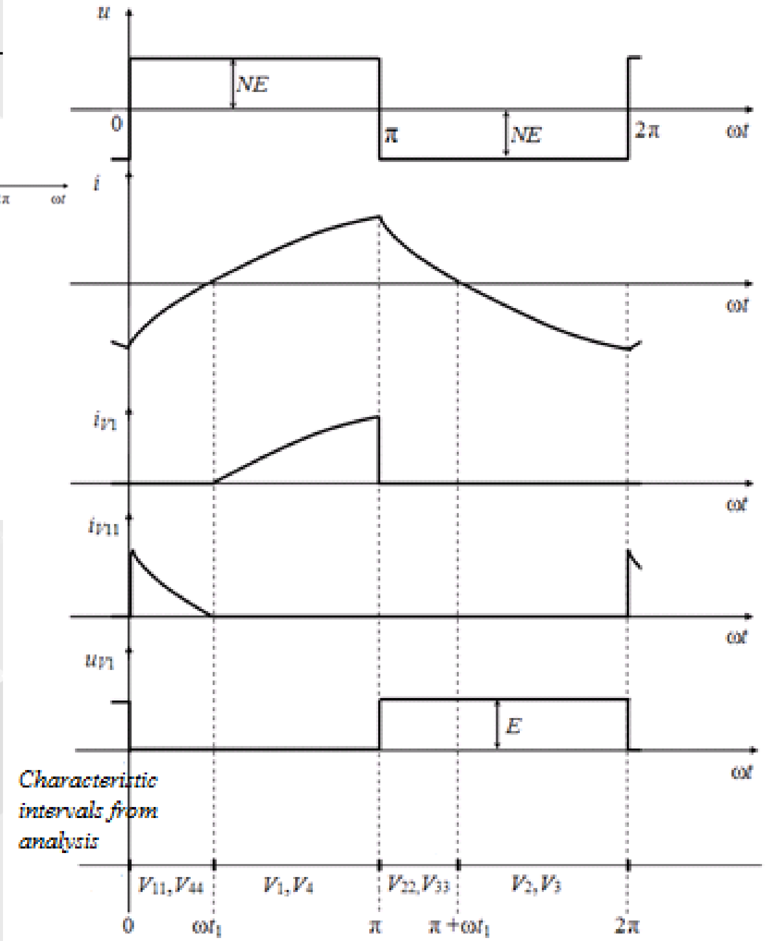
Single-phase autonomous voltage inverter in H-bridge topology with inductive load - *MODELLING*



$$u = \frac{4NE}{\pi}\sum_{n=1}^{\infty}\frac{\sin n\omega t}{n}$$







$$\mathrm{tg}\varphi\frac{di}{d(\omega t)} + i = \frac{NE}{R}\cdot\begin{cases} 1 & +0 \le \omega t \le \pi - 0 \\ -1 & \pi + 0 \le \omega t \le 2\pi - 0 \end{cases}$$

$$i = \frac{NE}{R}\cdot\begin{cases} 1 - \dfrac{2e^{-\frac{\omega t}{\mathrm{tg}\varphi}}}{1+e^{-\frac{\pi}{\mathrm{tg}\varphi}}} & +0 \le \omega t \le \pi - 0 \\ -\left(1 - \dfrac{2e^{-\frac{\omega t-\pi}{\mathrm{tg}\varphi}}}{1+e^{-\frac{\pi}{\mathrm{tg}\varphi}}}\right) & \pi + 0 \le \omega t \le 2\pi - 0 \end{cases}$$