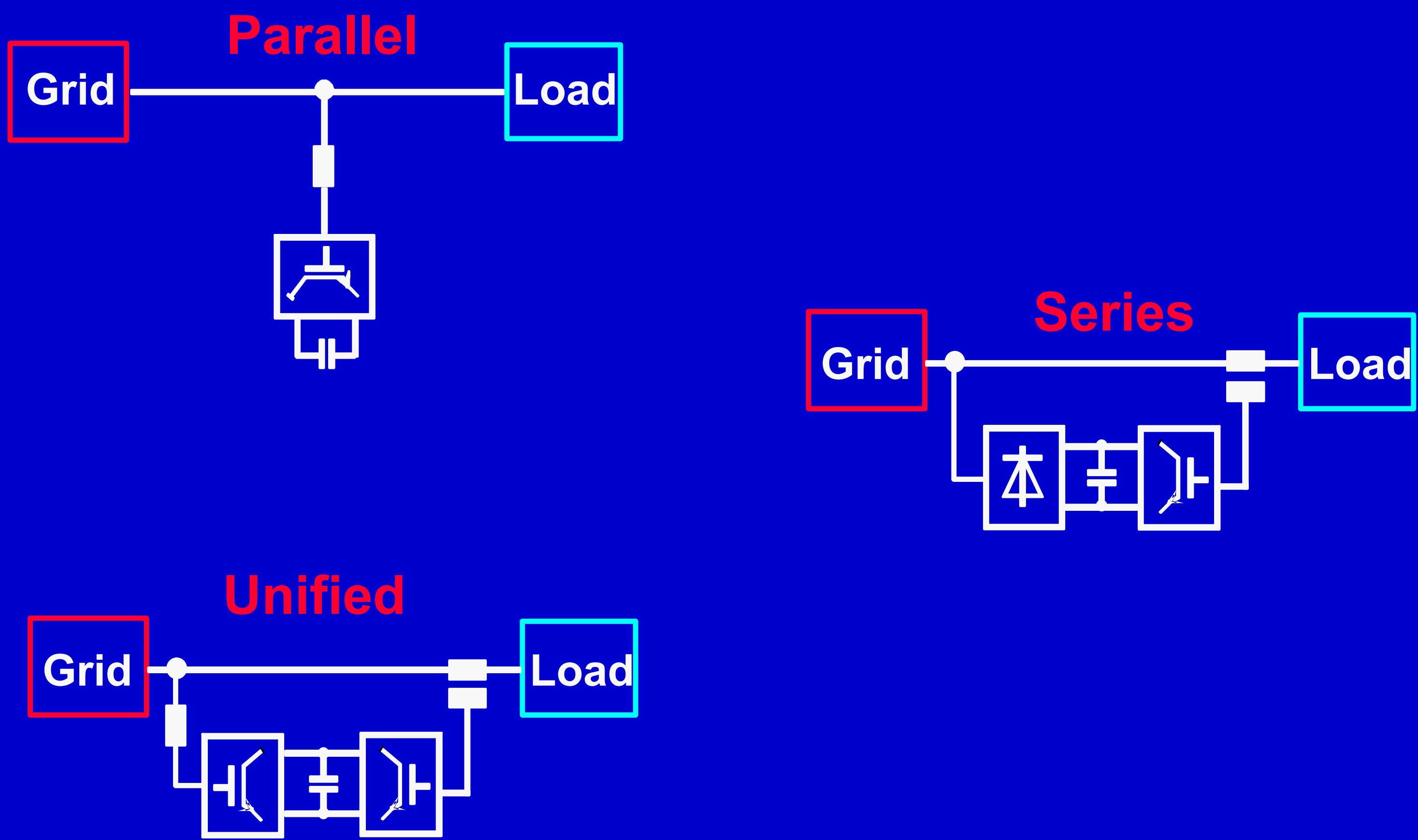
Active Filters

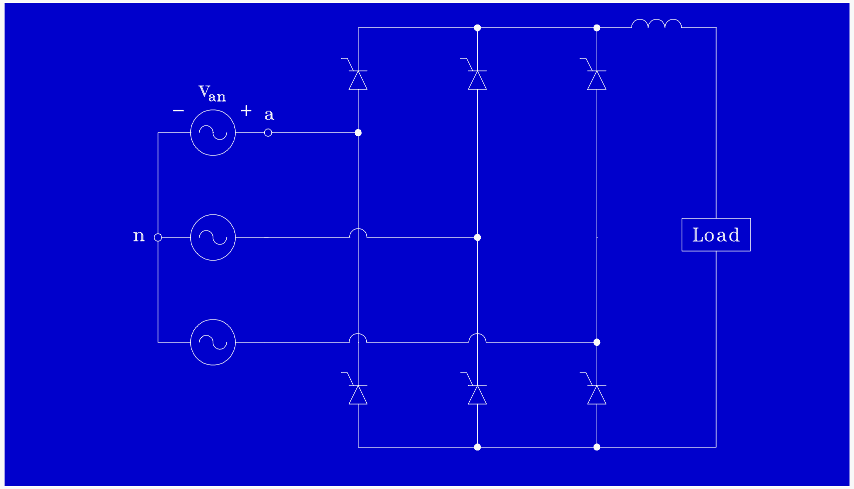
- An active filter is a device for reducing harmonic distortion by supplying harmonic components
- Classification : Parallel, Series, Unified
- Hybrid filters : Active + Passive
- Applications
- Modelling guidelines
- Example

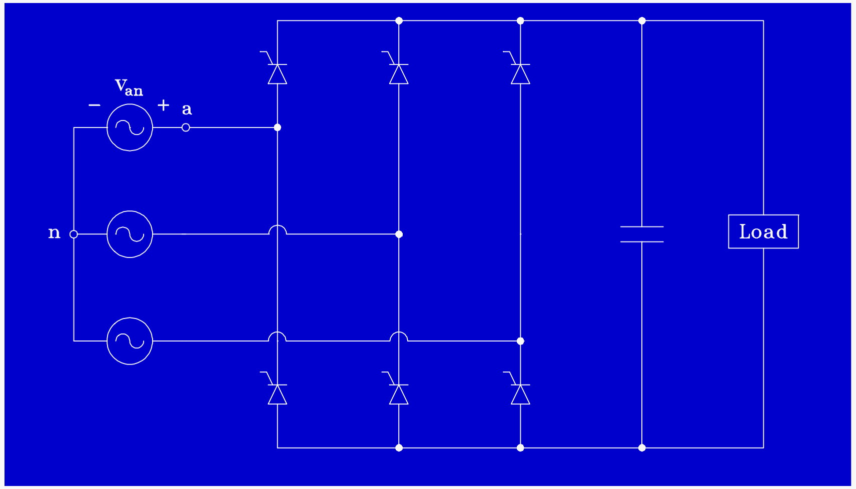
Active Filters

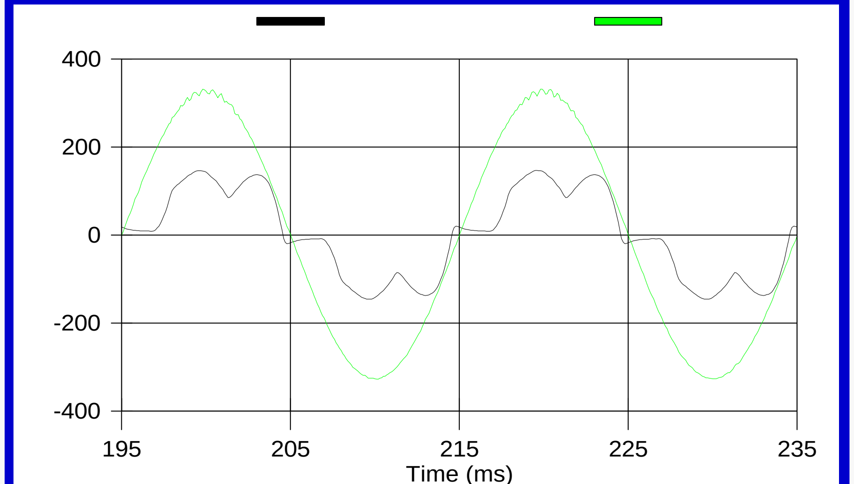


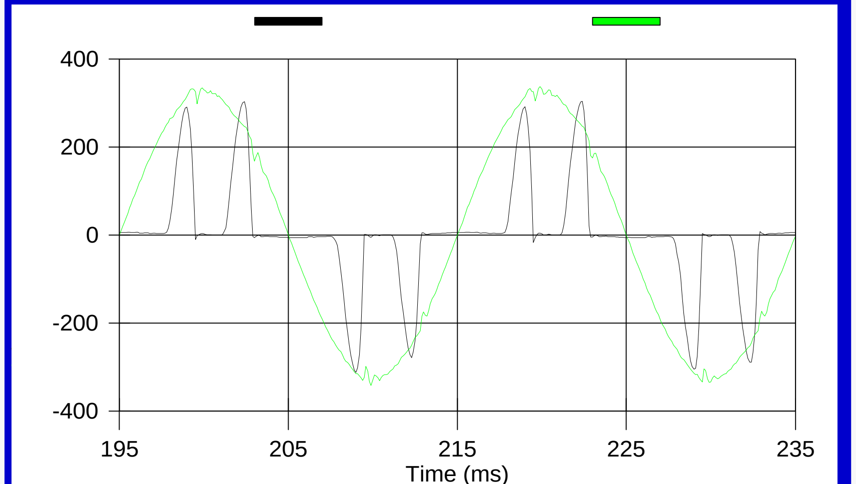
Active Filters

Harmonic Current Source	Harmonic Voltage Source







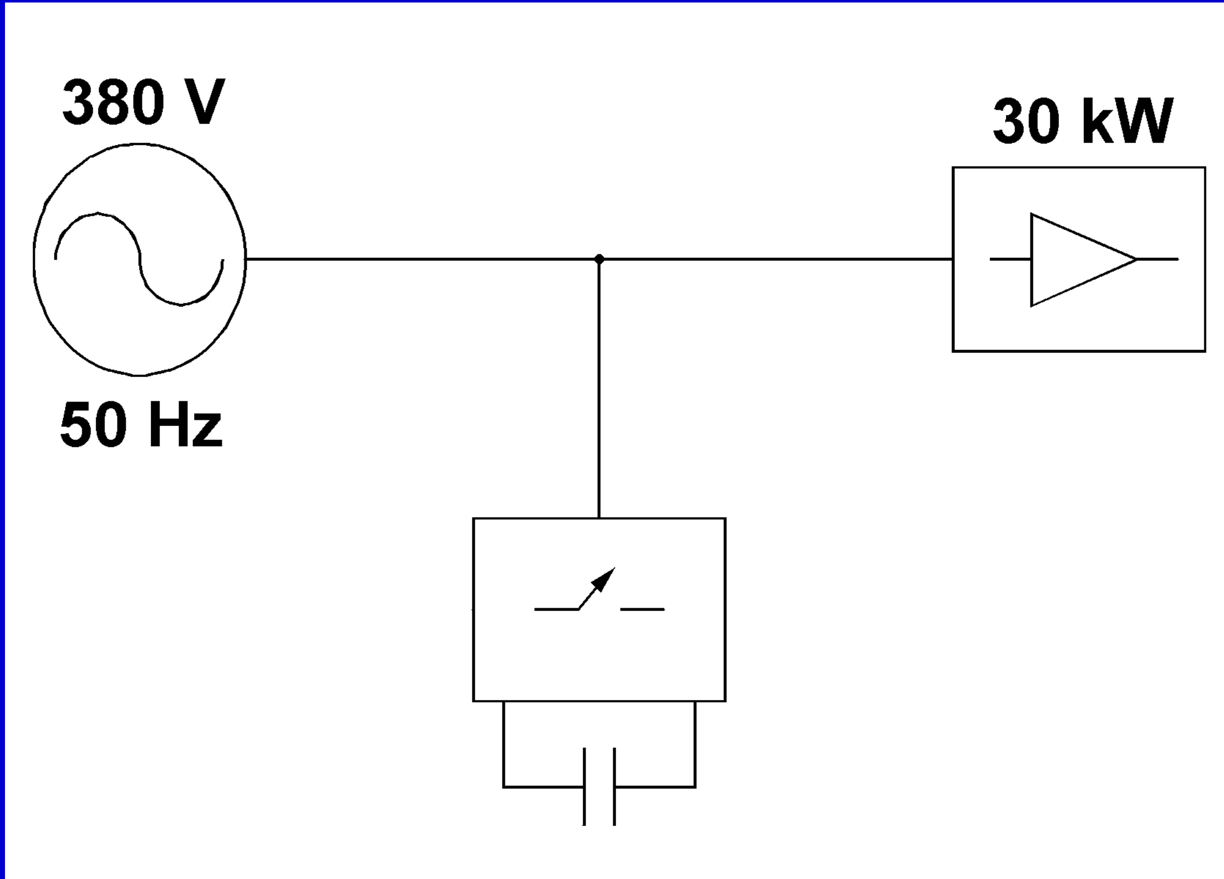


Active Filters

Configuration	SHUNT	SERIES
Operating principle	Operates as a current source	Operates as a voltage source
Power circuit	Voltage-fed PWM inverter with current minor loop	Voltage-fed PWM inverter without current minor loop
Loads	Inductive, current-source loads, harmonic current sources	Capacitive, voltage-source loads, harmonic voltage sources
Required operating conditions	High load impedance	Low load impedance
Compensation charactersitics	Excellent and independent of the source impedance for current-source loads, but depend on the source impedance when the load impedance is low	Excellent and independent of the source and the load impedances for voltage-source loads, but depend on the source impedance for current-source type loads
Additional function	Reactive power compensation	Voltage regulation
Present situation	Commercial stage	Laboratory stage

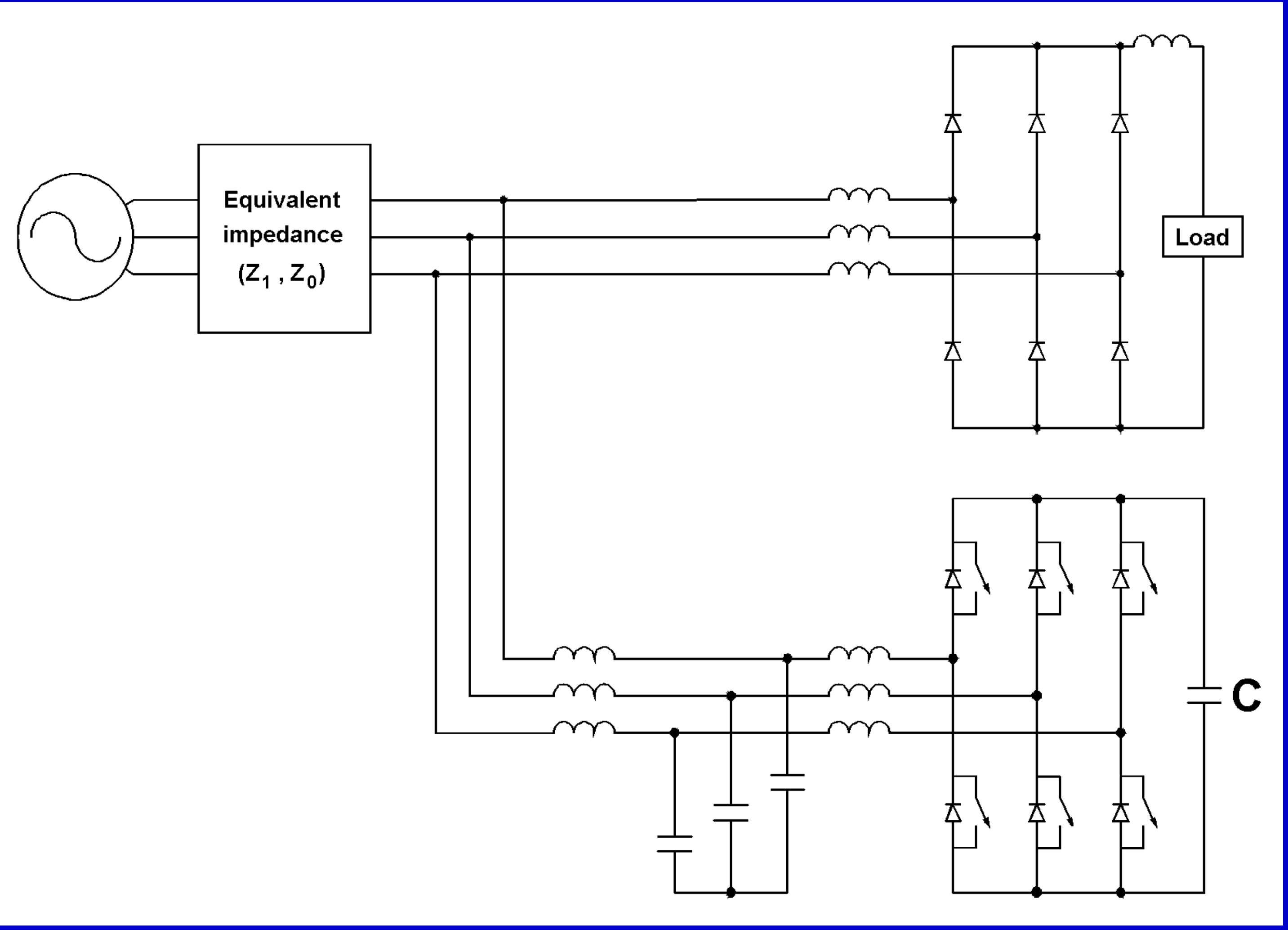
(Sources : Zeng, 1998; Akagi, 2000)

Active Filters



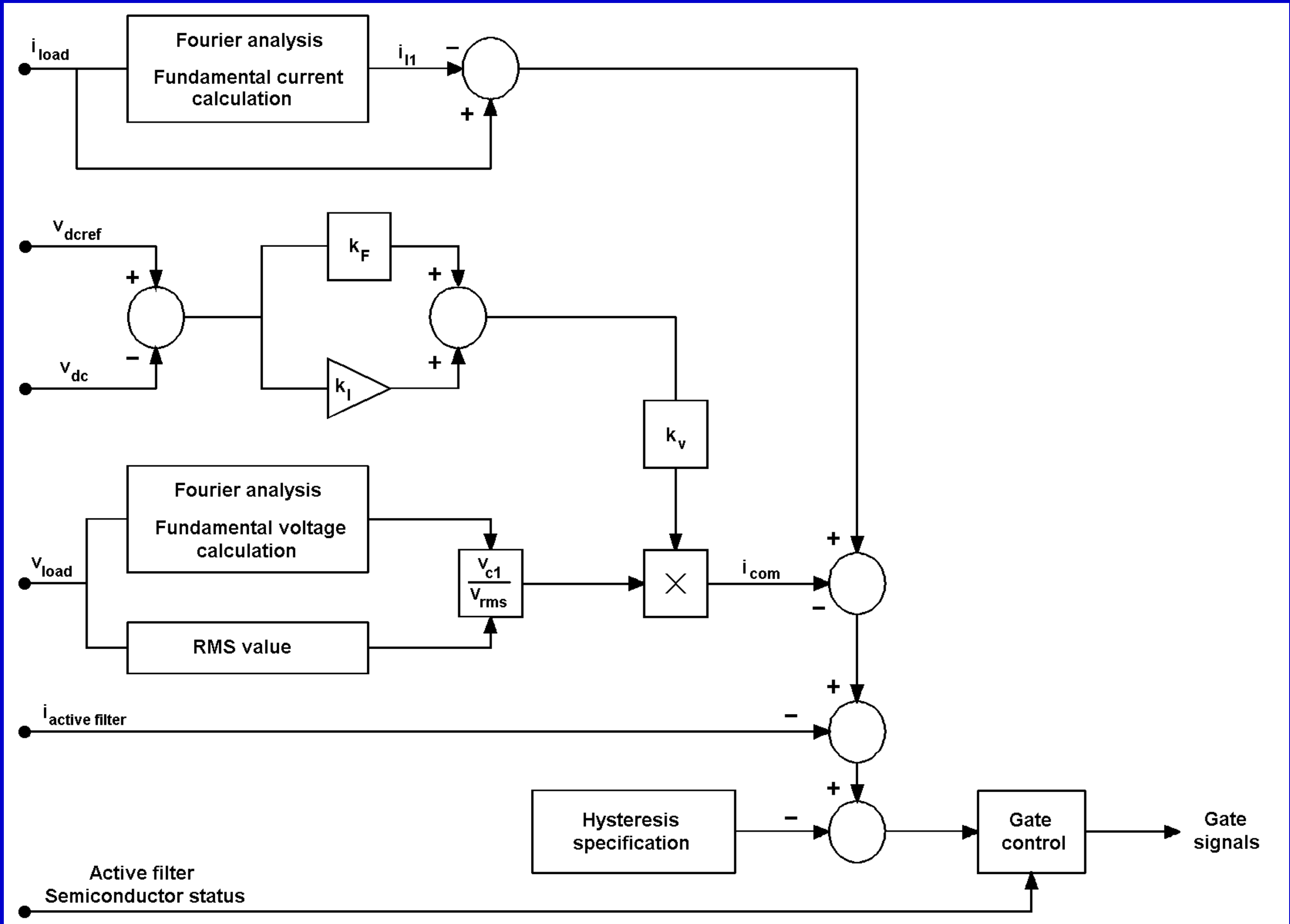
Scheme of the test system

Active Filters



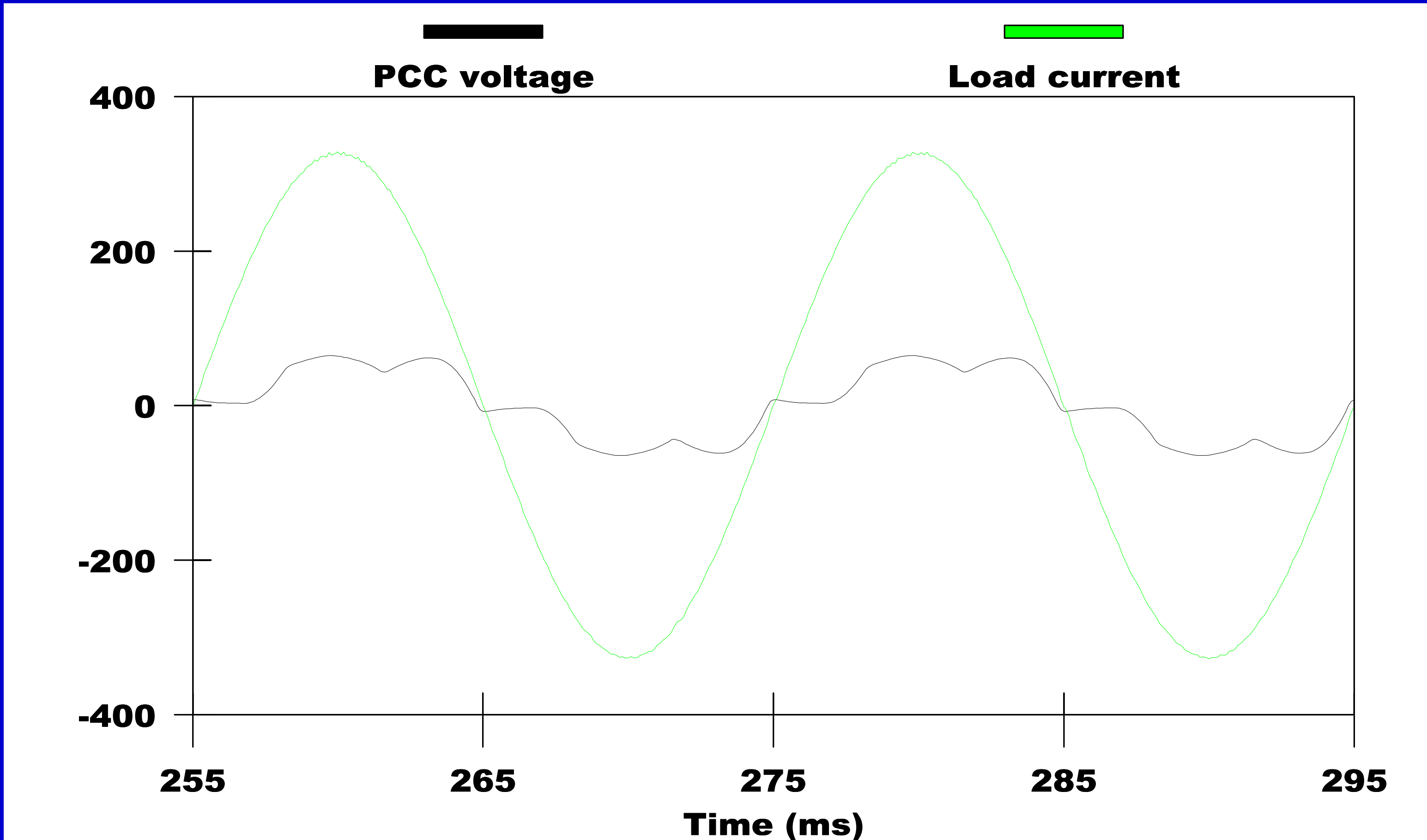
Detailed scheme of the power circuit

Active Filters



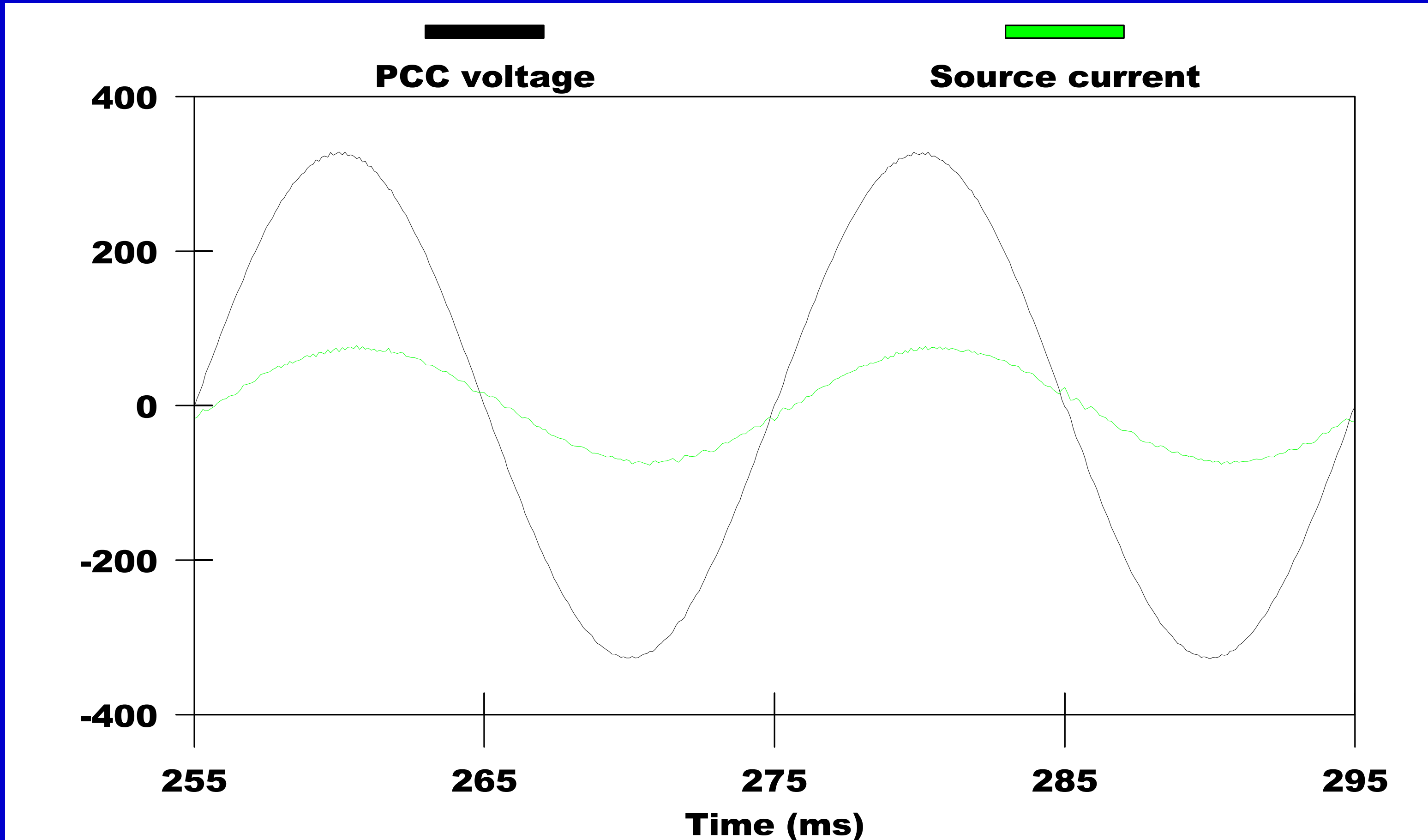
Control unit

Active Filters - 1



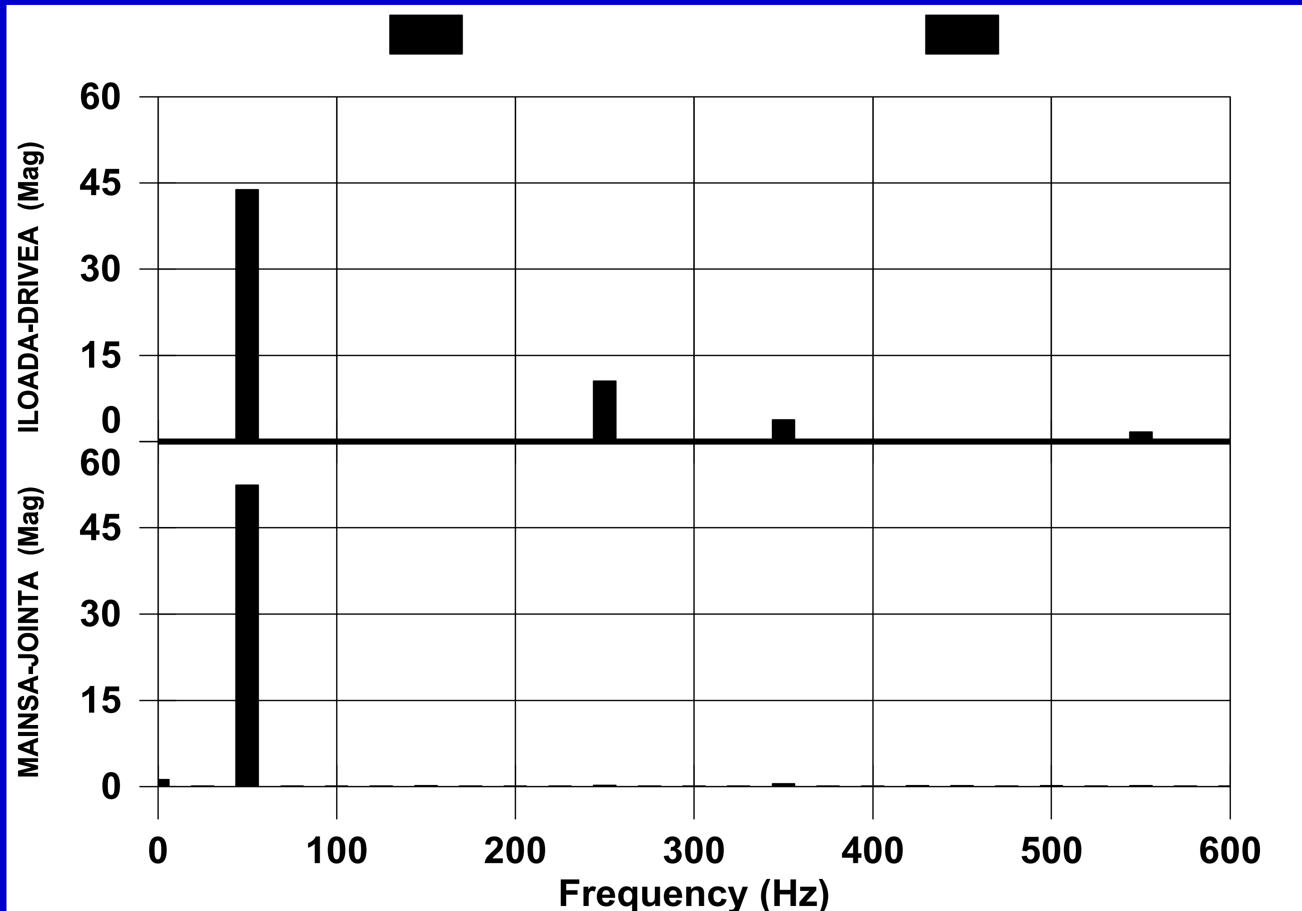
PCC voltage and rectifier current

Active Filters - 1



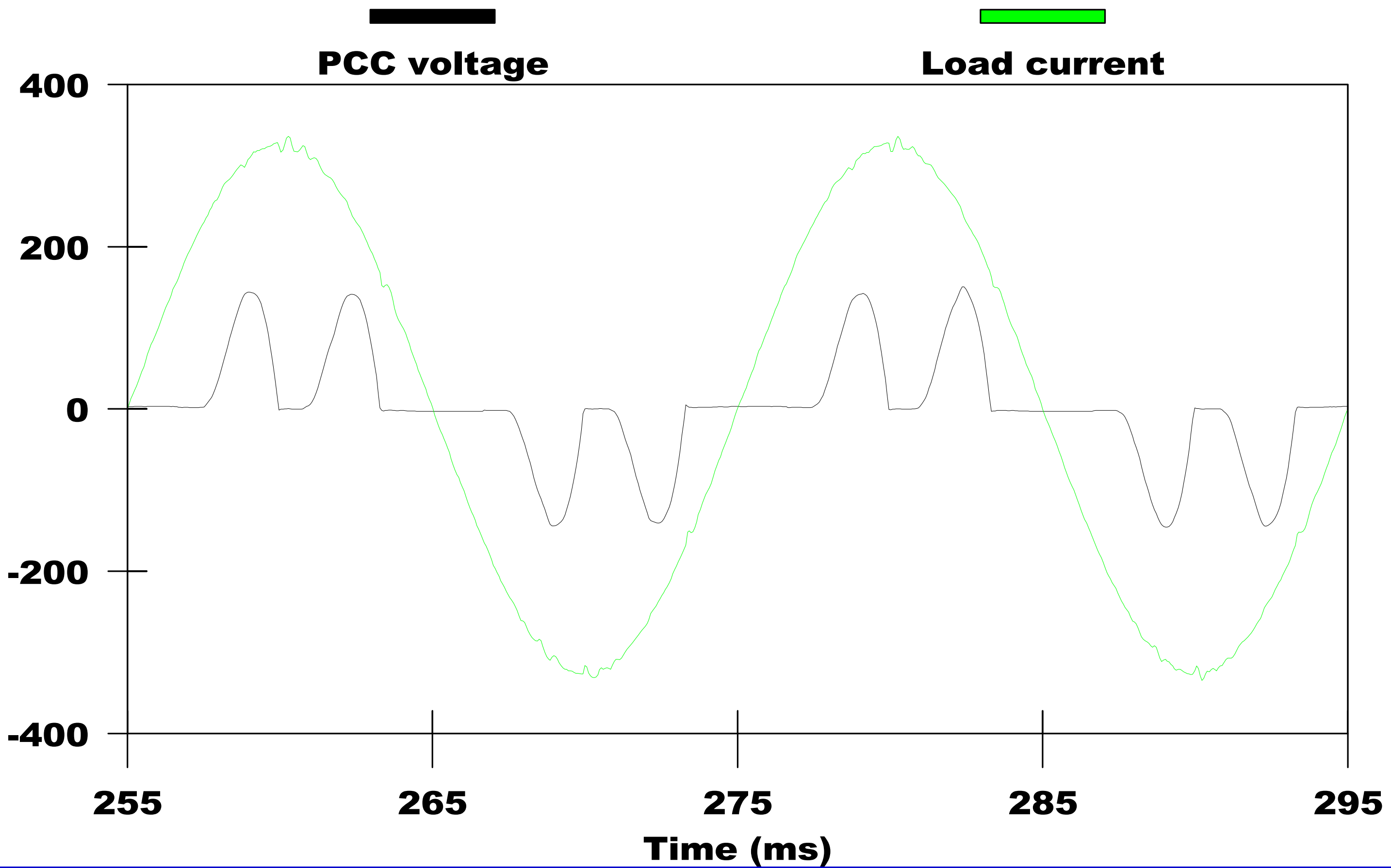
PCC voltage and source current

Active Filters - 1



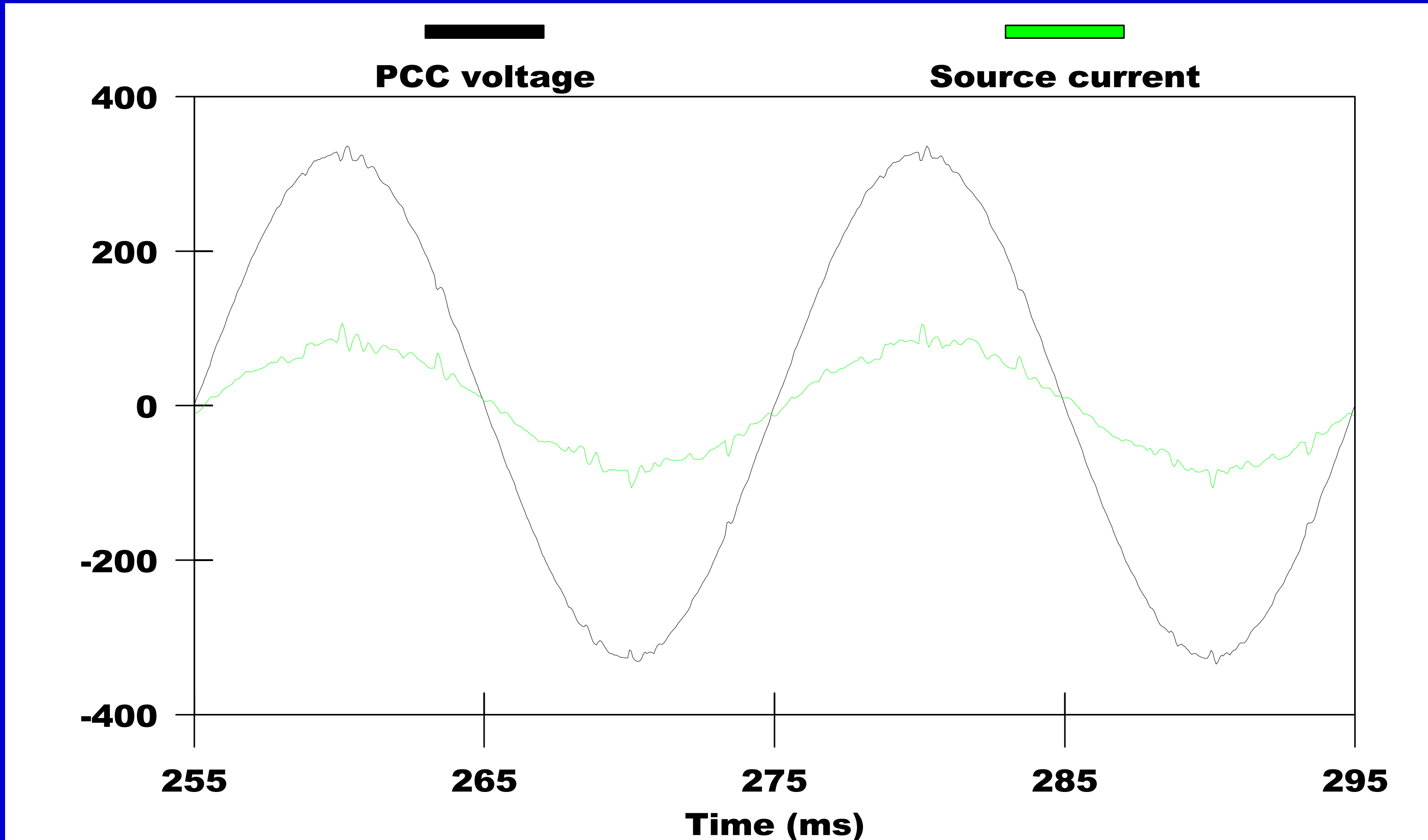
Rectifier and source currents

Active Filters - 2



PCC voltage and rectifier current

Active Filters - 2



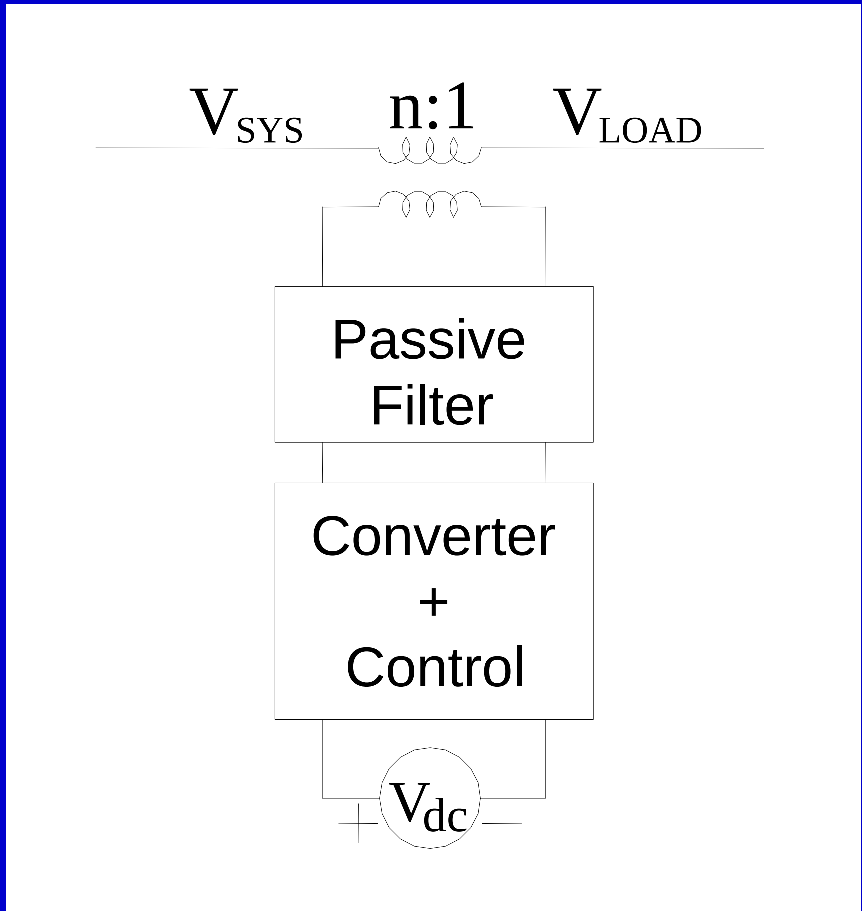
PCC voltage and source current

Active Filters

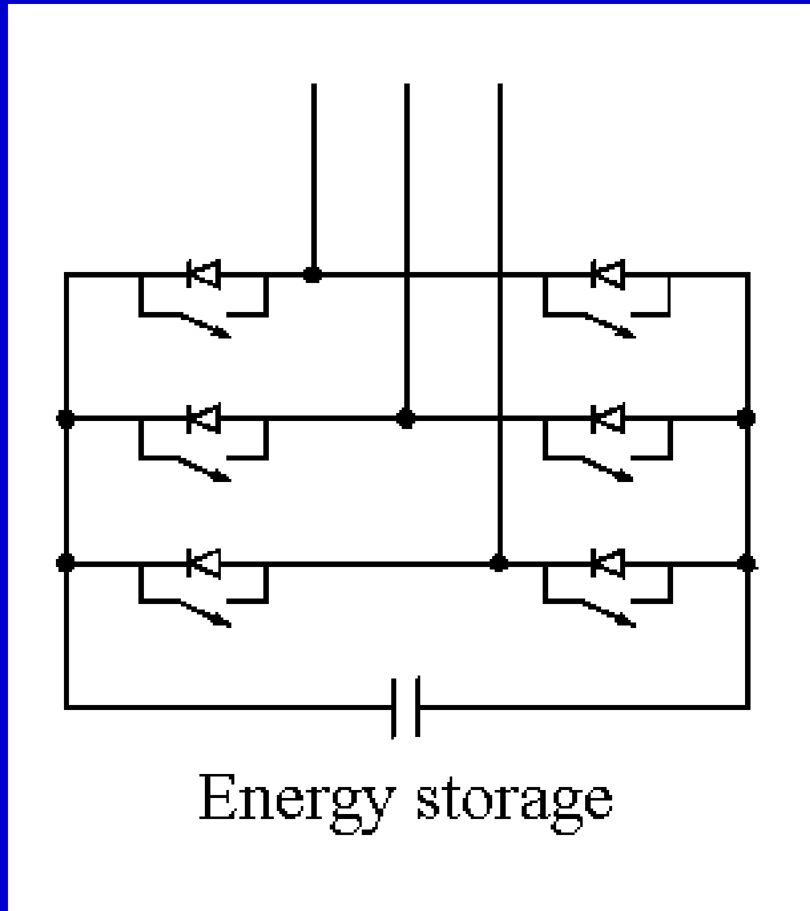
Harmonic Distortion

CASE	Current	RMS (A)	H1 (A)	THD (%)	H5 (%)	H7 (%)	H11 (%)	H13 (%)
1	Load	45.26	43.80	26.00	23.99	8.599	3.802	3.001
	Source	52.43	52.41	2.739	0.427	0.961	0.306	0.270
2	Load	67.43	49.39	92.96	73.70	52.90	16.43	8.357
	Source	59.15	59.02	6.374	3.707	4.089	0.903	1.776
3	Load	66.70	49.19	91.57	72.78	52.18	15.42	7.786
	Source	58.72	58.13	14.10	9.324	9.944	0.968	1.185

Dynamic Voltage Restorer

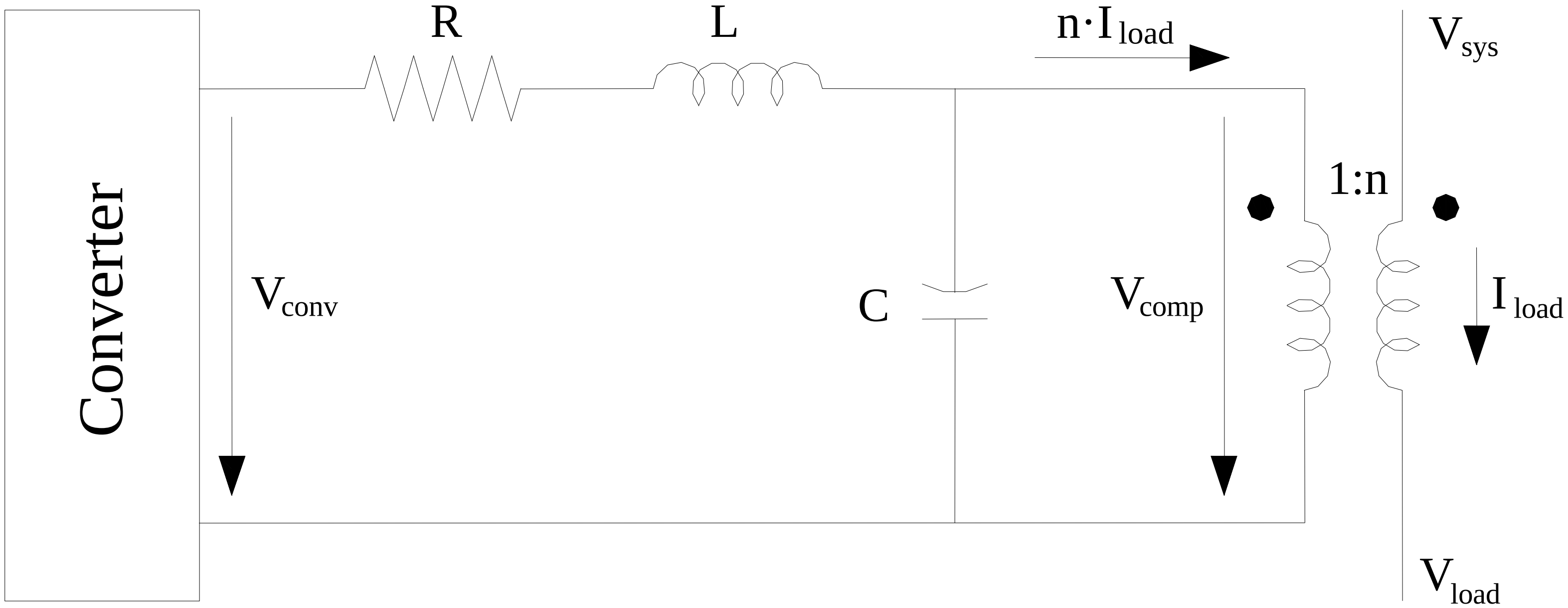


Power Circuit



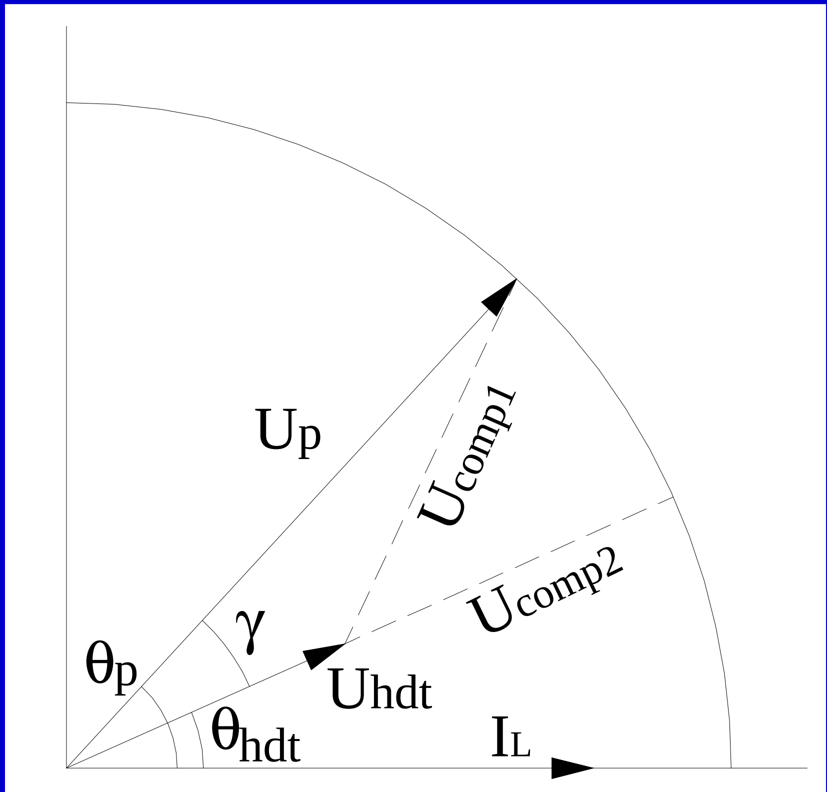
DVR Converter

Dynamic Voltage Restorer



Single-phase scheme

Dynamic Voltage Restorer



- **Voltage compensation**
  - **Only magnitude**
  - **Total compensation**

$$U_{comp} = \sqrt{\left(U_p \cdot Cos\theta_p - U_{hdt} \cdot Cos\theta_{hdt}\right)^2 + \left(U_p \cdot Sin\theta_p - U_{hdt} \cdot Sin\theta_{hdt}\right)^2}$$

$$= \sqrt{U_p^2 + U_{hdt}^2 - 2 \cdot U_p \cdot U_{hdt} \cdot Cos\gamma} \; ; \qquad \gamma = \theta_p - \theta_{hdt}$$

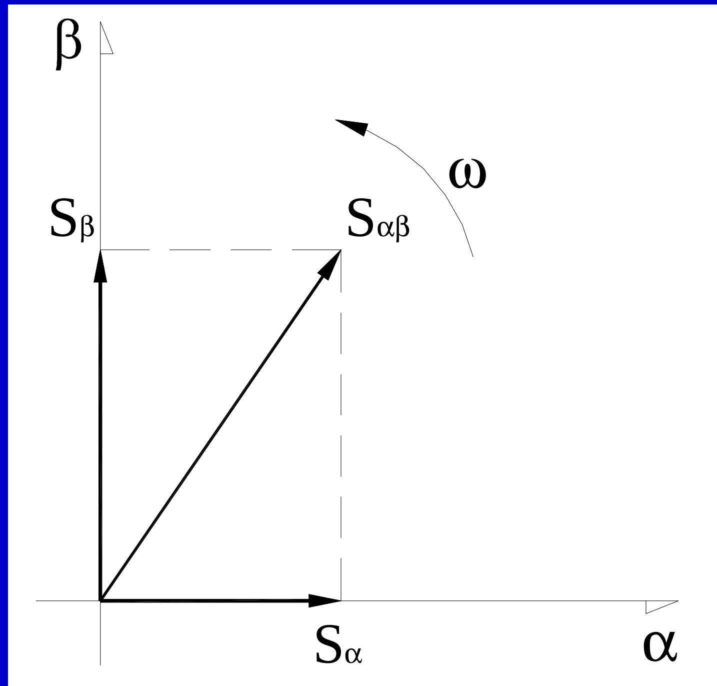
Dynamic Voltage Restorer

‘ab’ transformation

$$S_{ab} = S_a + j \cdot S_b = \sqrt{\frac{2}{3}} \cdot \left(S_a \cdot e^{j0} + S_b \cdot e^{j\frac{2 \cdot p}{3}} + S_c \cdot e^{j\frac{4 \cdot p}{3}} \right)$$

$$\begin{bmatrix} S_a \\ S_b \\ S_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \cdot \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix}$$

$$\begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & 0 & 1/\sqrt{2} \\ -1/2 & \sqrt{3}/2 & 1/\sqrt{2} \\ -1/2 & -\sqrt{3}/2 & 1/\sqrt{2} \end{bmatrix} \cdot \begin{bmatrix} S_a \\ S_b \\ S_0 \end{bmatrix}$$



Dynamic Voltage Restorer

‘ab’ transformation

$$\mathrm{v}_a(t) = \mathrm{x} \cdot Cos(wt + j_d) + \mathrm{y} \cdot Cos(wt + j_i)$$

$$\mathrm{v}_b(t) = \mathrm{x} \cdot Cos\left(wt + j_d - \frac{2p}{3}\right) + \mathrm{y} \cdot Cos\left(wt + j_i + \frac{2p}{3}\right)$$

$$\mathrm{v}_c(t) = \mathrm{x} \cdot Cos\left(wt + j_d + \frac{2p}{3}\right) + \mathrm{y} \cdot Cos\left(wt + j_i - \frac{2p}{3}\right)$$

$$a = \sqrt{\frac{3}{2}} \cdot \left[\mathrm{x} \cdot Cos(wt + j_d) + \mathrm{y} \cdot Cos(wt + j_i)\right] = a_+ + a_-$$

$$b = \sqrt{\frac{3}{2}} \cdot \left[\mathrm{x} \cdot Sen(wt + j_d) - \mathrm{y} \cdot Sen(wt + j_i)\right] = b_+ + b_-$$

Dynamic Voltage Restorer

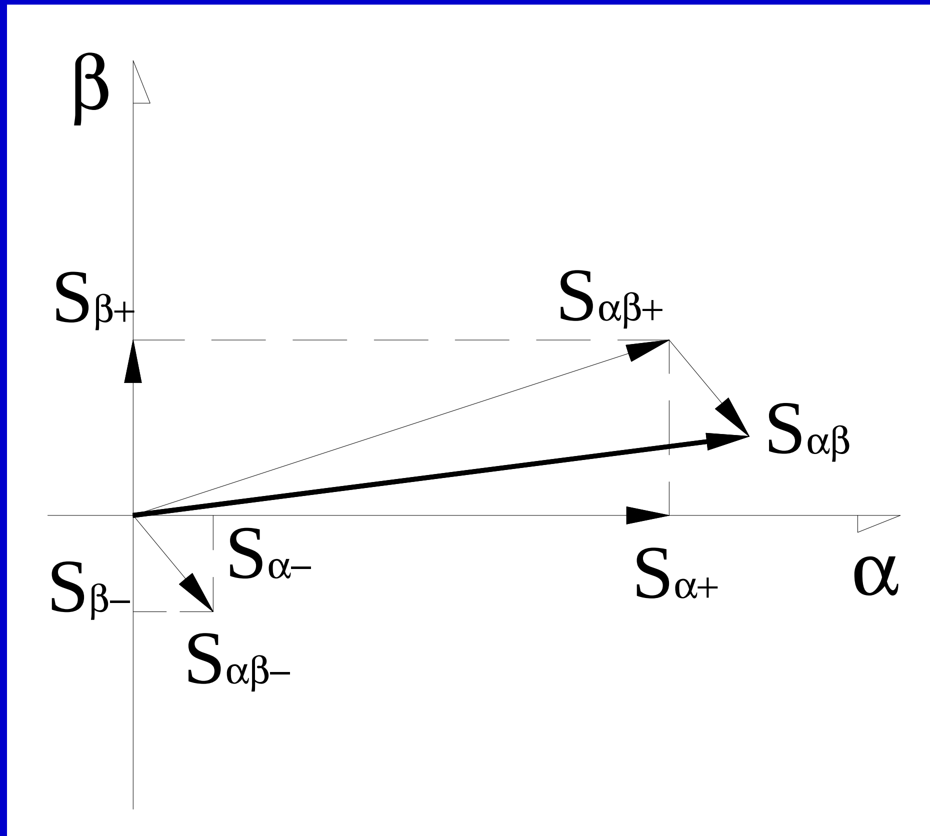
Symmetrical component calculation

$$a_+ = \frac{1}{2} \cdot \left[a - b_{(-p/2)} \right]$$

$$b_+ = \frac{1}{2} \cdot \left[a_{(-p/2)} + b \right]$$

$$a_- = \frac{1}{2} \cdot \left[a + b_{(-p/2)} \right]$$

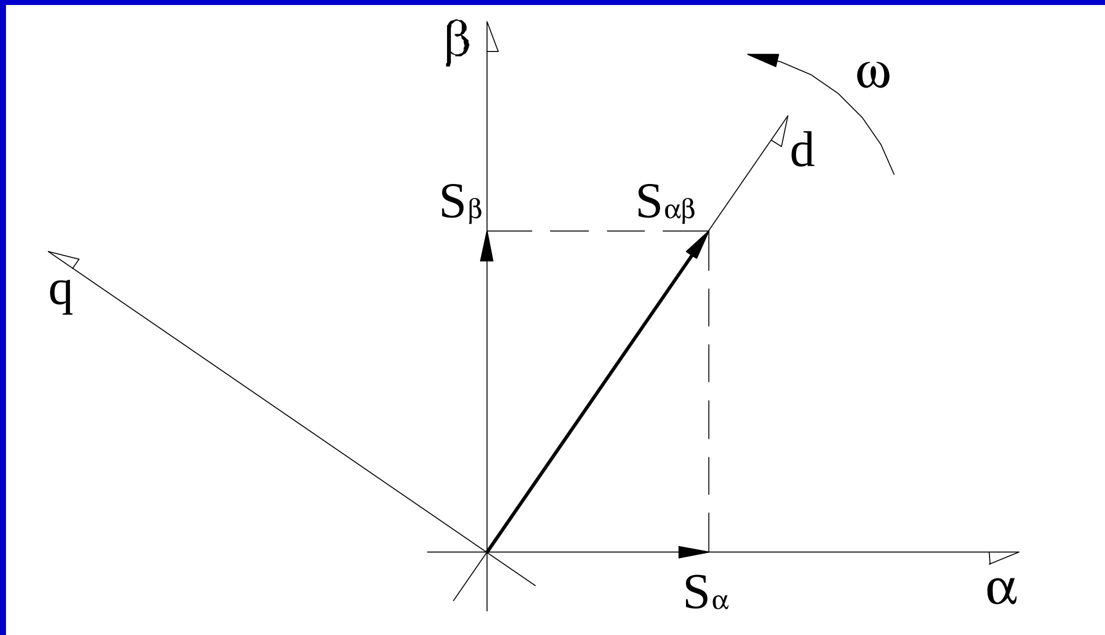
$$b_- = \frac{1}{2} \cdot \left[a_{(-p/2)} - b \right]$$



Dynamic Voltage Restorer

Synchronous reference - ‘dq’ transformation

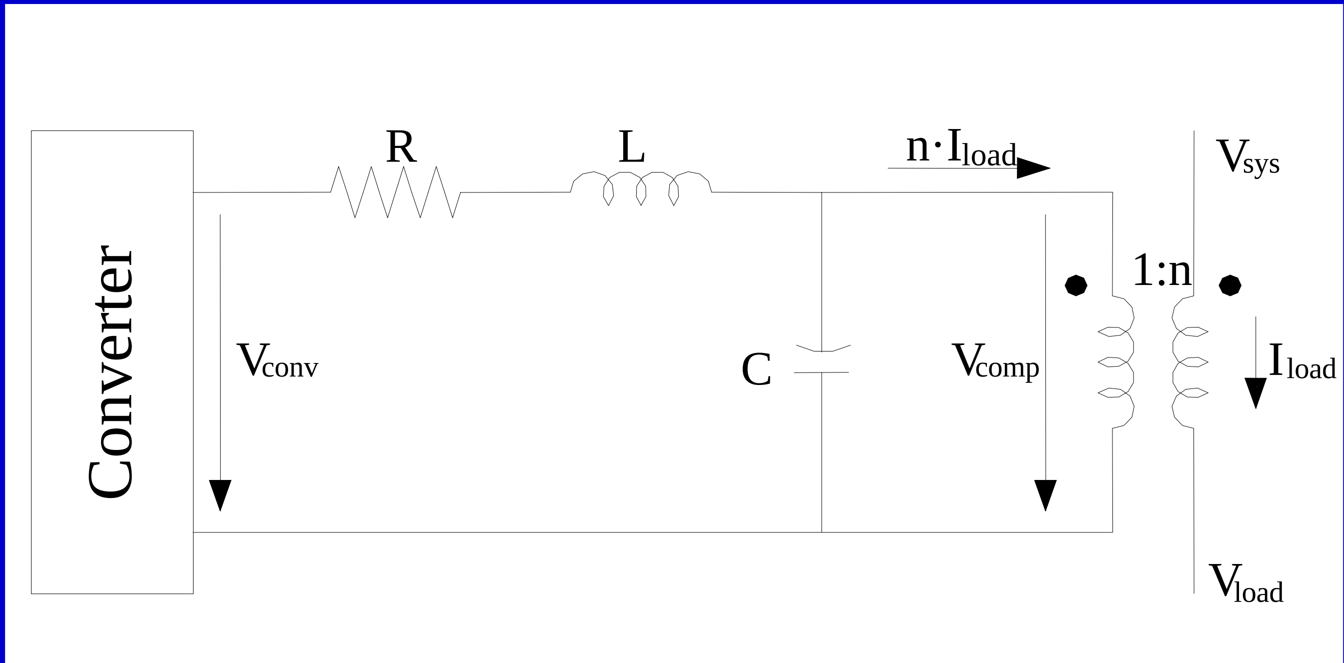
$$\begin{bmatrix} S_d \\ S_q \end{bmatrix} = \begin{bmatrix} Cosq & Senq \\ -Senq & Cosq \end{bmatrix} \cdot \begin{bmatrix} S_a \\ S_b \end{bmatrix}$$



Dynamic Voltage Restorer

Calculation of the actual voltage compensation

$$V_{comp} = \frac{1}{LC \cdot s^2 + RC \cdot s + 1} \cdot V_{conv} - \frac{R + L \cdot s}{LC \cdot s^2 + RC \cdot s + 1} \cdot \left(n \cdot I_{load}\right)$$



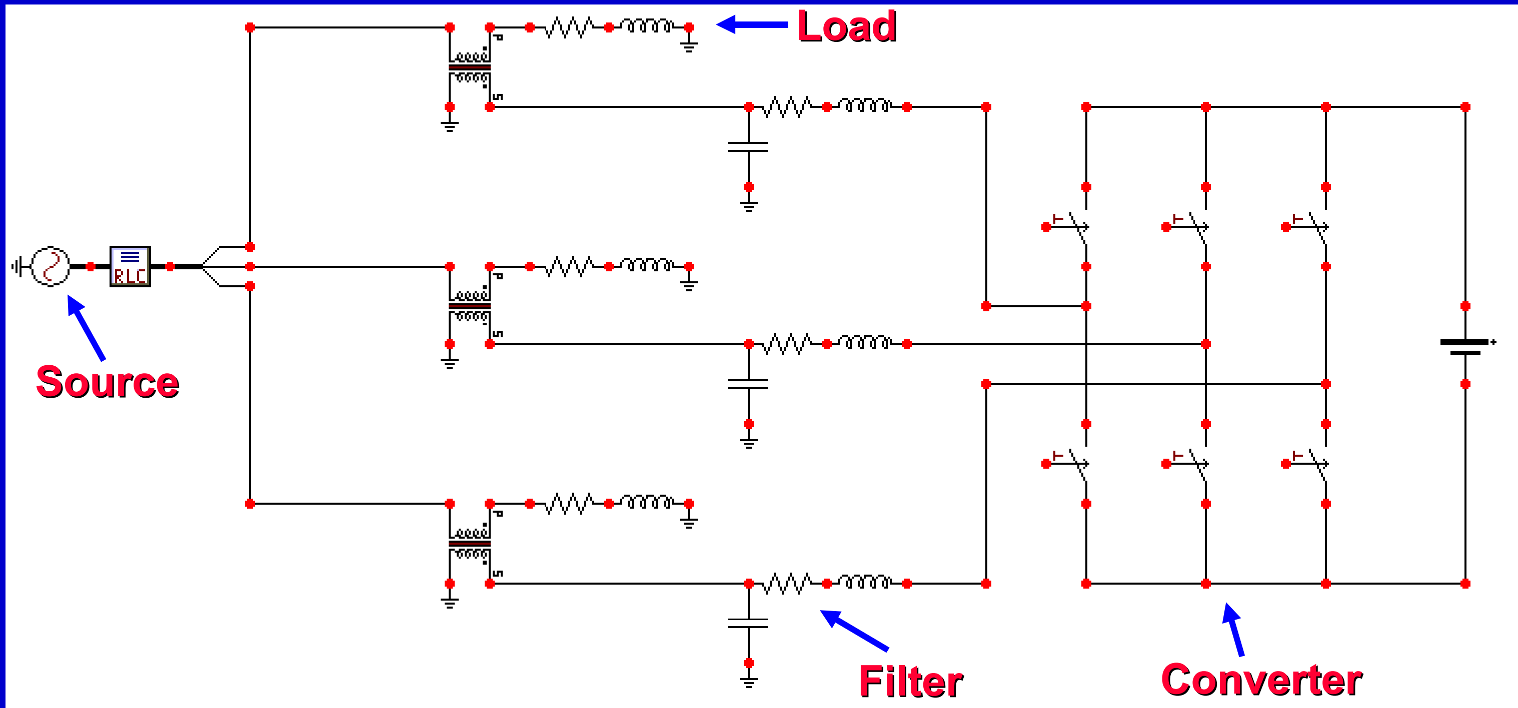
Dynamic Voltage Restorer

Control strategy

- Measure system voltages and currents
- Apply ‘ab’ transform to voltages and currents, and obtain symmetrical components
- Obtain ‘dq’ components
- Determine voltage compensation in ‘dq’ values for positive and negative sequences
- Deduce the values to be obtained at the converter terminals, taking into account the passive filter effect
- Obtain compensation voltages by applying anti-transforms (‘dq’ → ‘ab’ → ‘abc’)
- Determine gate signals by means of a PWM control strategy

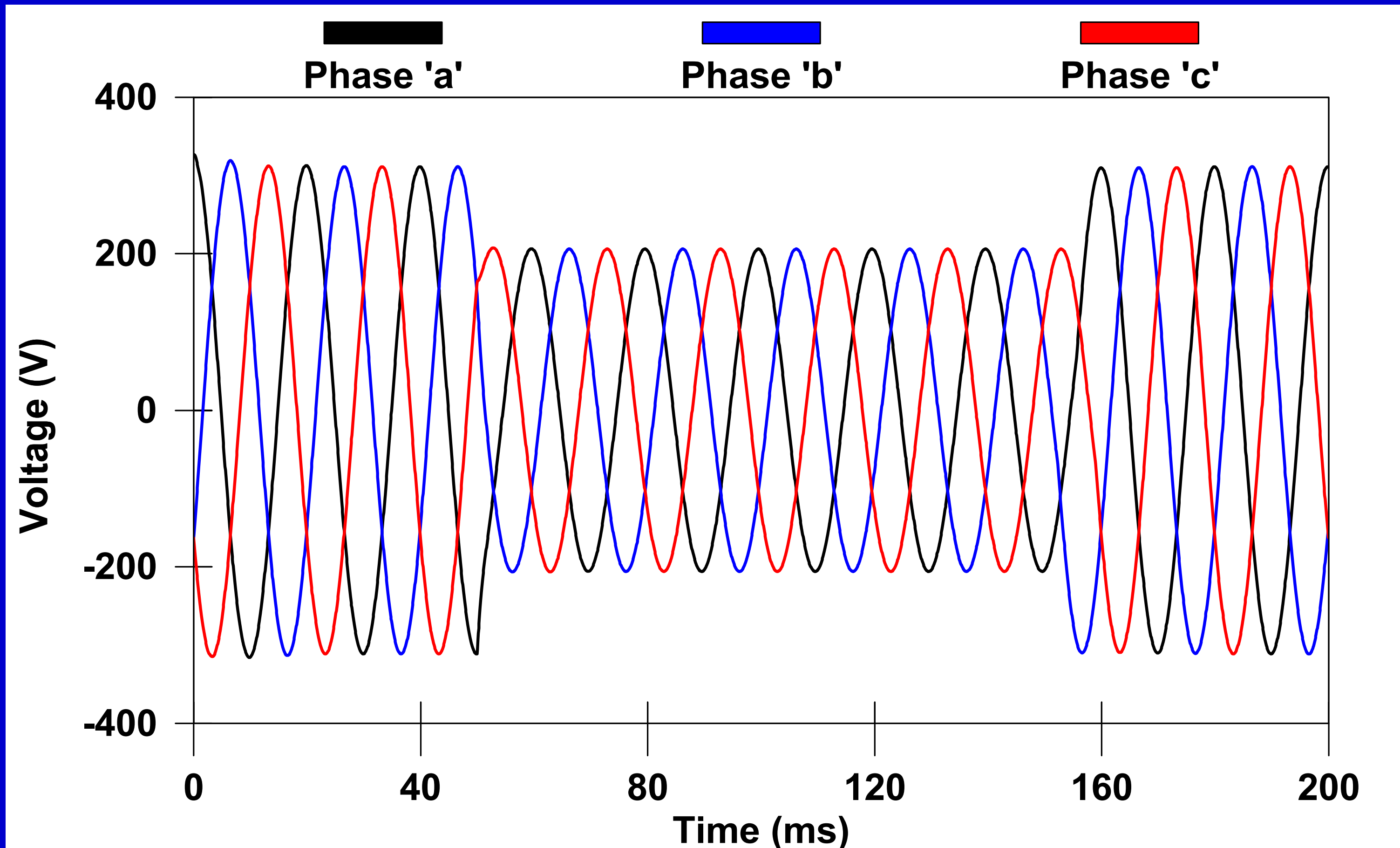
Dynamic Voltage Restorer

Test system



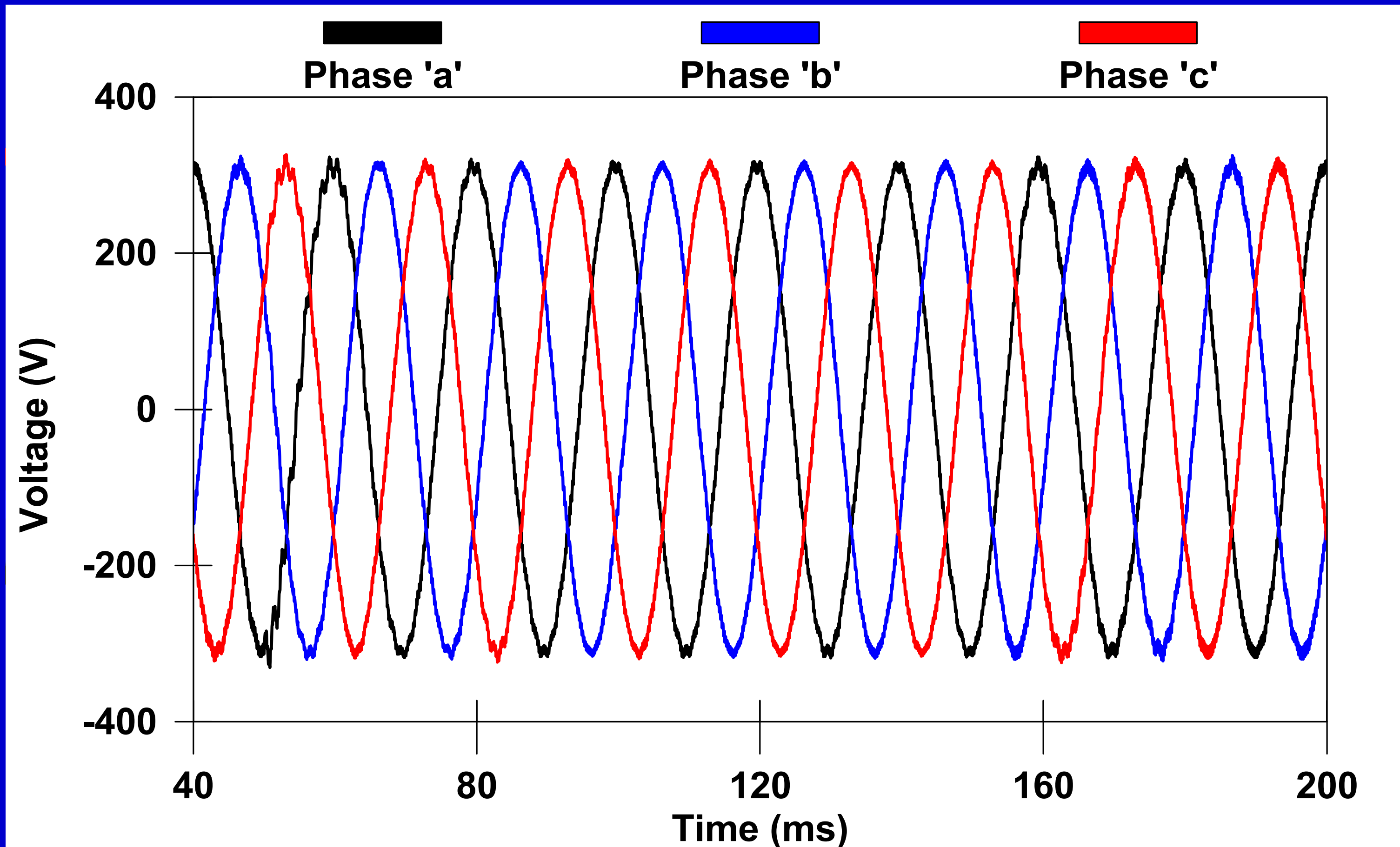
- **Test cases**
  - Same voltage dip at the three phases
  - Voltage dip in two phases, voltage swell in the third phase, with phase angle jumps

Dynamic Voltage Restorer - 1



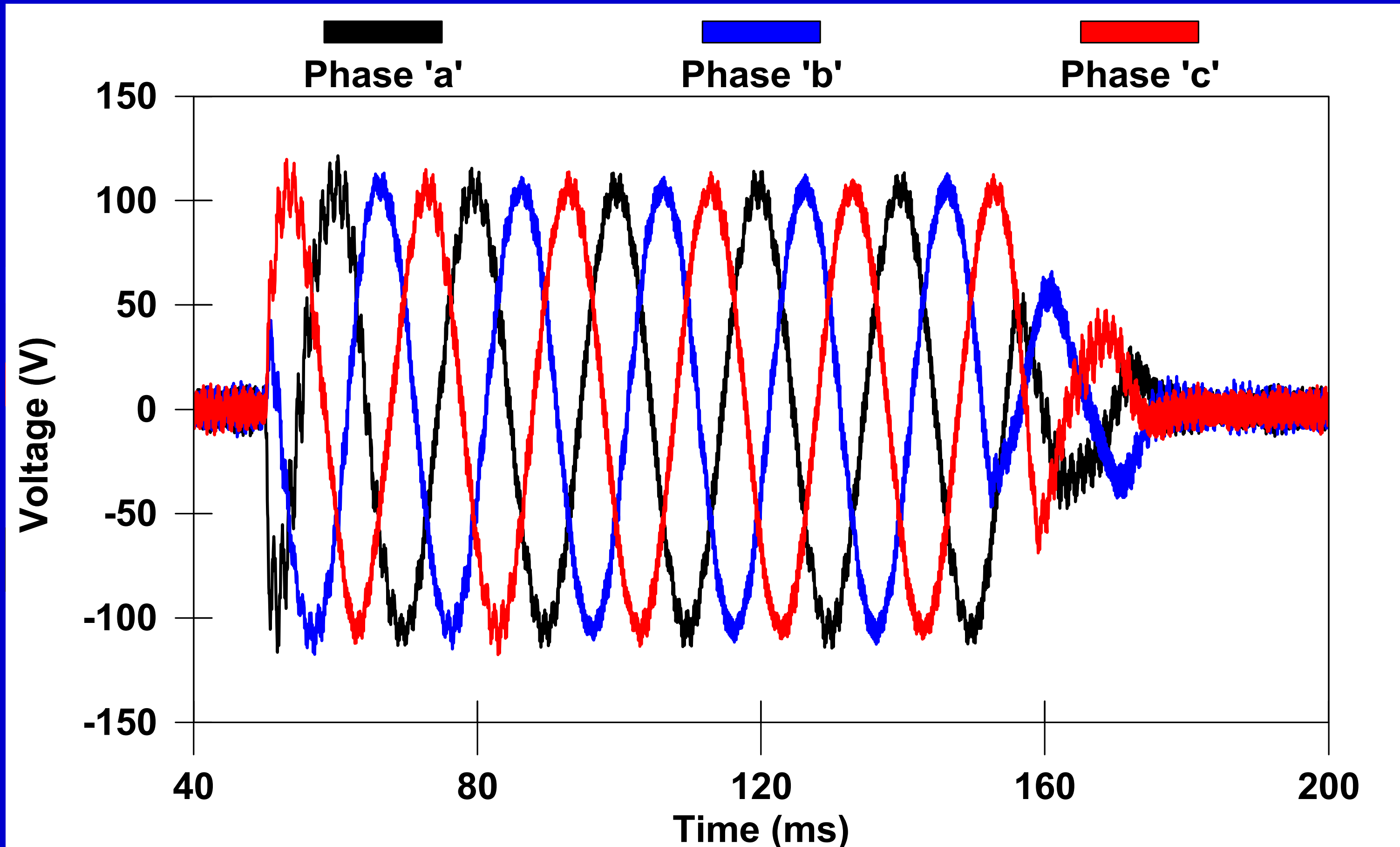
Input voltages

Dynamic Voltage Restorer - 1



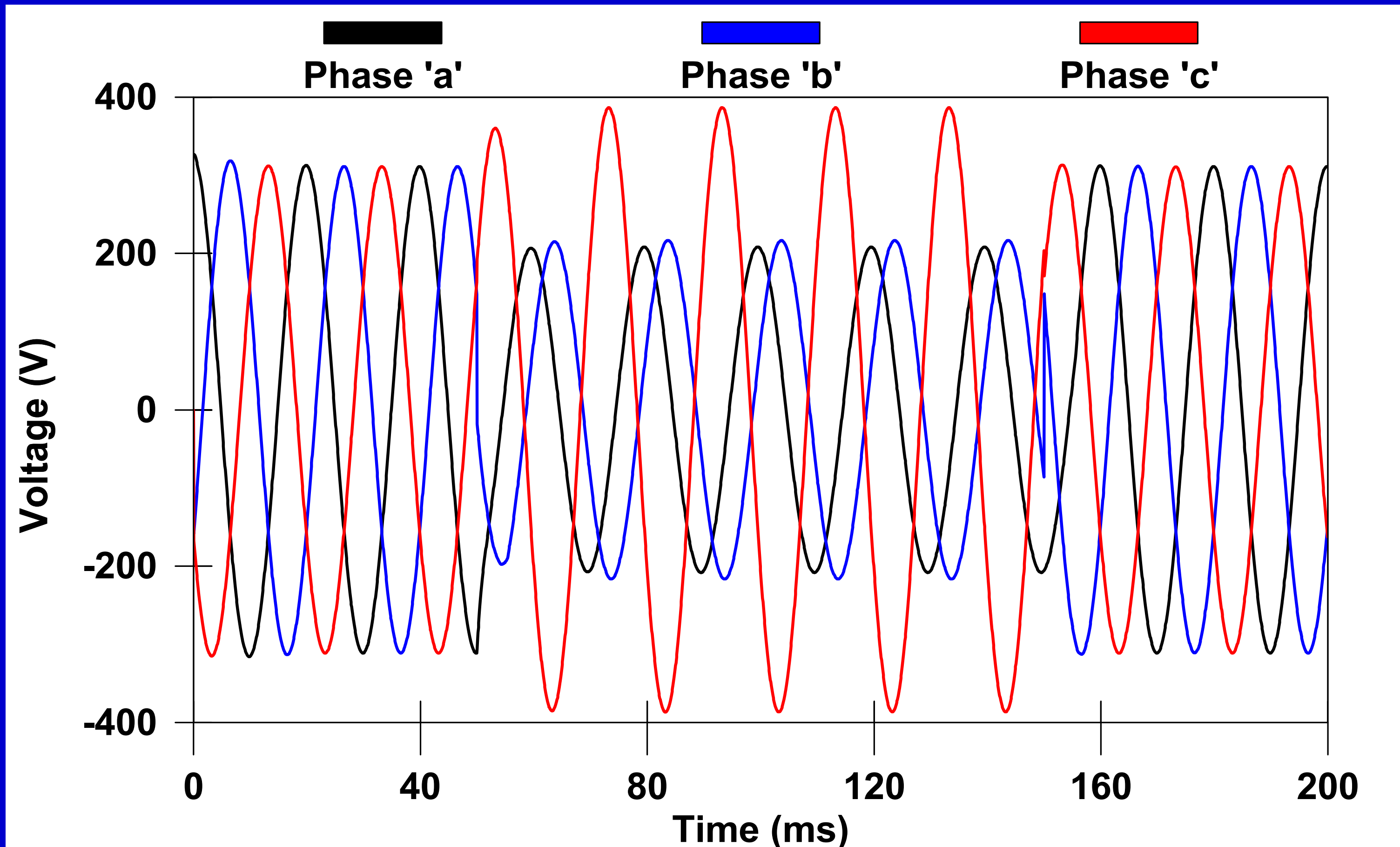
Load voltages

Dynamic Voltage Restorer - 1



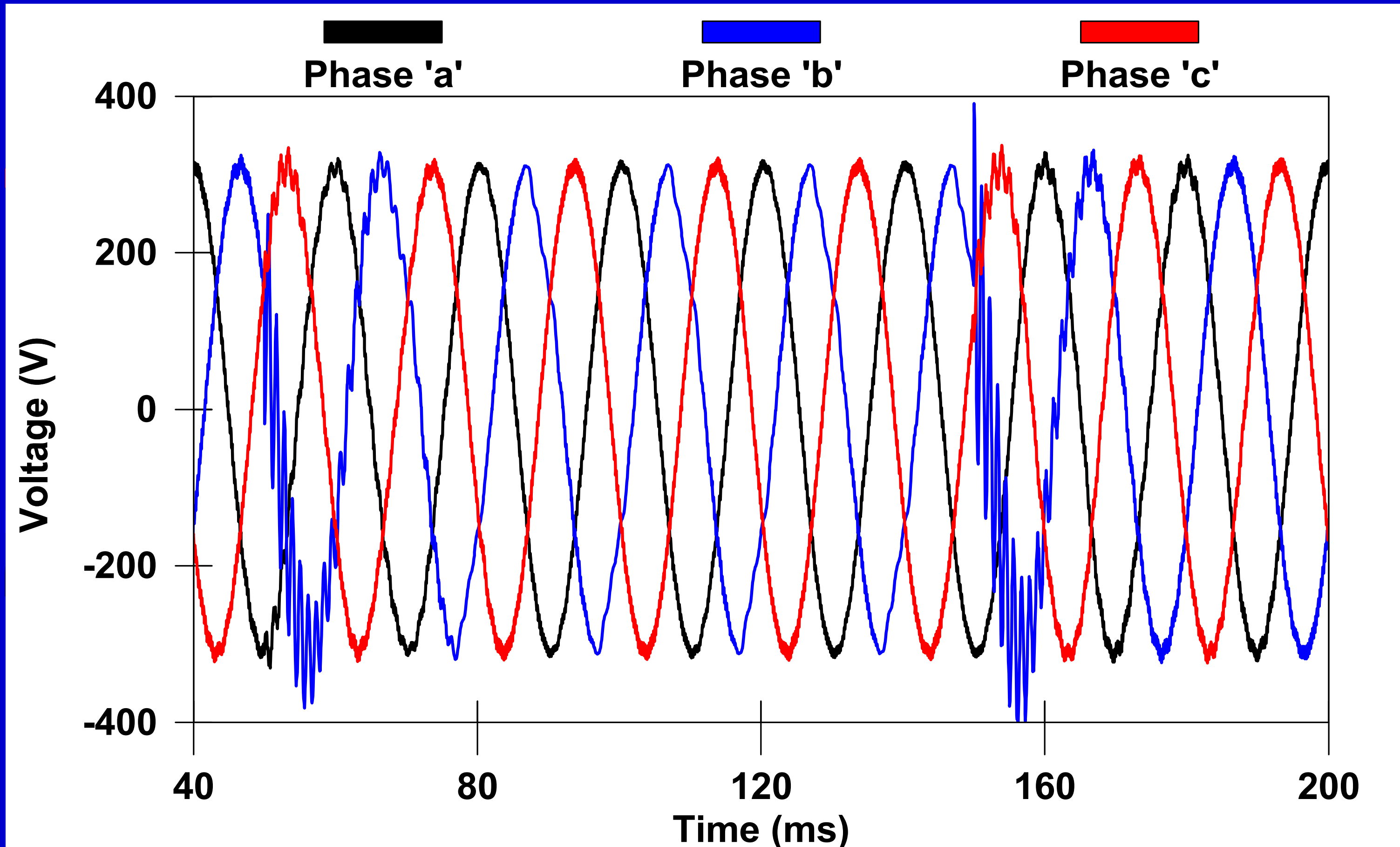
Voltages injected by the DVR

Dynamic Voltage Restorer - 2



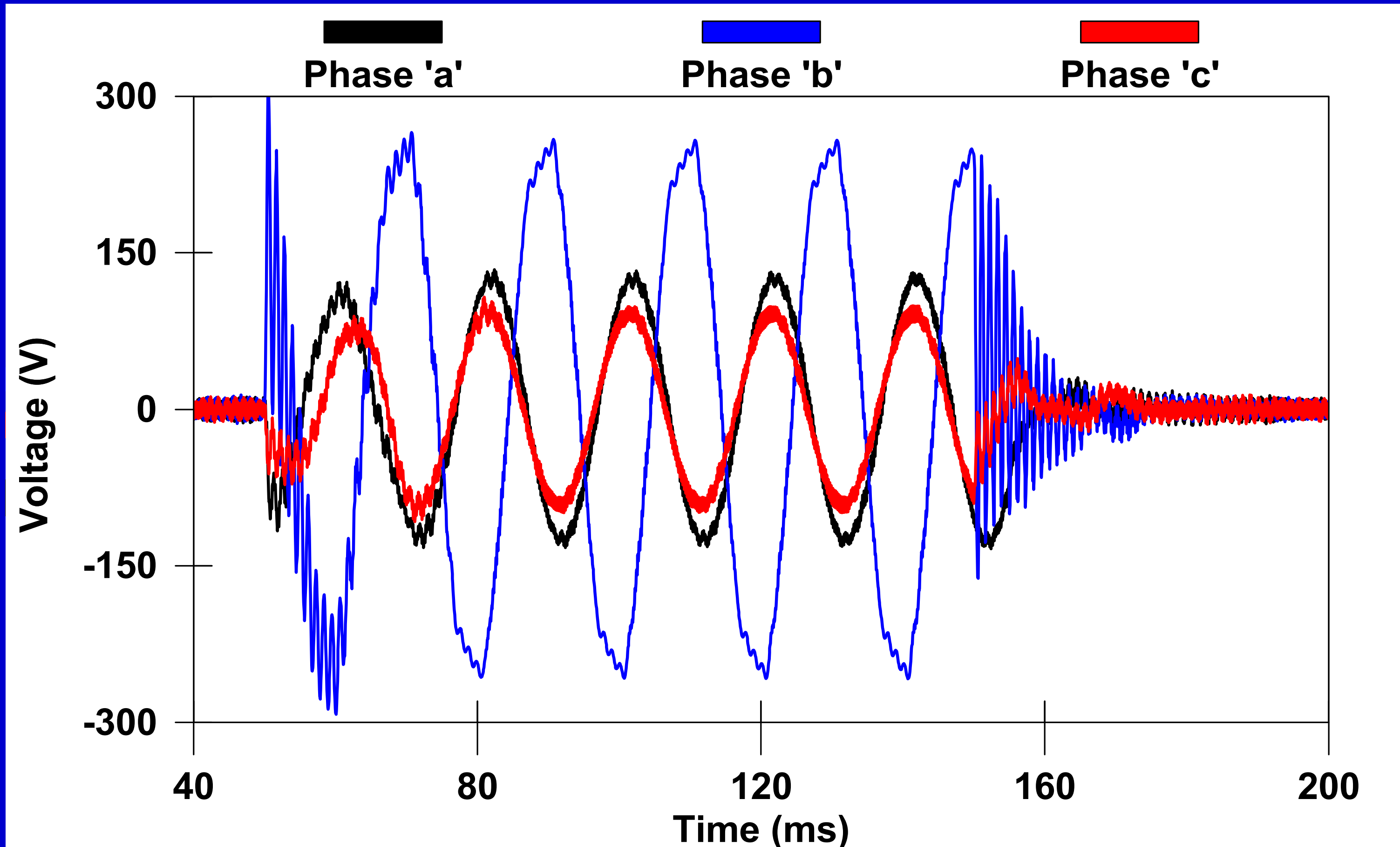
Input voltages

Dynamic Voltage Restorer - 2



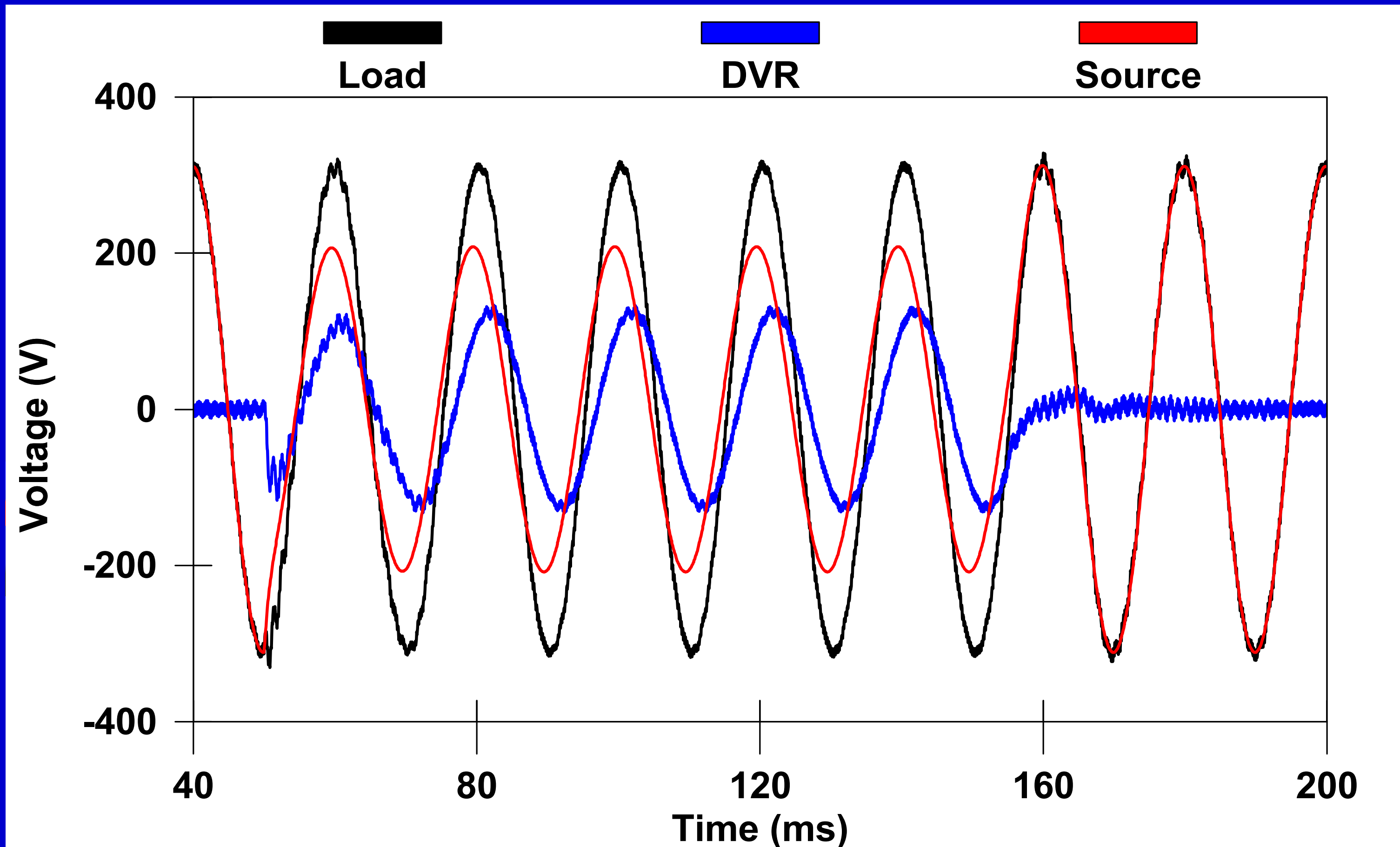
Load voltages

Dynamic Voltage Restorer - 2



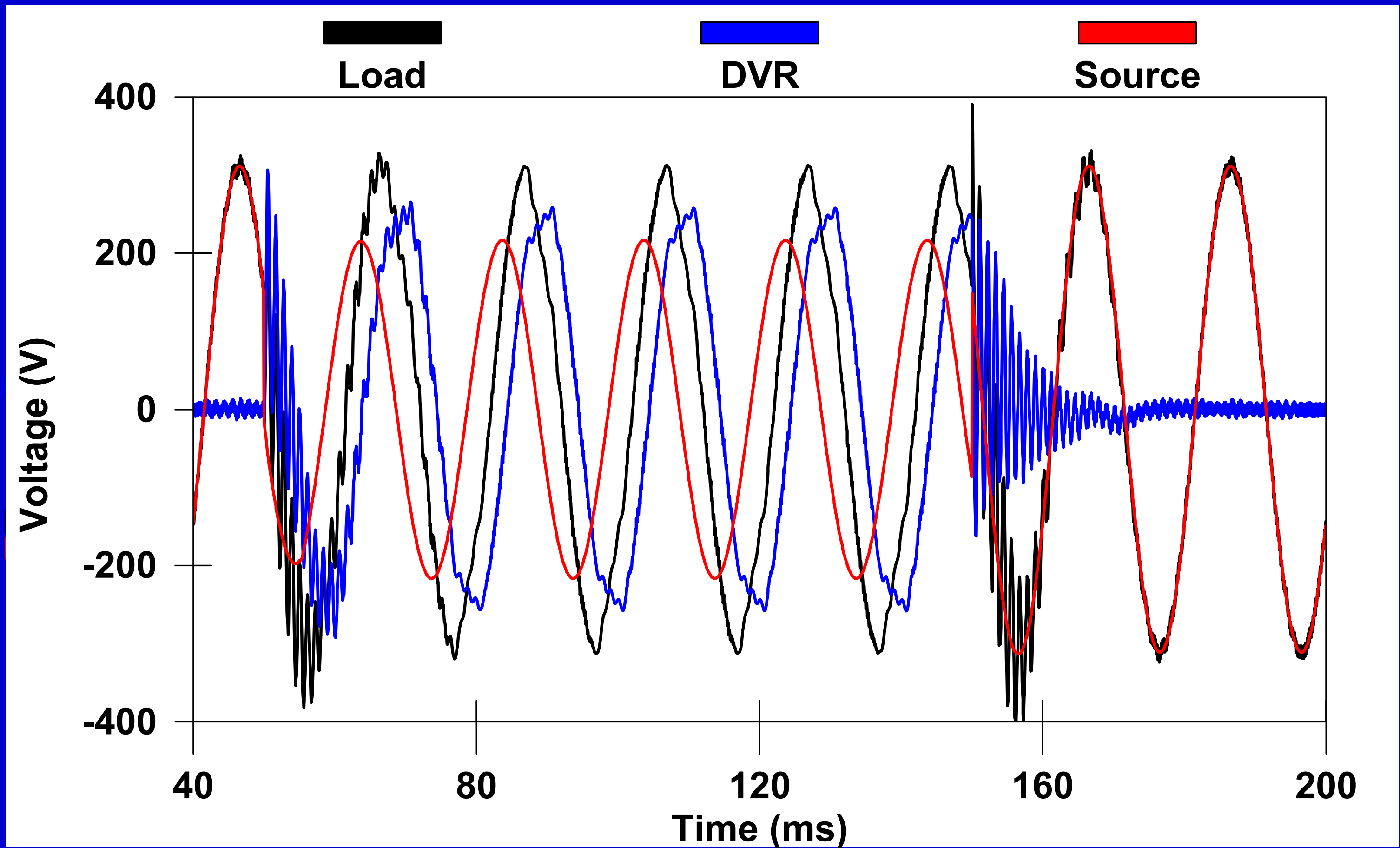
Voltages injected by the DVR

Dynamic Voltage Restorer - 2



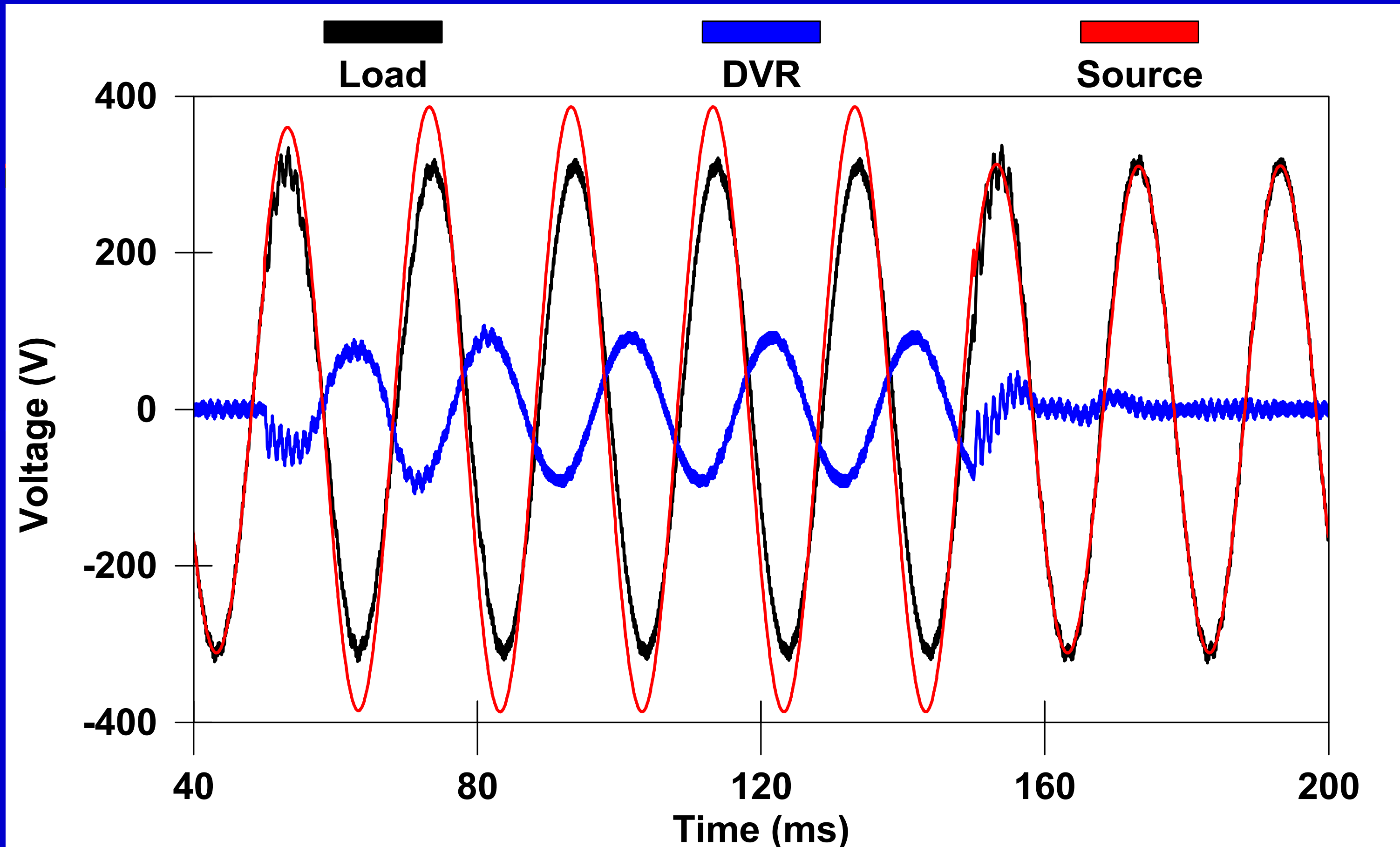
Phase - 'a'

Dynamic Voltage Restorer - 2



Phase - ‘b’

Dynamic Voltage Restorer - 2



Phase - ‘c’

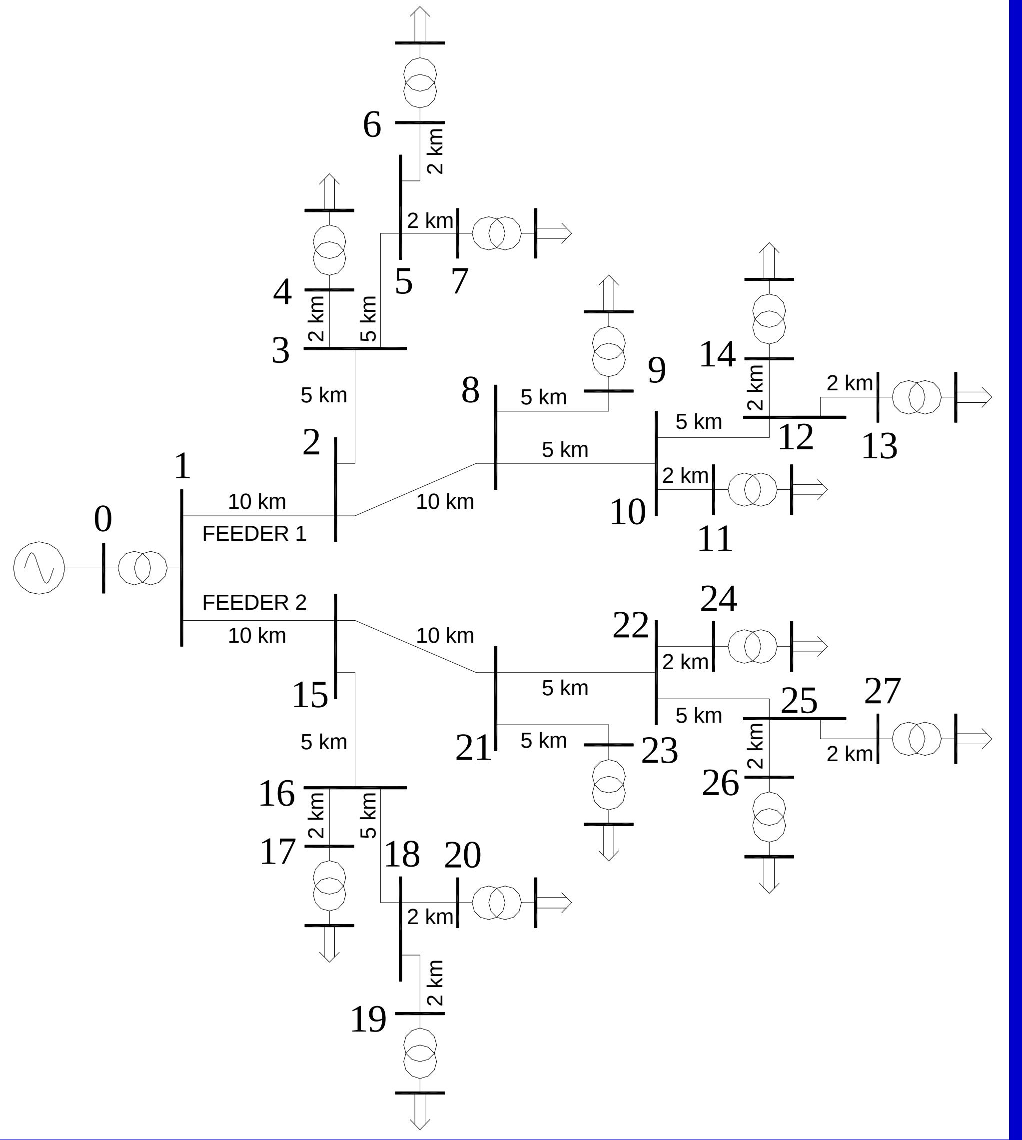
Stochastic Prediction of Voltage Dips

- The Monte Carlo method
- Diagram of the test system
- Assumptions
- Voltage dip calculations
  - voltage dip probability density
  - number of voltage dips
- Effect of protective devices

The Monte Carlo Method

- A widely used technique for analyzing multidimensional complex systems
- It can be used for solving both stochastic and deterministic problems
- This technique is based on a iterative procedure that is repeated using in every new step a set of values of the random variables involved in the process, being these values generated according to the probability density function associated to each variable.

Scheme of the Test System



HV equivalent : 110 kV, 1500 MVA, X/R = 10

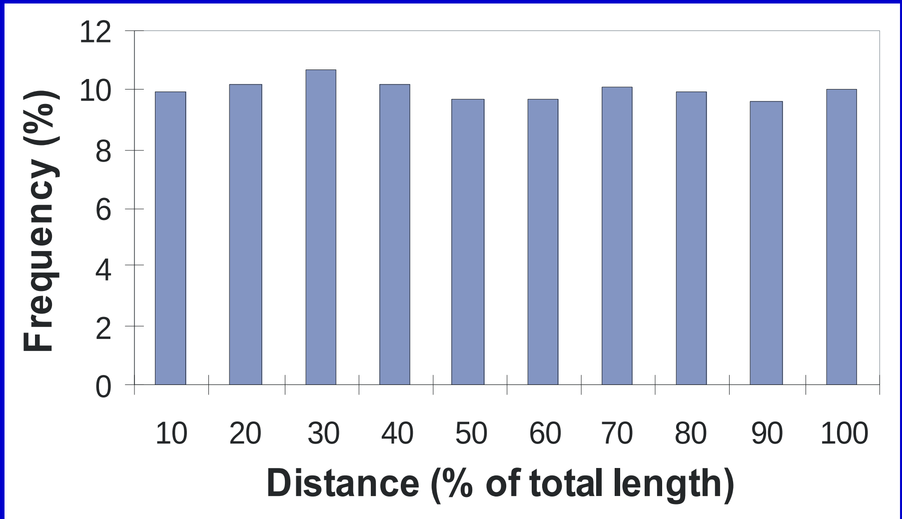
Substation transformer : 110/25 kV, 10 MVA, 8%, Yd11

Distribution transformers: 25/0.4 kV, 1 MVA, 6%, Dy

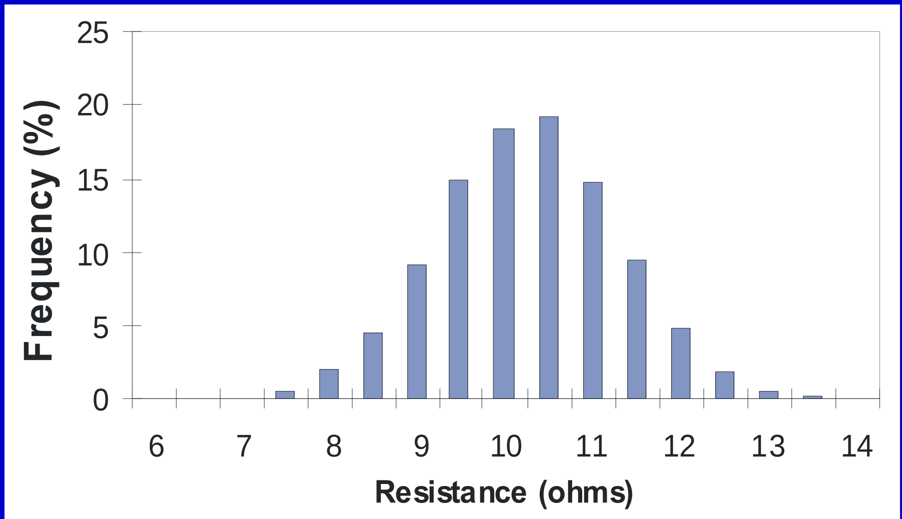
Lines : $Z_{1/2} = 0.61 + j0.39$, $Z_0 = 0.76 + j1.56\ \Omega/km$

Stochastic Prediction

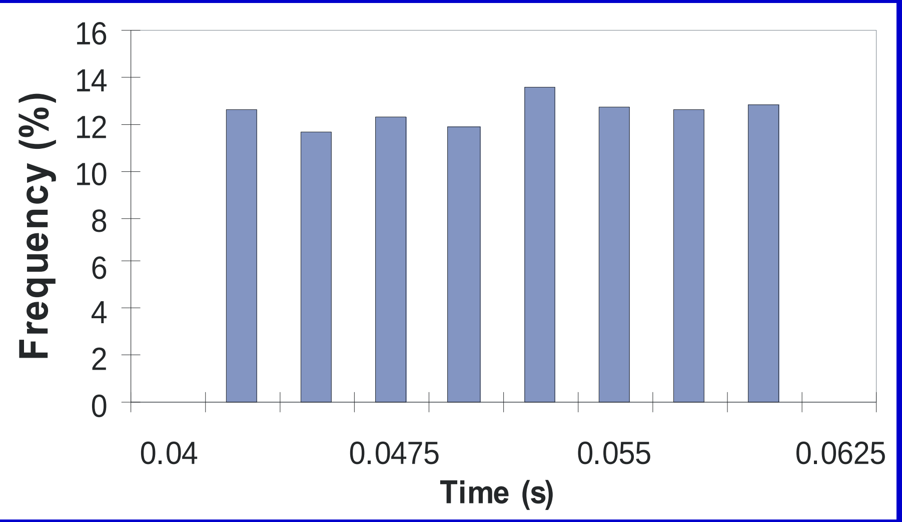
- Voltage dips are generated only by faults
- Characteristics of the faults
  - Fault location : It is selected by generating a uniform random number
  - Fault resistance: normal distribution, average value =10 S, standard deviation =1 S
  - Duration of the fault: normal distribution, average value = 0.06s, standard deviation =0.01 s
  - Initial time of the fault: uniform distribution between 0.04 and 0.06 s
  - Probability of each type of fault: LG: 80%, 2LG: 17%, 3LG: 0%, LL: 2%, 3L: 1%
- The test system was simulated 5000 times
- Assuming 12 faults per 100 km and year, this equals the performance of the network during 366 years



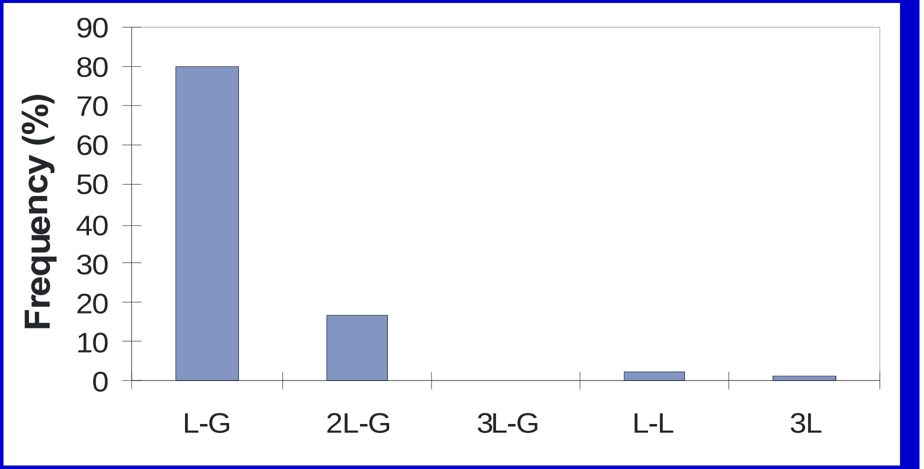
Fault location probability density



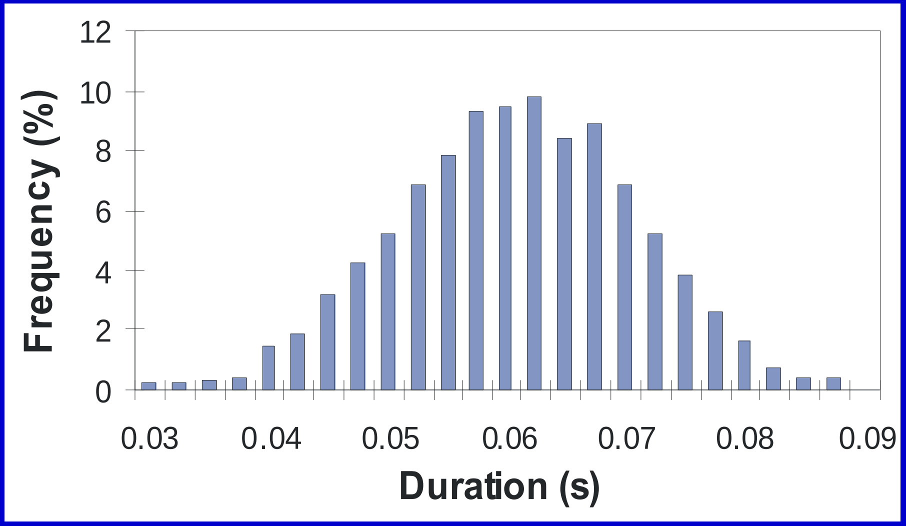
Fault resistance probability density



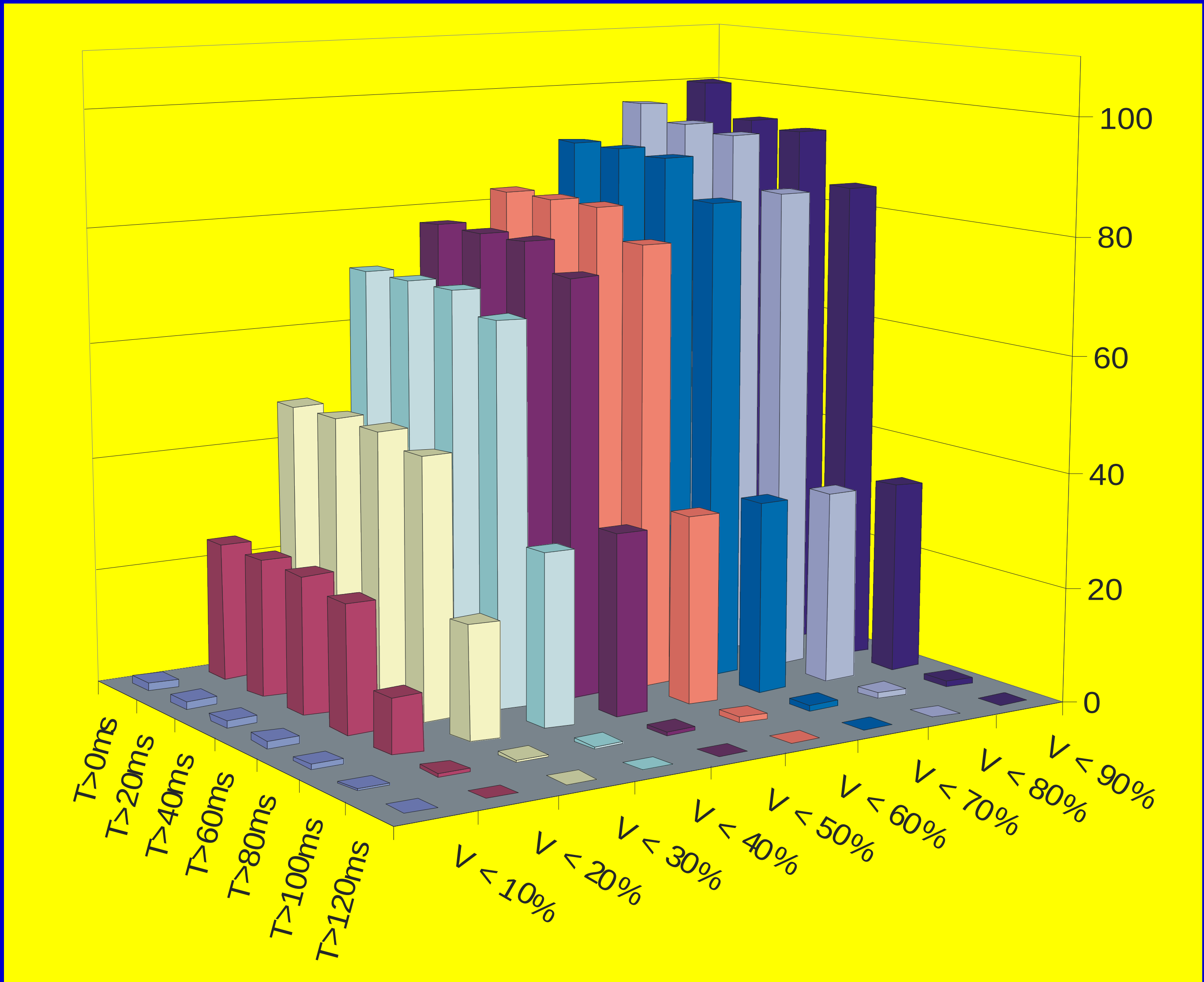
Initial fault time probability density



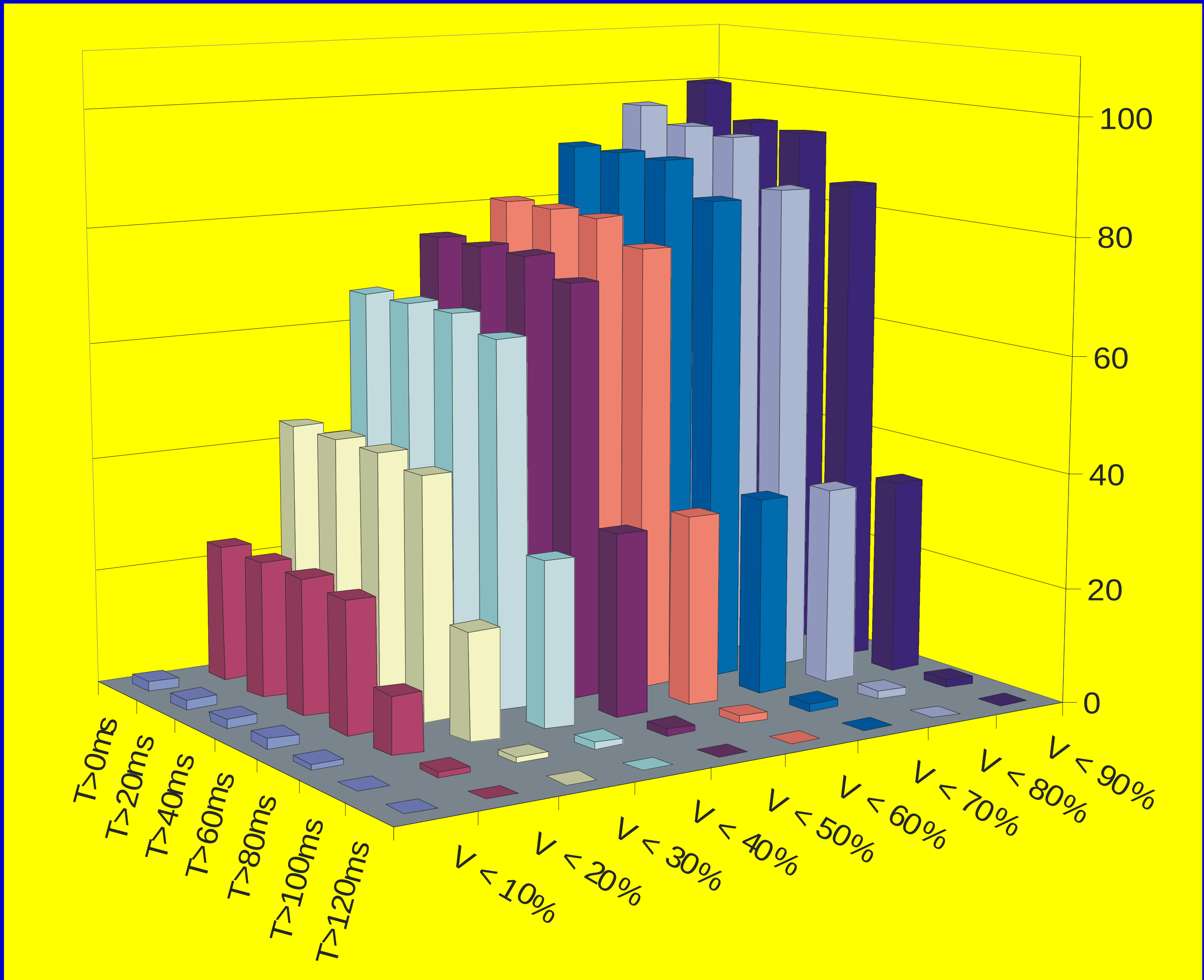
Fault type probability



Fault duration probability density



Dip density function at Node 4 - phase 'a' - after 1000 runs

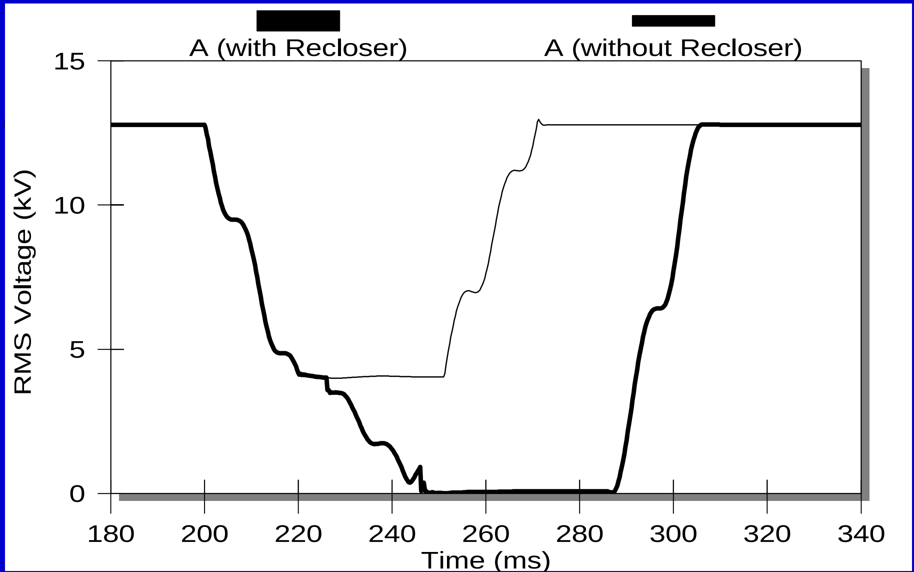


Dip density function at Node 4
- phase ‘a’ - after 5000 runs

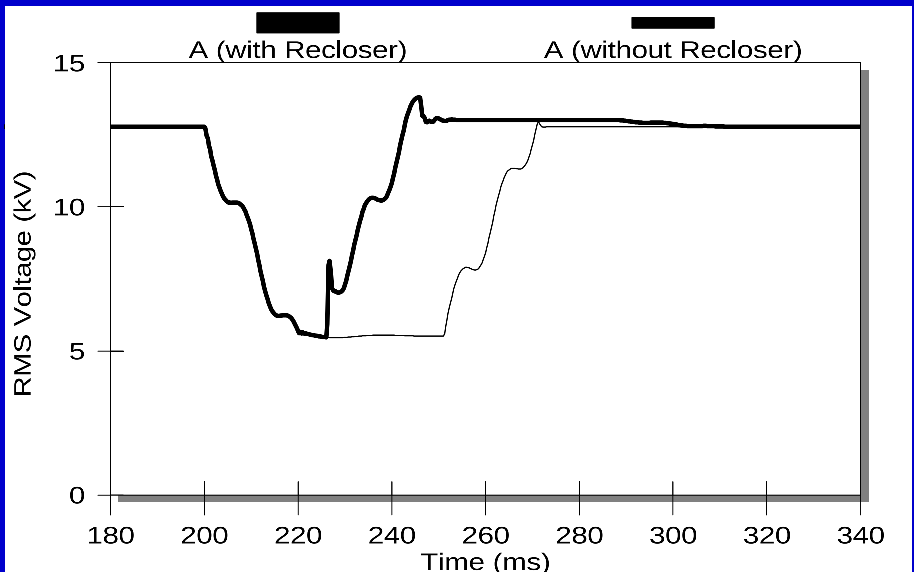
Protective devices

- Significant influence of protection devices
- Only reclosers have been simulated
  - Very simple model based on a delay and a reclo-sing interval
  - Only one reclosing operation
- Dip density function considering different reclosing intervals : 100 and 120 ms
- Number of dips per year and phase, with and without reclosers

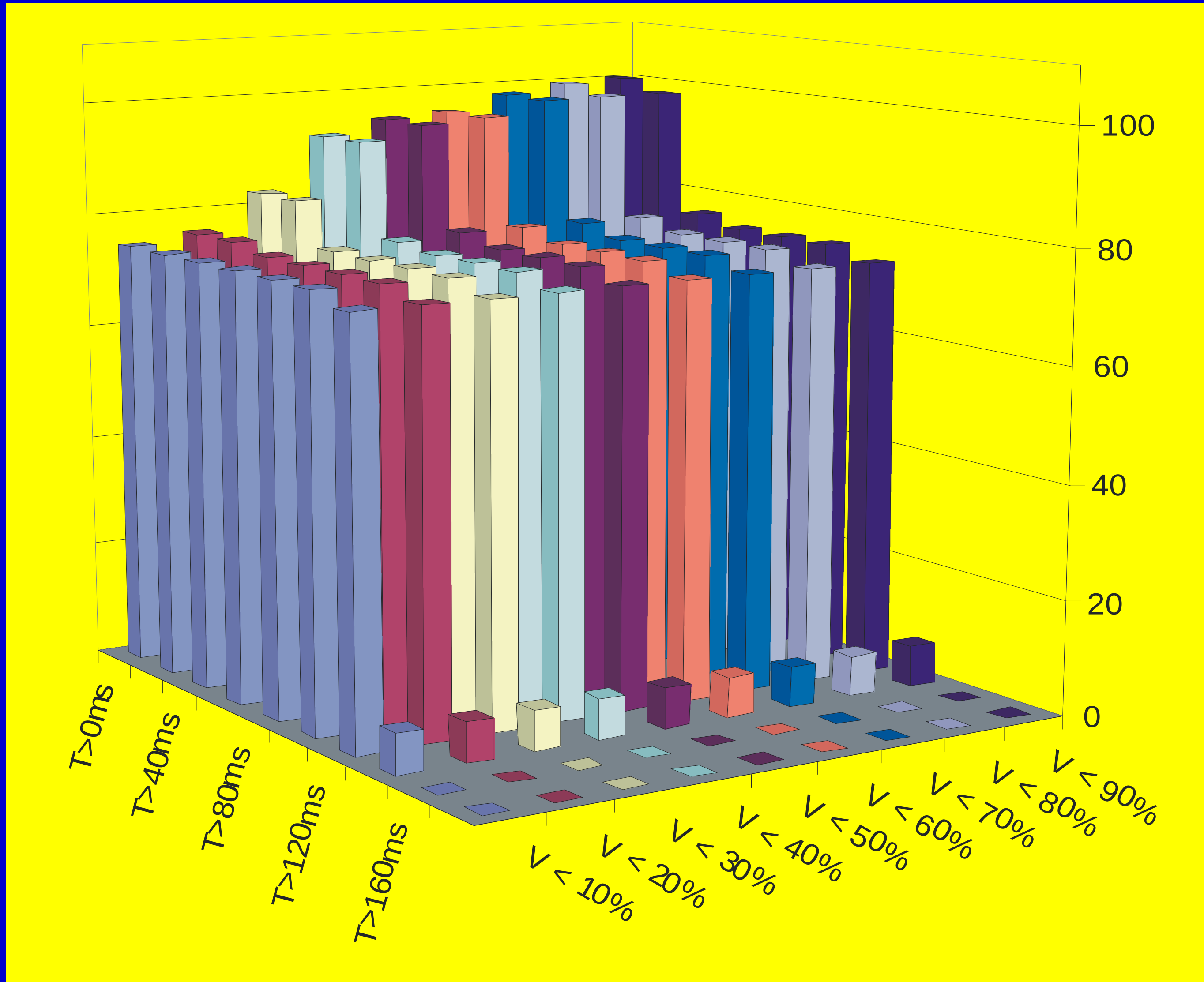
Protective devices



Voltage at a node located in the faulted feeder

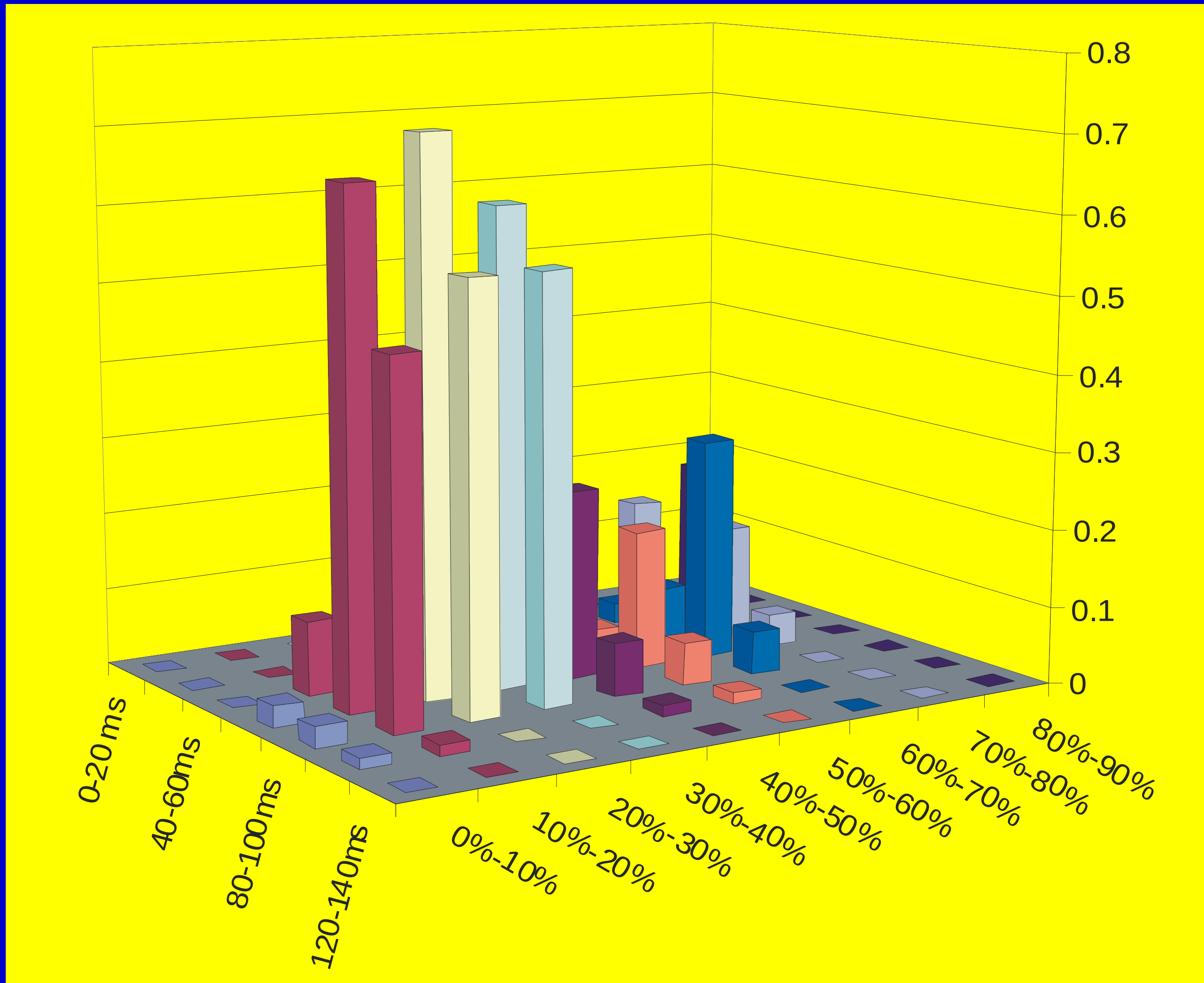


Voltage at a node located in the unfaulted feeder



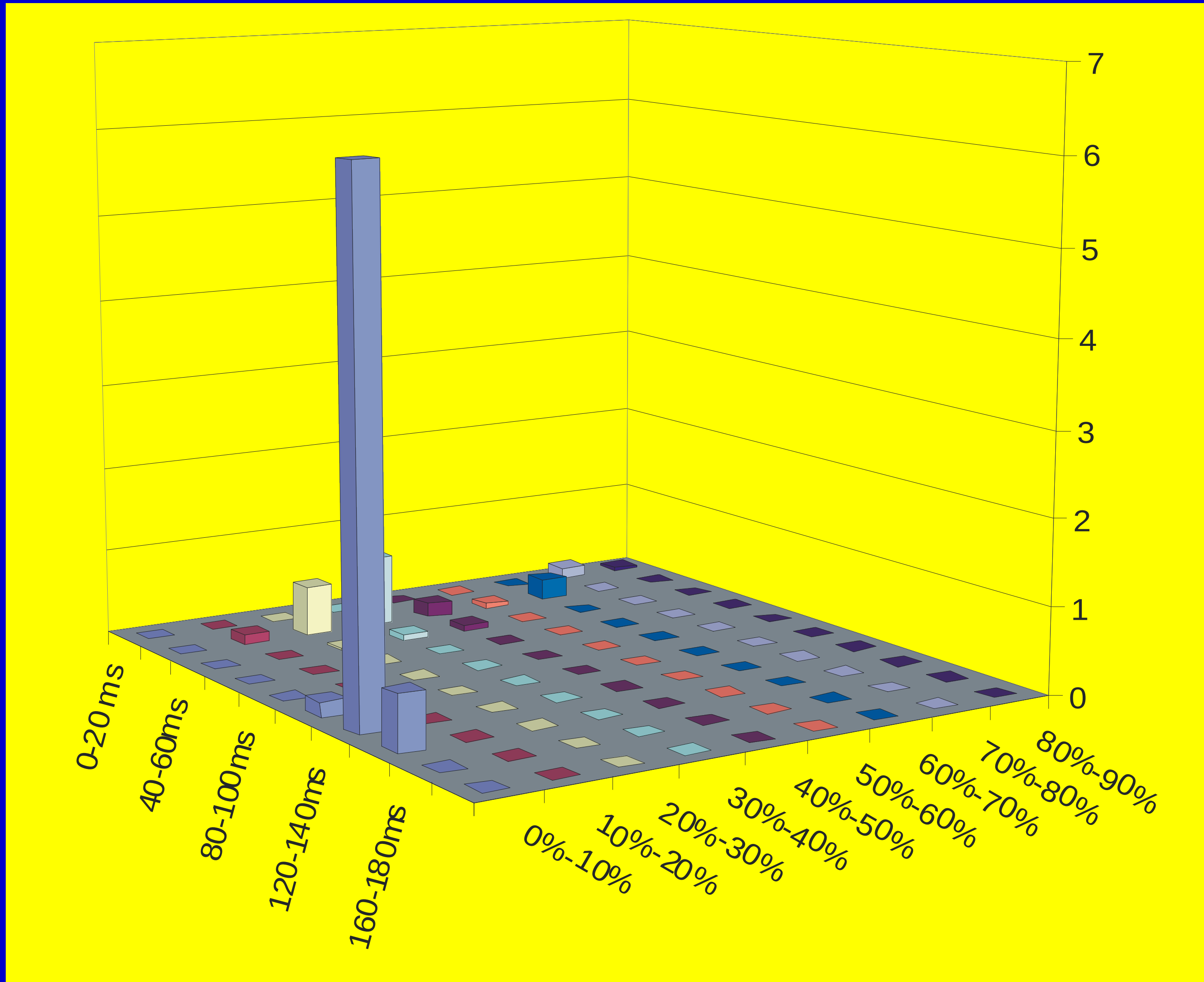
Dip density function at Node 4 - phase ‘a’

Reclosing interval : 100 ms



Number of dips per year at Node 4 - phase ‘a’

Without recloser



Number of dips per year at Node 4 - phase ‘a’

With recloser - Reclosing interval : 100 ms

Conclusions

- EMTP-like tools are sophisticated packages that are regularly updated and expanded
- They tools provide capabilities for obtaining transient and harmonic solutions, and representing nonlinear and frequency-dependent components
- They are very efficient to predict disturbance effects and to evaluate new mitigation techniques, but their capabilities are very limited to represent semiconductors
- There is a growing trend towards open systems, with the design of more efficient interfaces and the improvement of post-processing capabilities