CEGELEC

Systems Engineering on
Large Railway Projects

D.C. Power System Studies for Jubilee Line

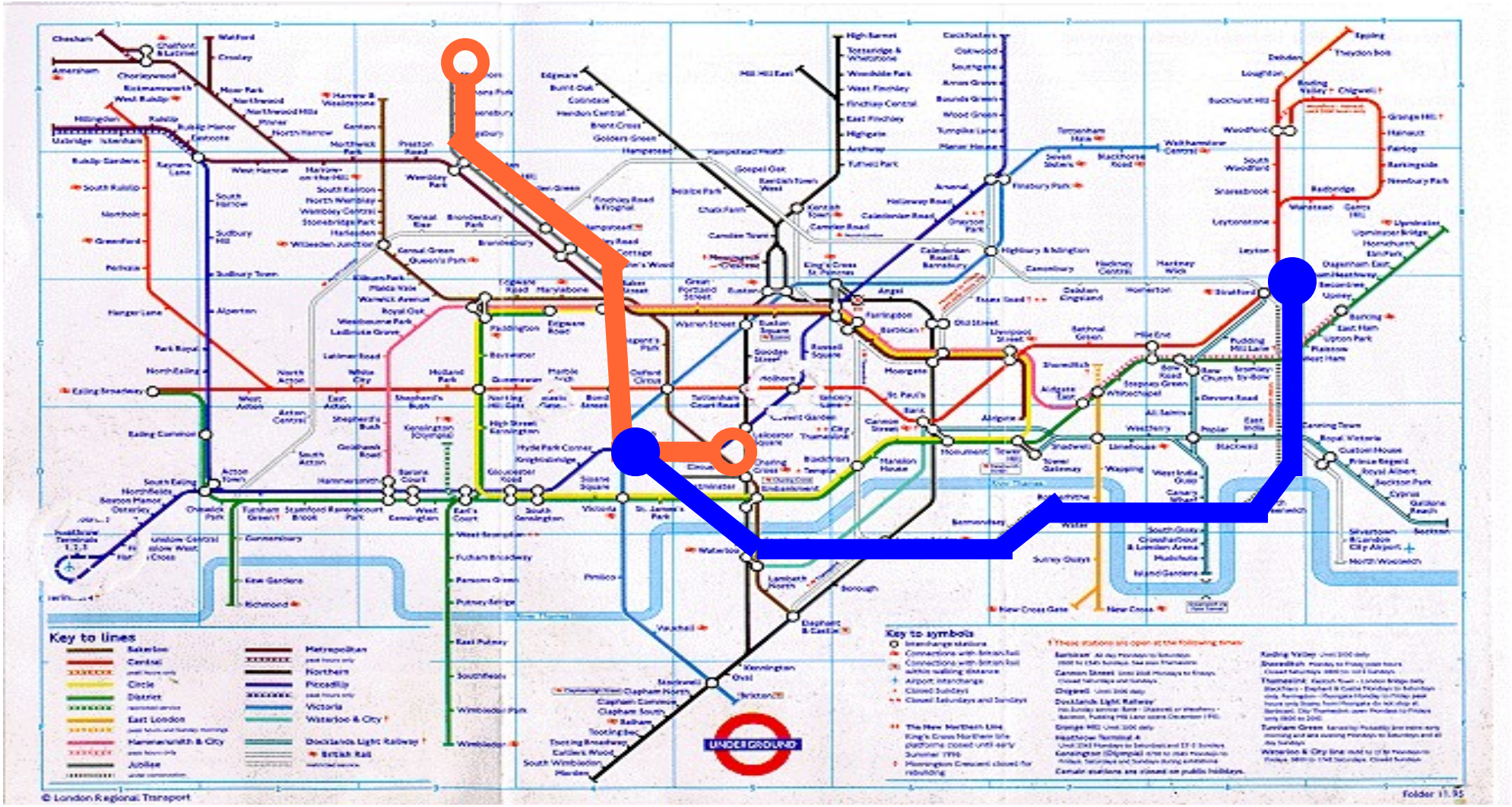
IEE Colloquium, 7 May 1997, London

Jianguo Yu, *BSc PhD CEng MIEE*

Cegelec Projects Ltd, Rugby, U.K.

CEGELEC

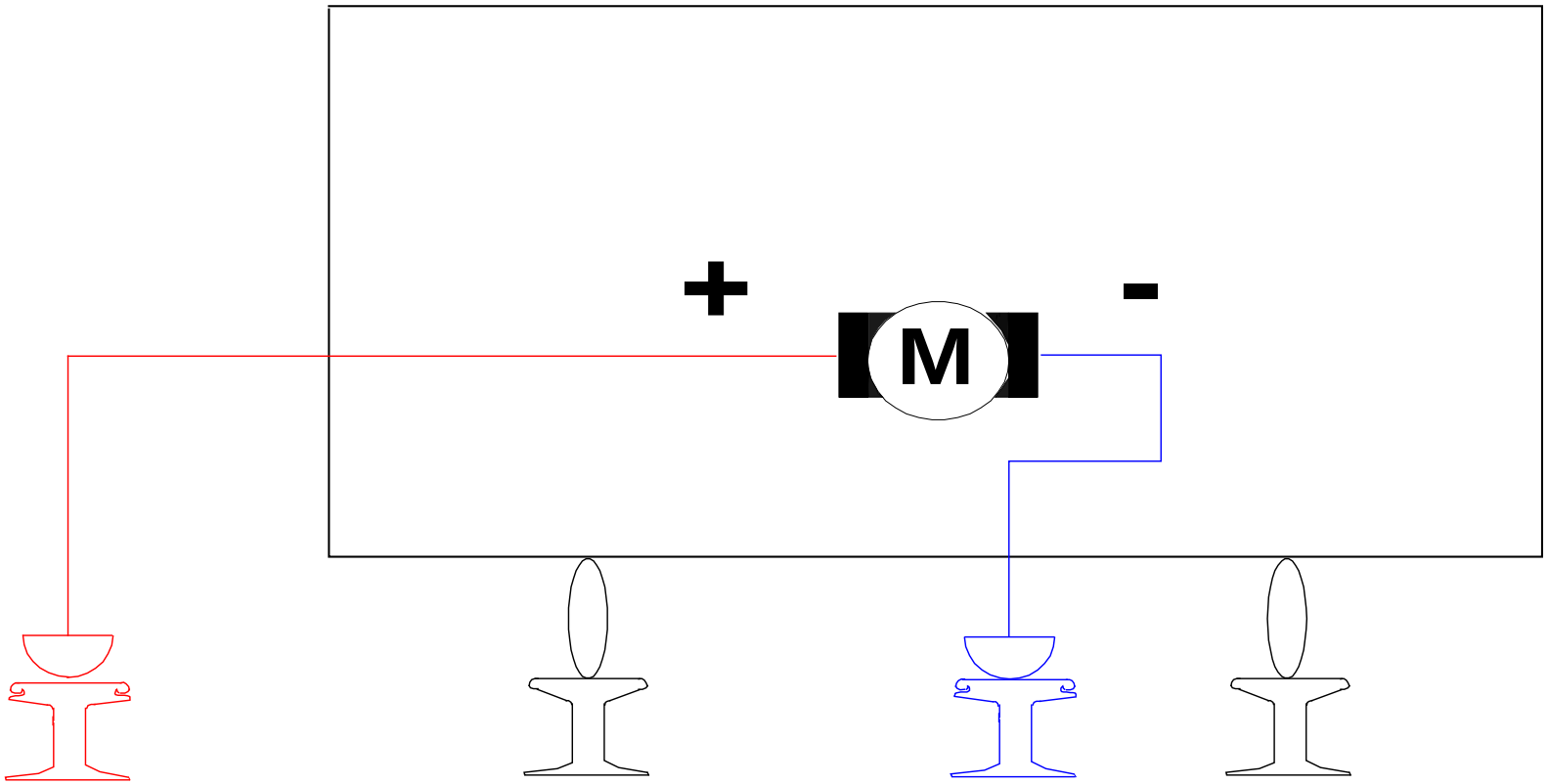
LUL Travel Map
Jubilee Line & Extension



CEGELEC

JLE Contract 203 Scope of Works
Power, Cabling & Conductor Rails

- Primary A.C. Distribution (11 & 22 kV)
- A.C./D.C. Conversion
  - Rectifiers & Transformers
- D.C. Distribution (630 V)
- Secondary A.C. Distribution (415 V)
  - Batteries & Chargers
- Interfaces With Other Contractors



THIRD AND FOURTH RAIL POWER SUPPLY SYSTEM

CEGELEC

JLE Contract 203
Project Activities

- Design
  - Systems & Equipments
- Procurement & Manufacture
- Shipment & Installation
- Testing & Commission

CEGELEC

Jubilee Line Extension
Systems Design Activities

- Tendering Design
  - Various options on equipment combinations: substations, track paralleling huts and conductor rails, choice of traction motors, a.c. or d.c.
- Conceptual Design
- Preliminary Design
- Final Design
- Variations

- Simulation Studies - Optimisation
  - Equipment Ratings
  - System Performance
- D.C. System Protection
  - Enhanced track feeder protection for the upgrade
  - New protection equipment for the extension

CEGELEC

JLE C203
Specifications

- Ultimate Train Services: 36 Trains per Hour
- Average Motoring Voltage: > = 575 V
- Minimum Train Voltage: 450 V
- Rectifier: BS4417 Class F
- A.C. Harmonics: Engineering Recommendation G5/3

CEGELEC

Jubilee Line at Present
Stanmore - Charing Cross

- 17 Passenger Stations
- 22 km Route Length
- 9 Traction Substations
- Peak Hour Service: 20 Trains per Hour

CEGELEC

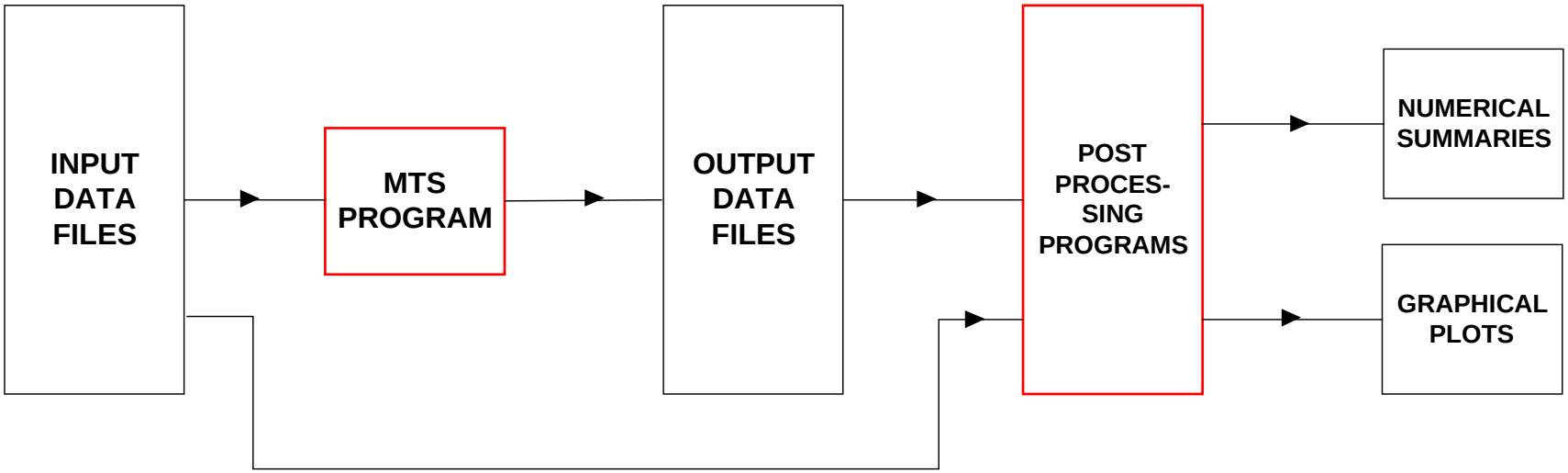
Jubilee Line Upgrading

- 3 New Traction Substations
  - Queensbury, Wembley Park, Kilburn, 2x1.5 MW each
- 2 New Track Paralleling Huts
  - St John's Wood, Green Park
- 1.5 km Route Composite Rail
  - Finchley Road to St John's Wood, north bound and south bound
- Reconfigration of Stanmore Substation
- Jubilee/Metropolitan Line Segregation
  - Preston Road, Willesden Green, Neasden, Finchley Road
- Enhanced Track Feeder Protection

CEGELEC

Jubilee Line Extension
Green Park - Stratford

- 16 km route length new line
- 11 passenger stations
- 5 new traction substations
- 1 track paralleling hut
- 1 new depot at Stratford Market
- Aluminium composite rails throughout
- Maximum train service capacity: 36 trains per hour



STRUCTURE OF MULTI TRAIN SIMULATOR

CEGELEC

Cegelec MTS
Data Input

- Track Profiles
  - Gradients, Curvatures, Speed Limits
- Locations
  - Substations, Track Paralleling Huts, Passenger Stations
- Train Characteristics
  - Train Weight, Traction & Auxiliary Loads, Drag Coefficients
- Electrical Resistances
  - Source, Cable & Conductor Resistances
- Train Services
  - Headways, Coasting Allowances

CEGELEC

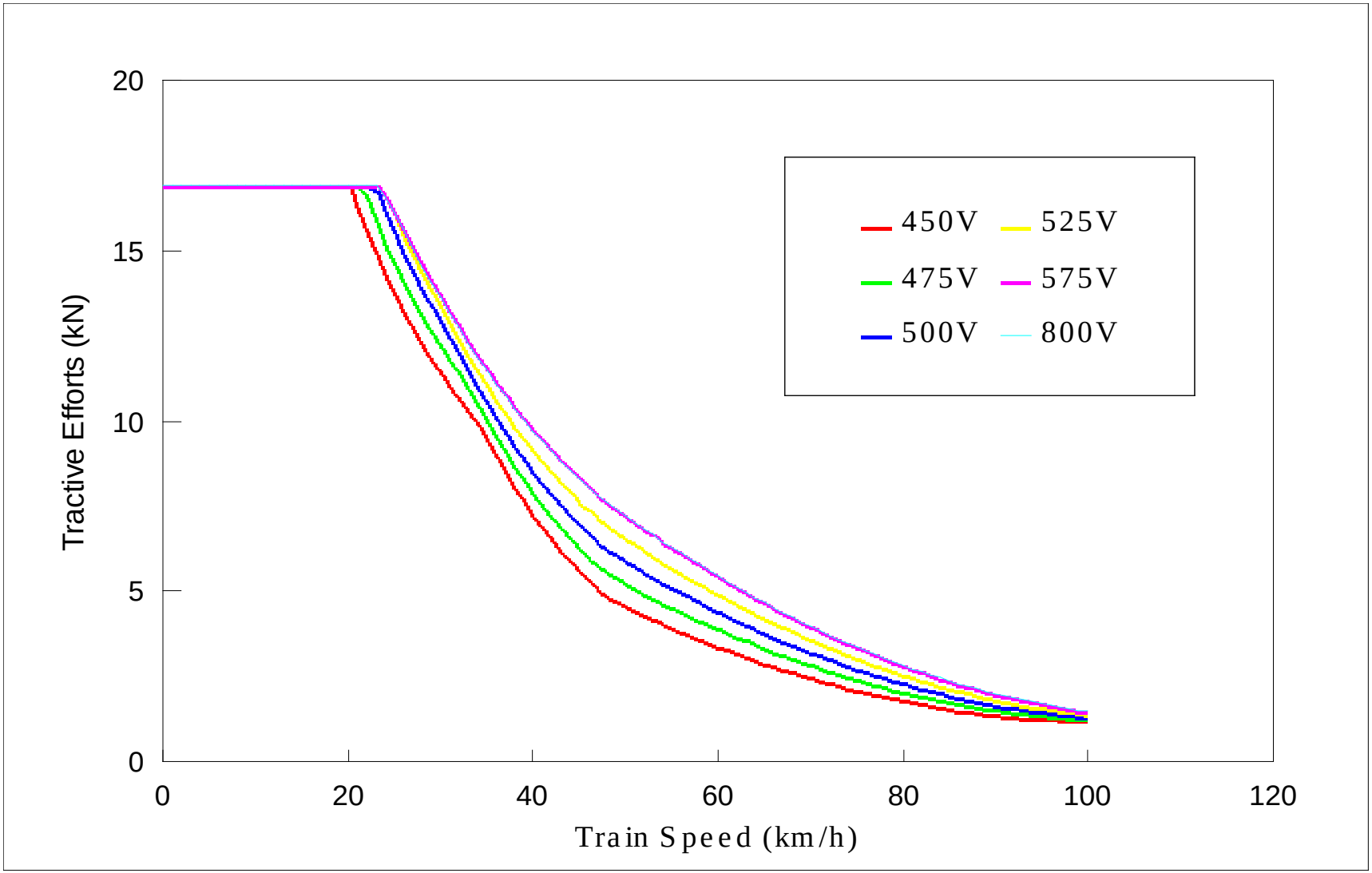
Jubilee Line Extension
Existing & New Trains

- Existing trains
  - camshaft controlled d.c. motor drives
  - No regeneration braking is available
  - train consist: 6 cars
- New trains
  - inverter controlled induction motor drives
  - with regenerative braking
  - initial train consist: 6 cars, crush load weight 228 tonnes, 27 trains per hour
  - ultimate train consist: 7 cars, crush load weight 260 tonnes, 36 trains per hour

- Motoring
  - Tractive Efforts
  - Input Line Currents
- Regenerative Braking
  - Braking Efforts
  - Output Line Currents

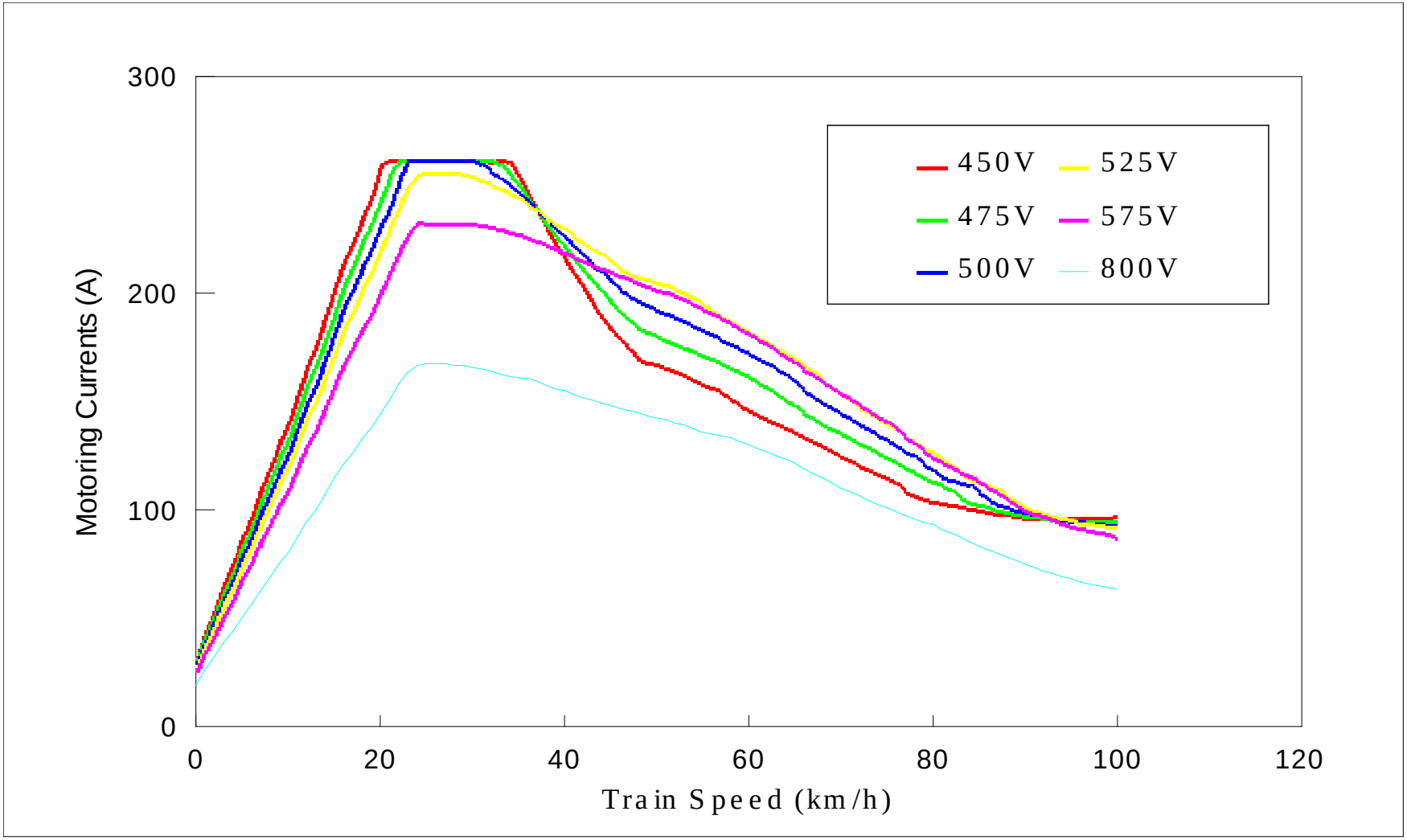
CEGELEC

Voltage Sensitive Motor Characteristics
Motoring - Tractive Efforts



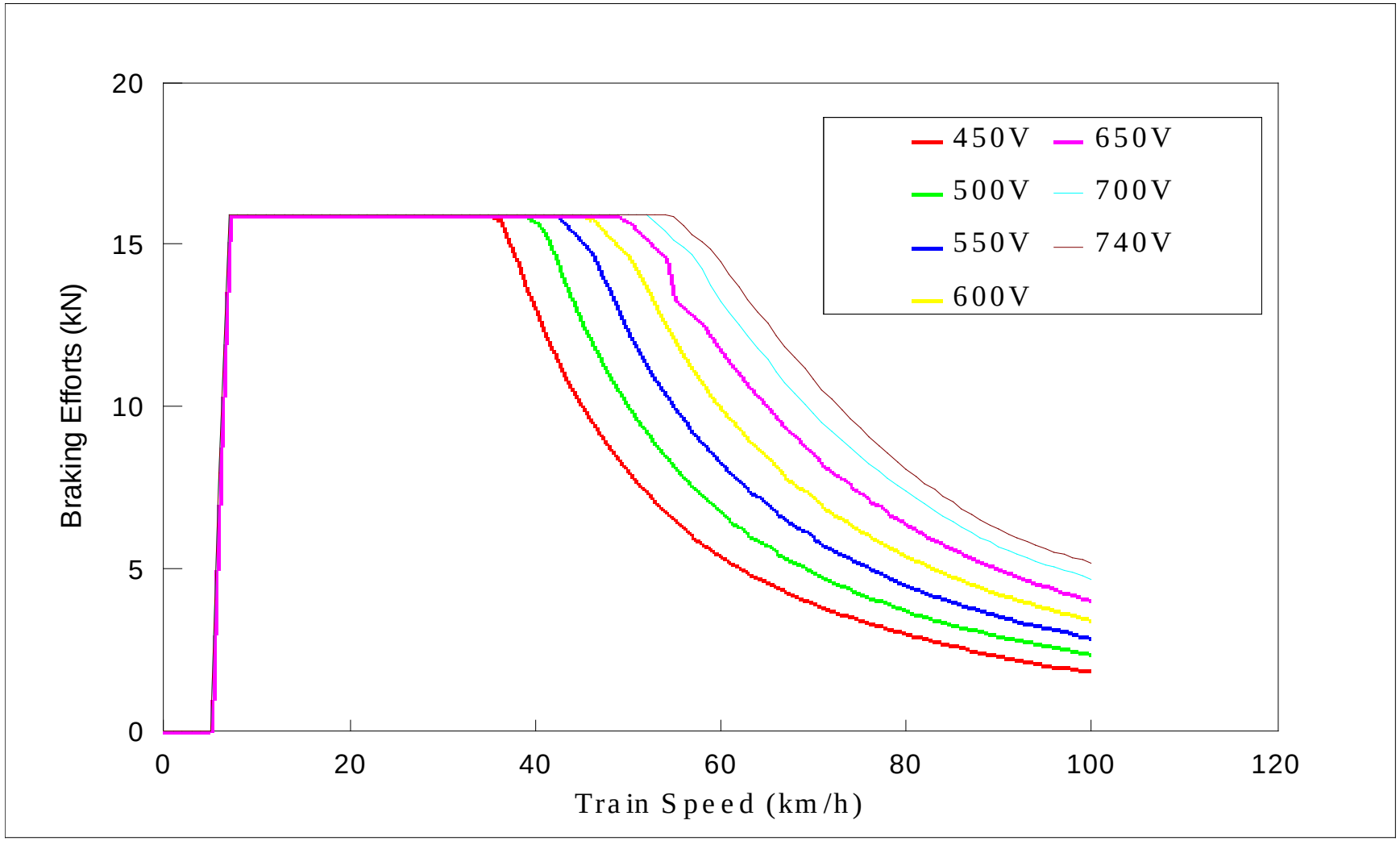
CEGELEC

Voltage Sensitive Motor Characteristics
Motoring - D.C. Line Currents



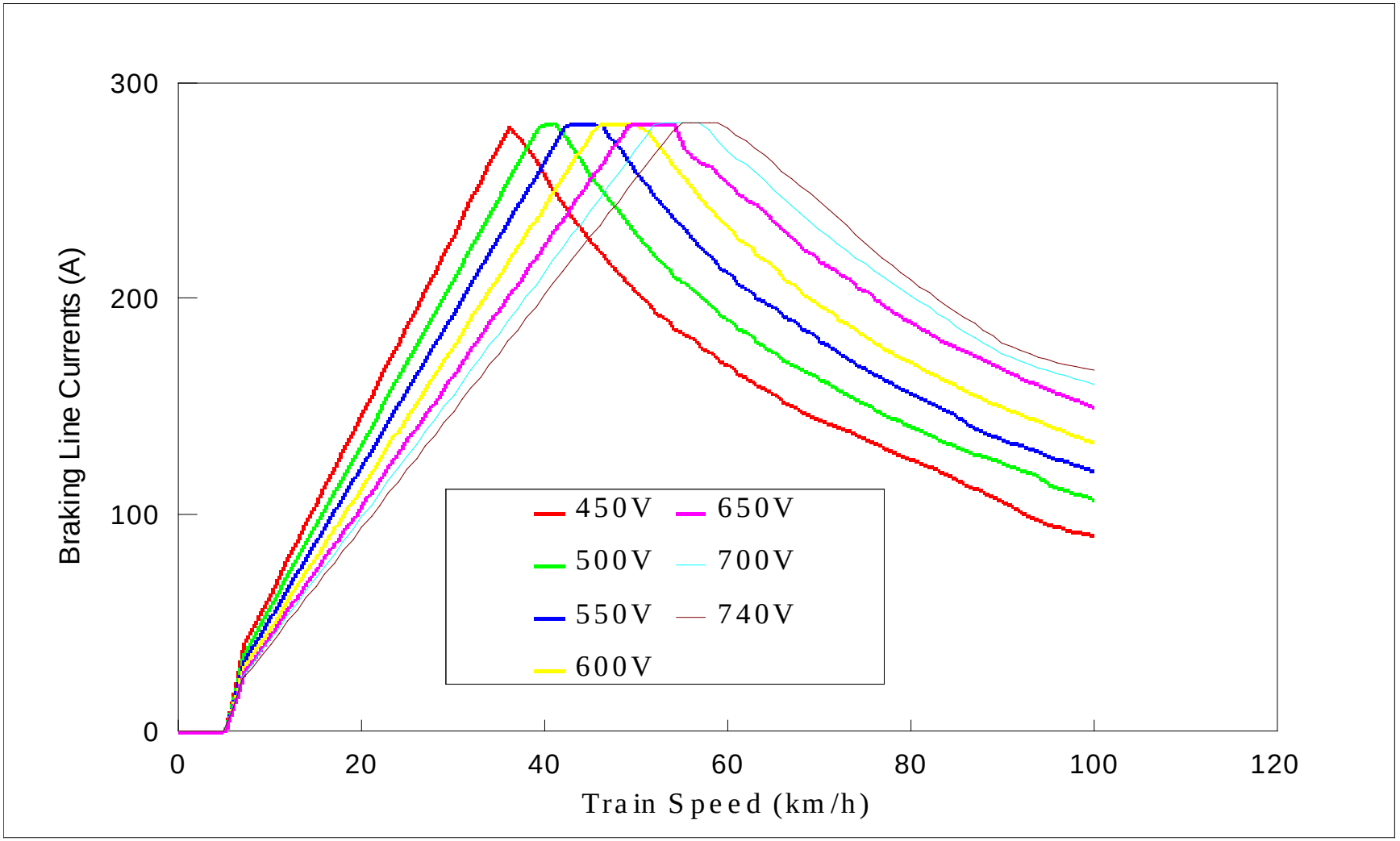
CEGELEC

Voltage Sensitive Motor Characteristics
Braking - Braking Efforts



CEGELEC

Voltage Sensitive Motor Characteristics
Braking - D.C. Line Currents



CEGELEC

Cegelec MTS
Graphical Plots

- Typical train performance
  - Uproad & downroad
- Train time-distance curves (trajectories)
- Substation load cycles
  - Rectifiers & individual feeders
- Conductor rail currents
  - Uproad & downroad
- Harmonic currents and voltage distortions
  - At points of common coupling

Graphical Plots (transparencies)

- Overall summary of train voltages
- Rectifier loadings
- Track feeder loadings
- Inter-station run results
  - run times, train speeds, voltages, etc
- Conductor rail currents
- Harmonic currents and voltage distortions

CEGELEC

MTS Numerical Summaries
Train Voltages

	Uproad	Downroad
Mean no. of units on road	34.9	35.6
Average motoring voltage (V)	626.	624.
Average braking voltage (V)	674.	673.
Min. train voltage (V)	513.	517.
Max. train voltage (V)	754.	753.
Max. train current (A)	4093.	4107.

Occurences of motoring tapers (both roads): 0

Occurences of braking tapers (both roads): 259

CEGELEC

MTS Numerical Summaries
Rectifier Loadings

TSS Name	Avg MW	Avg Volts	Min Volts	Avg kA	RMS kA	Peak kA
STA	.28	665	630	.43	.75	2.36
CAP	.66	666	650	1.00	1.39	3.35
CDW	1.83	652	631	2.84	3.32	6.95
NOG	2.17	650	629	3.37	3.93	7.17
CAT tph	.00	637	599	.00	.00	.00
SMD	1.64	656	637	2.53	2.89	5.73

Total mean loading: 20.09 MW

Total mean losses: 1.45 MW or 7.2 % of system loading

CEGELEC

MTS Numerical Summaries
Track Feeder RMS Currents (kA)

TSS/TPH	F 1	F 2	F 3	F 4
STA	.00	.78	.00	.30
CAP	1.02	.77	1.09	.61
CDW	1.13	2.22	1.62	1.11
NOG	1.42	1.90	1.55	1.22
CAT tph	.87	1.57	1.42	1.10
SMD	1.33	1.04	1.35	1.57
Max.	1.49	2.22	1.70	2.11

CEGELEC

MTS Numerical Summaries
Track Feeder Peak Currents (kA)

TSS/TPH	F 1	F 2	F 3	F 4
STA	.00	2.75	.00	.96
CAP	3.20	2.65	3.46	1.70
CDW	2.97	5.05	3.57	4.12
NOG	4.39	3.70	3.15	3.74
CAT tph	1.96	4.35	3.24	4.44
SMD	2.83	4.33	2.68	3.53

CEGELEC

MTS Numerical Summaries
Inter Station Run Results

from stn	to stn	Section Length	Run Time	Avg Spd	Avg Volt	Av.Mot Volt	Min. Volt
STA	CAP	1262.	91.	50.	664.	621.	604.
CAP	QUE	1712.	108.	57.	675.	649.	636.
CRW	NOG	1711.	109.	56.	643.	618.	580.
NOG	CAT	1671.	113.	53.	644.	637.	608.
CAT	WEH	1601.	110.	52.	642.	623.	597.
WEH	STR	1541.	121.	46.	657.	637.	602.
Sums		37105.	2655.				
Averages				50.	654.	620.	
Minimum				32.	628.	575.	525.

CEGELEC

MTS Numerical Summaries
Harmonic Distortion at POCC

		Neasden BSP	Cromwell Curve
Power Delivered (MVA, mean)		4.41	7.51
Fundamental Current (A, RMS)		276	435
11th Harmonic Current (A, RMS)		19.72	27.47
13th Harmonic Current (A, RMS)		15.20	20.35
Total Voltage Distortion (%)	Peak	6.58	6.79
	Mean	2.34	3.46
Busbar Voltage (%)	Mean	99.63	99.21
	Min	98.15	97.35
Power Factor (p.u.)	Mean	0.989	0.982
	Min	0.976	0.960

CEGELEC

Cegelec MTS Validation

Substation Identity	Installed Capacity (kW)	Simulated Load (kW)	Metered Load (kW)	Error (%)
TSS 1	600	470	486	-3
TSS 2	600	460	450	2
TSS 3	600	440	394	12
TSS 4	600	350	356	-2
TSS 5	600	250	104	140
TSS 6	600	400	366	9
TSS 7	600	260	240	8

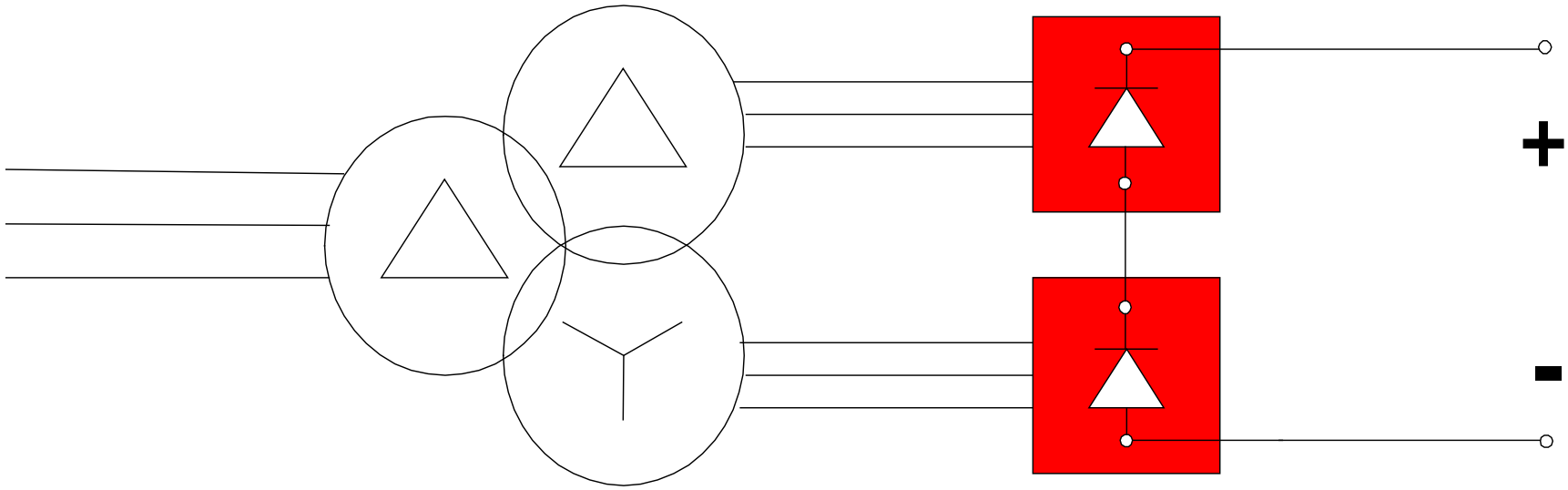
CEGELEC

D.C. Traction Systems
Power Conductor Rails

	No.75 Steel Rail	Composite Rail
Resistance (milli-Ohm/km)	14	7
Weight (kg/km)	75	14
Cross Sectional Area (sq.mm)	9489	5633

Power Conductor Rails (transparencies)

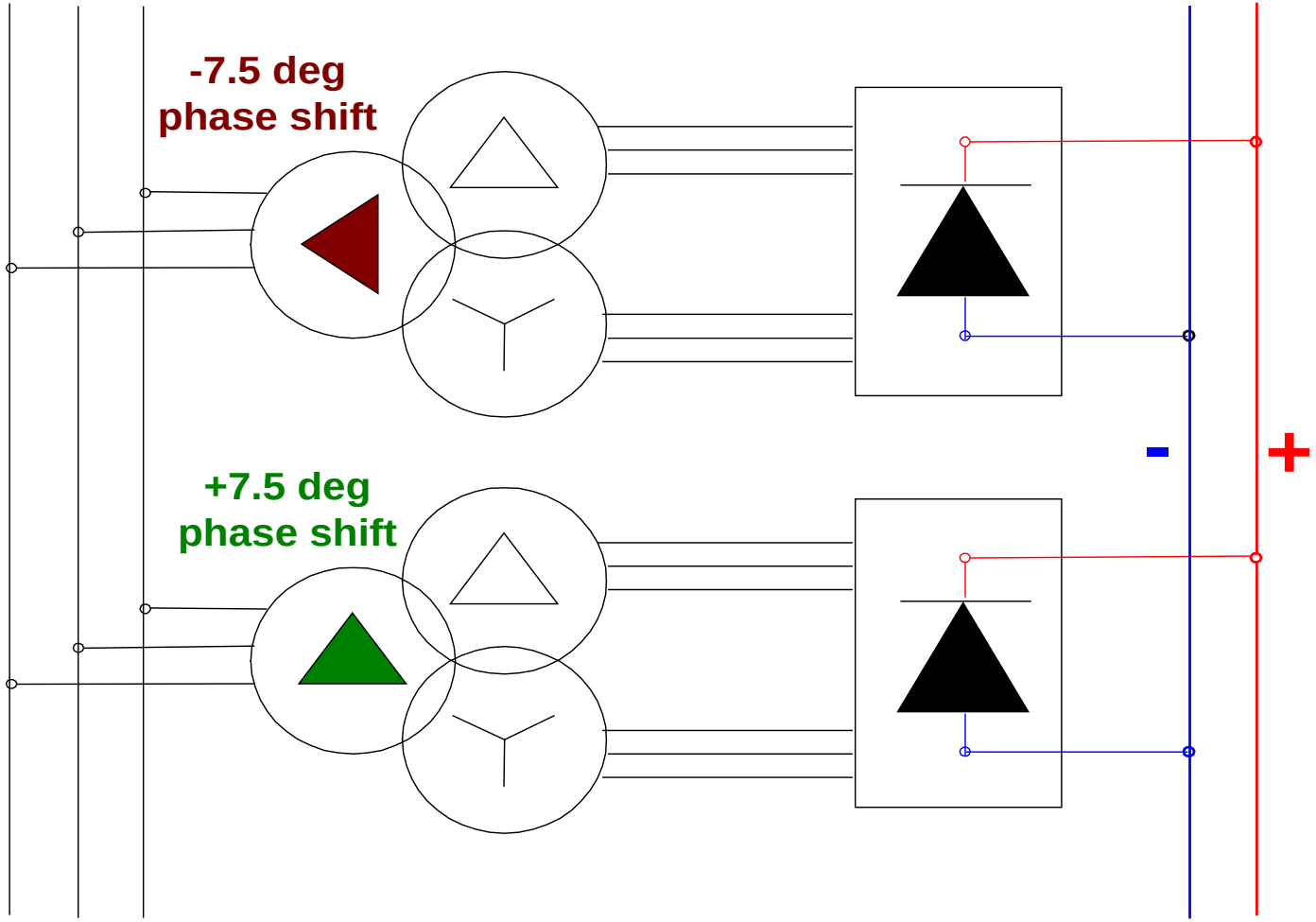
Rectifier Design Plot (transparencies)



12 PULSE RECTIFIER, SERIES BRIDGE

CEGELEC

D.C. Traction Systems
24 Pulse Operation of Rectifiers



- Normal Operations
- Outage Conditions
  - Single rectifier outages
  - A.C. bus outage
  - D.C. feeder outasges (single end feeding)
- Substation Outages due to Upgrade Works

CEGELEC

D.C. System Protection Coordination

- Objectives
  - To achieve maximum protection without spurious tripping
- Coordination Studies
  - Characteristics of traction drives
  - Fault analysis
- Verification of Settings
  - Drop short tests
  - Online tests

CEGELEC

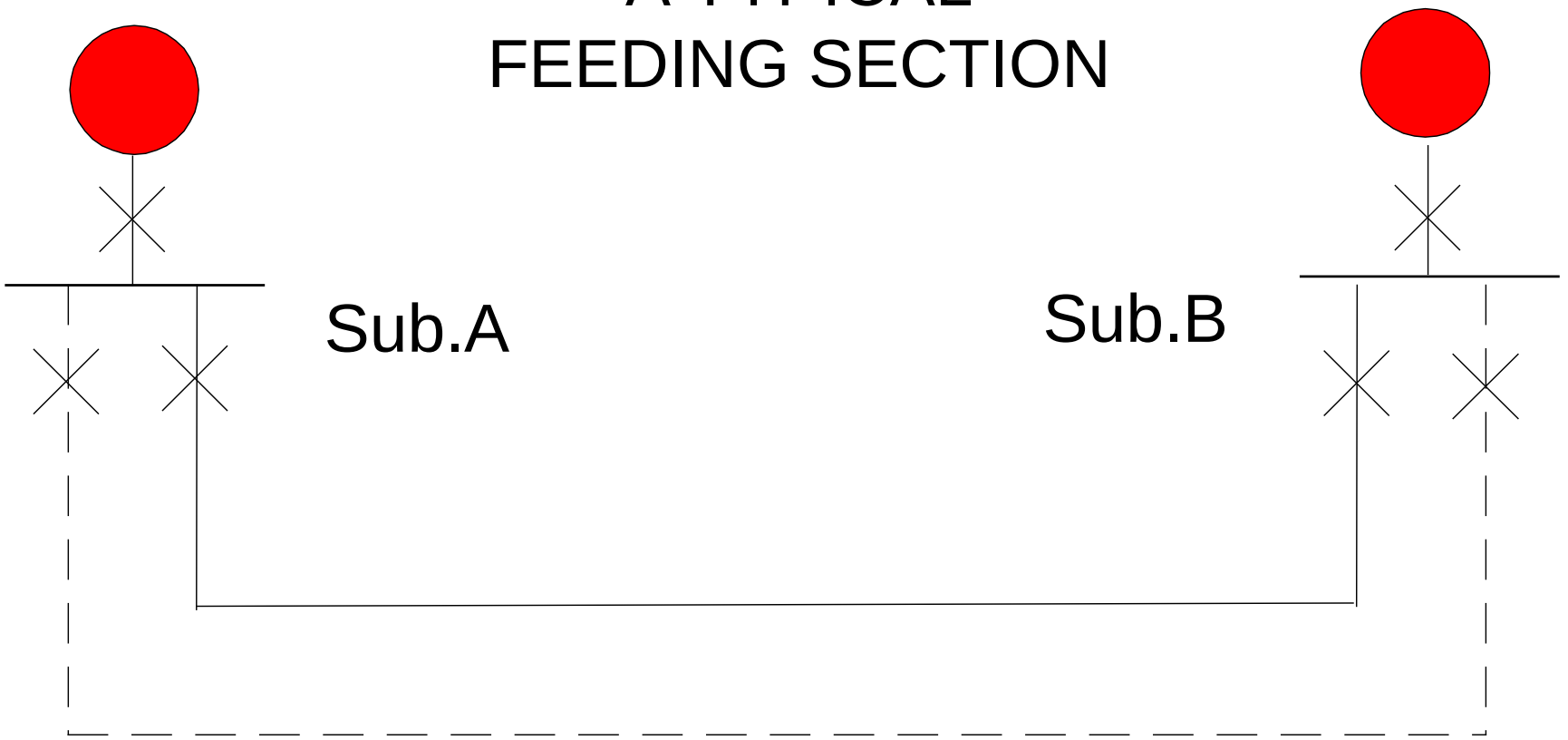
D.C. System Protection
Protective Devices

- Direct Acting Overload Protection
  - Integral part of high speed circuit breaker
- Whipp & Bourne MITRE Relay
  - Microprocessor controlled digital relay with memories for tripping history
- Under Voltage Relay
  - With multiplexed inter tripping system (MITS) and pilot cables

- Instantaneous Overcurrent
  - Unidirectional
- Rate of Rise with Delta I
  - Unidirectional
- Inverse Time Overcurrent
  - Unidirectional
- Thermal Modelling
  - Bidirectional

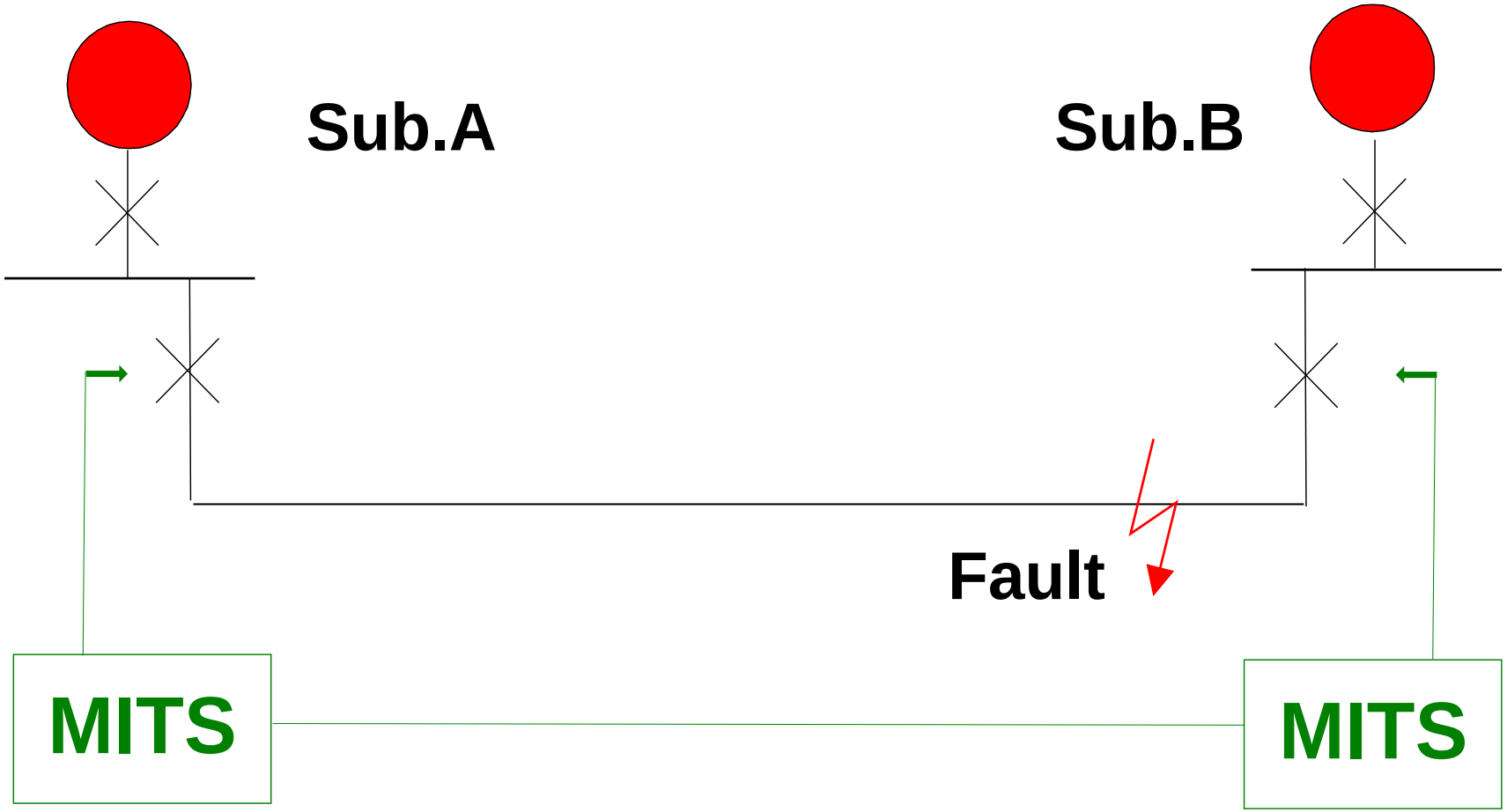
MITRE Relay Front View (transparencies)

A TYPICAL FEEDING SECTION

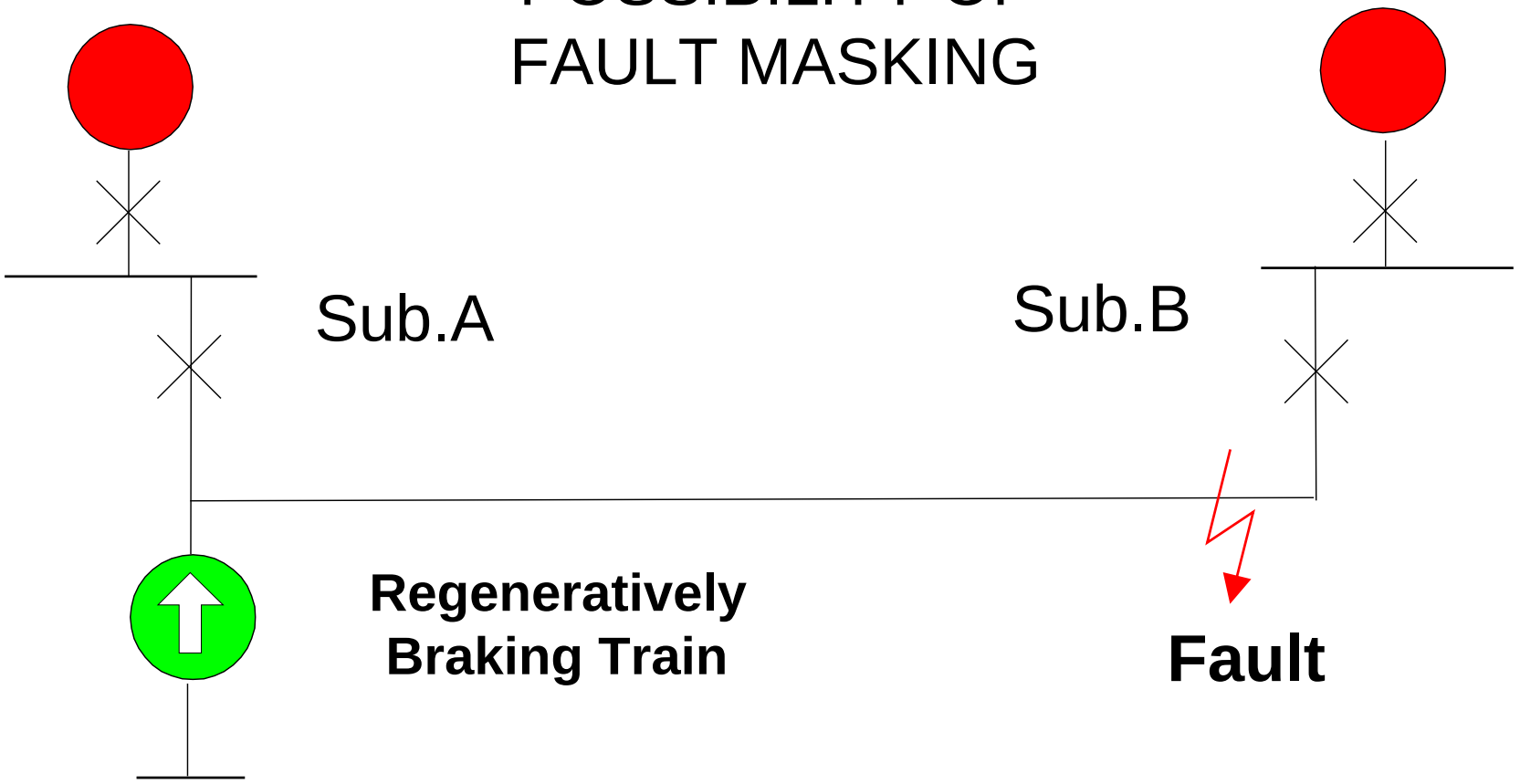


CEGELEC

D.C. System Protection
UV/MITS Scheme

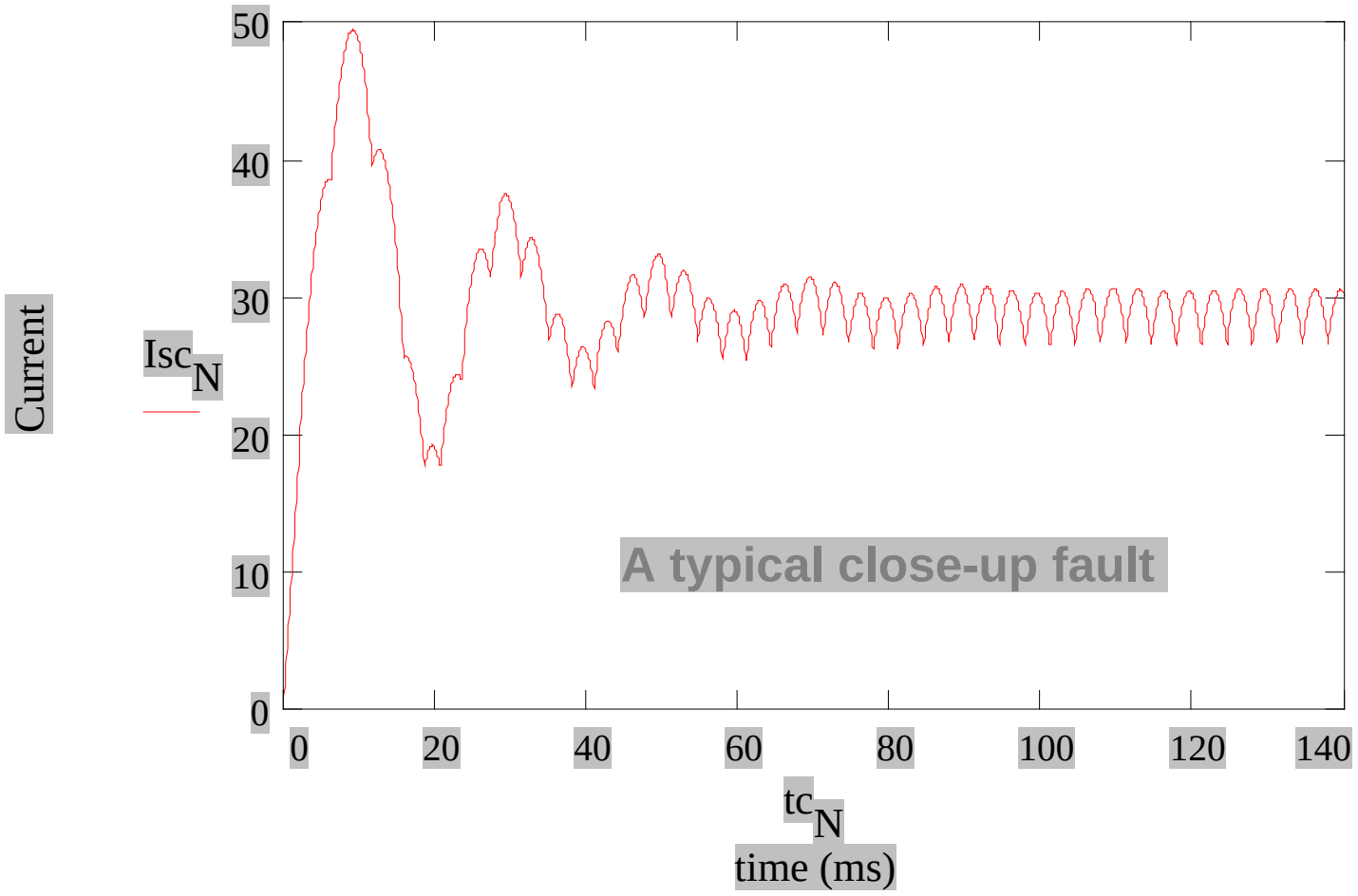


POSSIBILITY OF FAULT MASKING



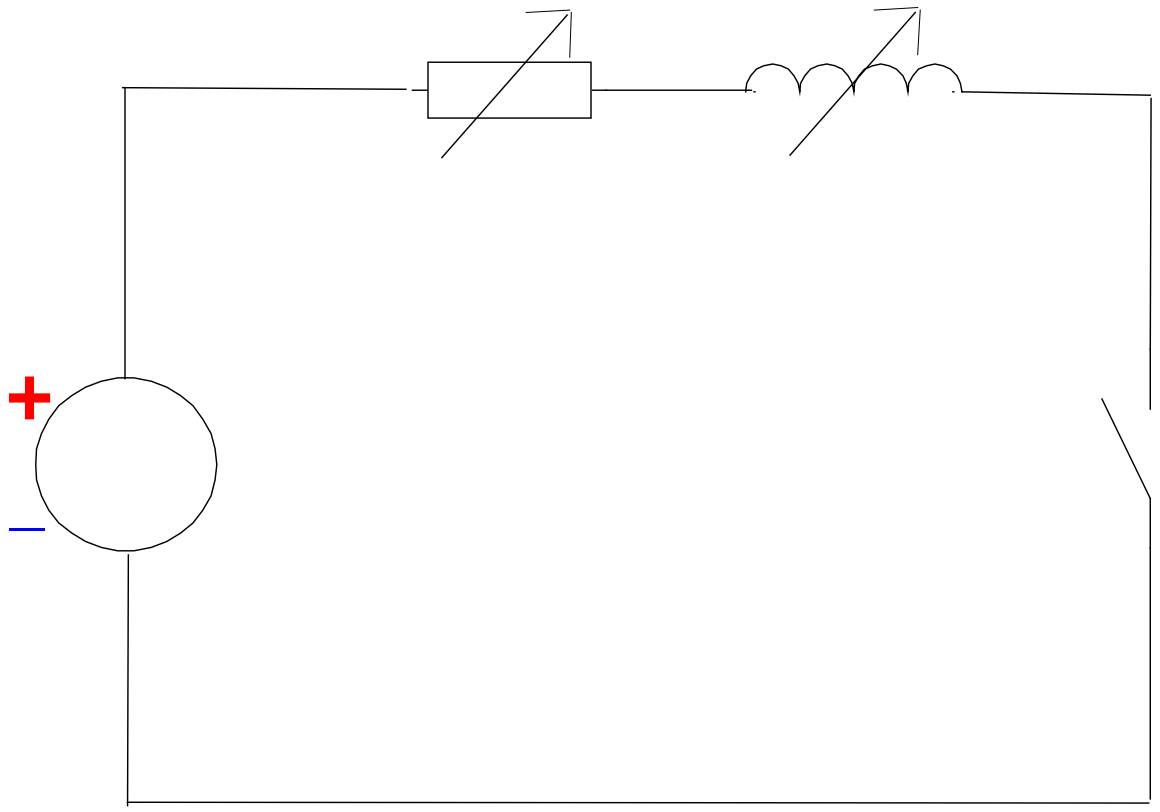
CEGELEC

D.C. System Protection
Fault Calculation



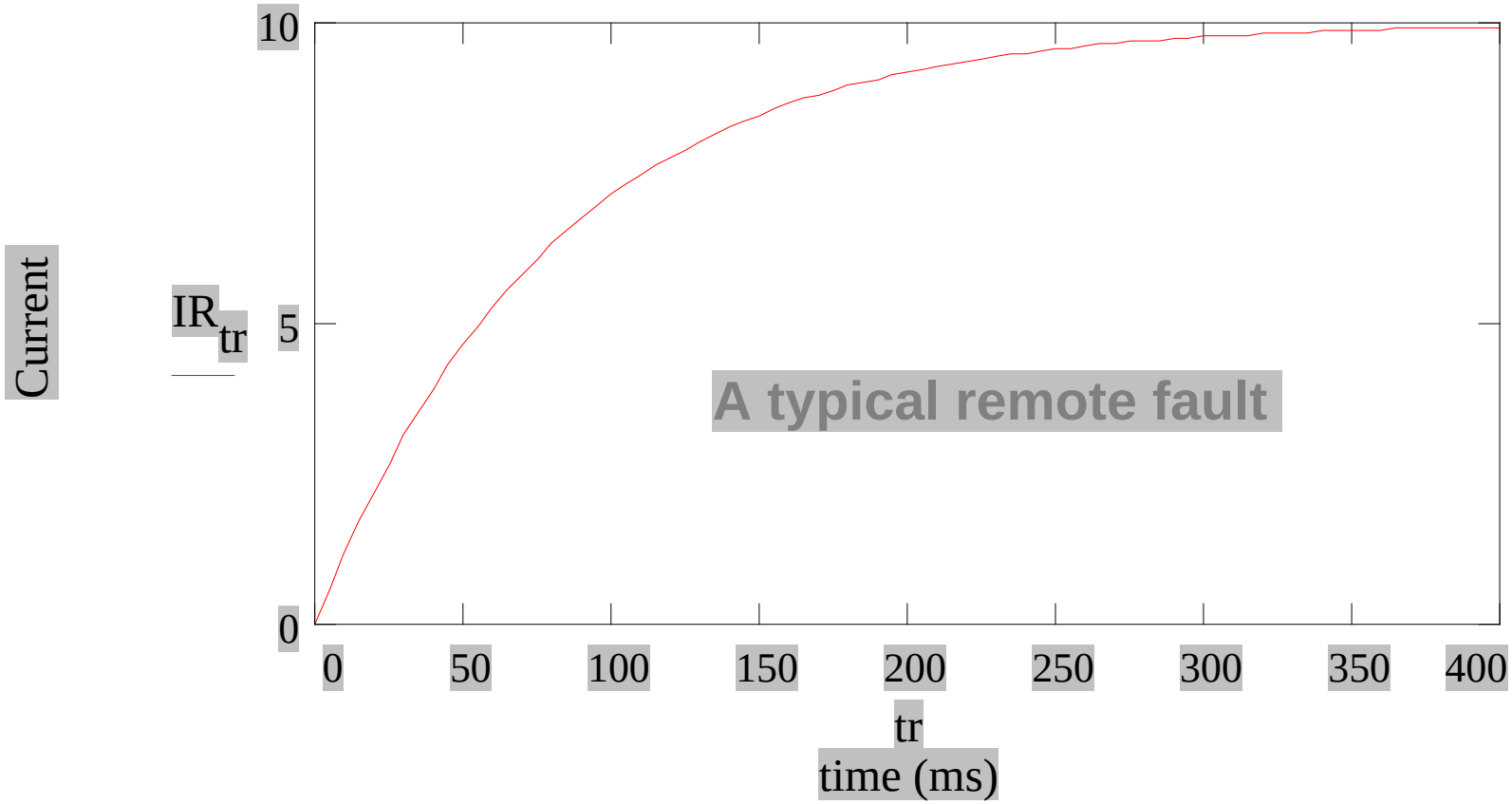
CEGELEC

D.C. System Protection
Track Fault Calculation



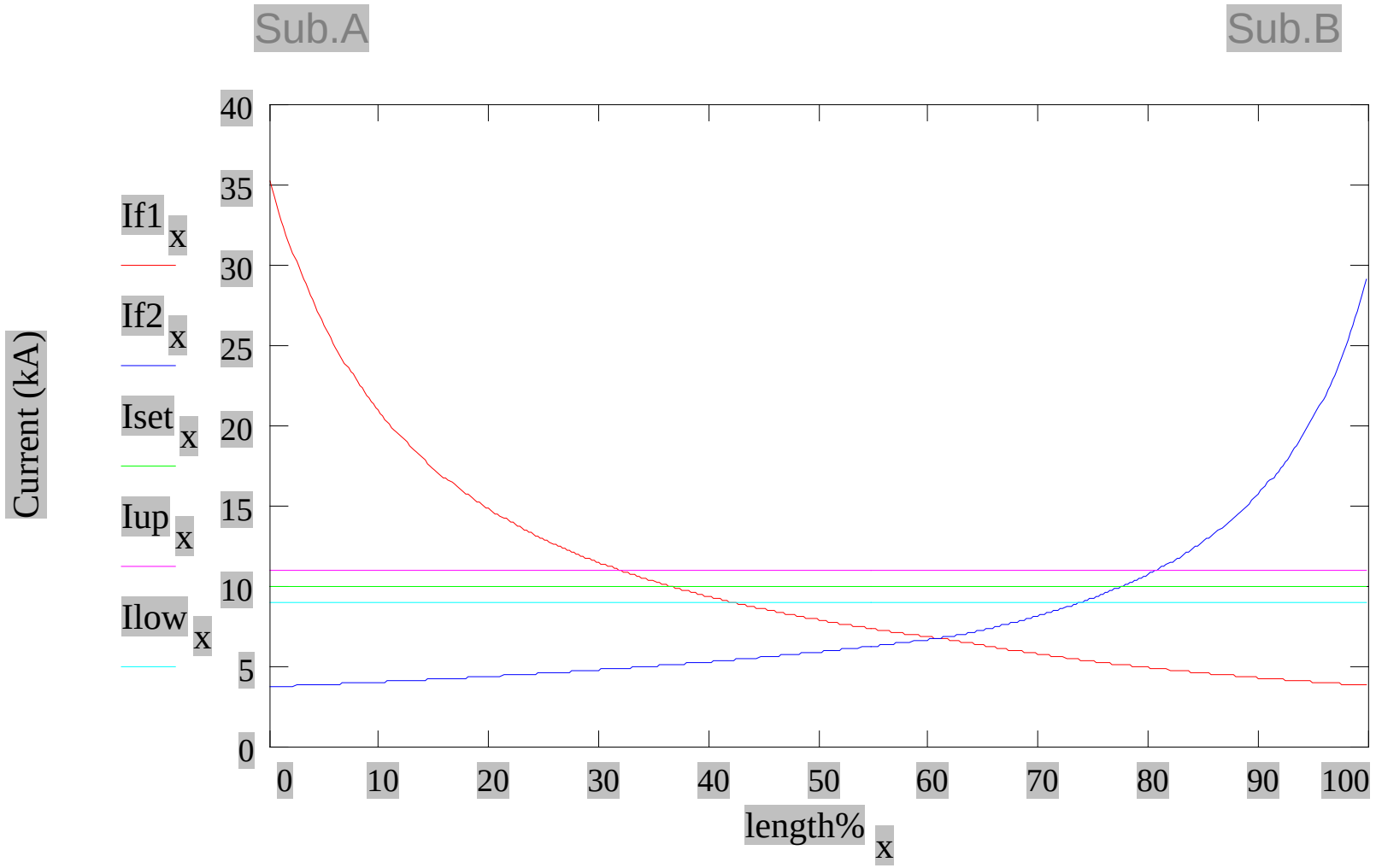
CEGELEC

D.C. System Protection
Fault Calculation



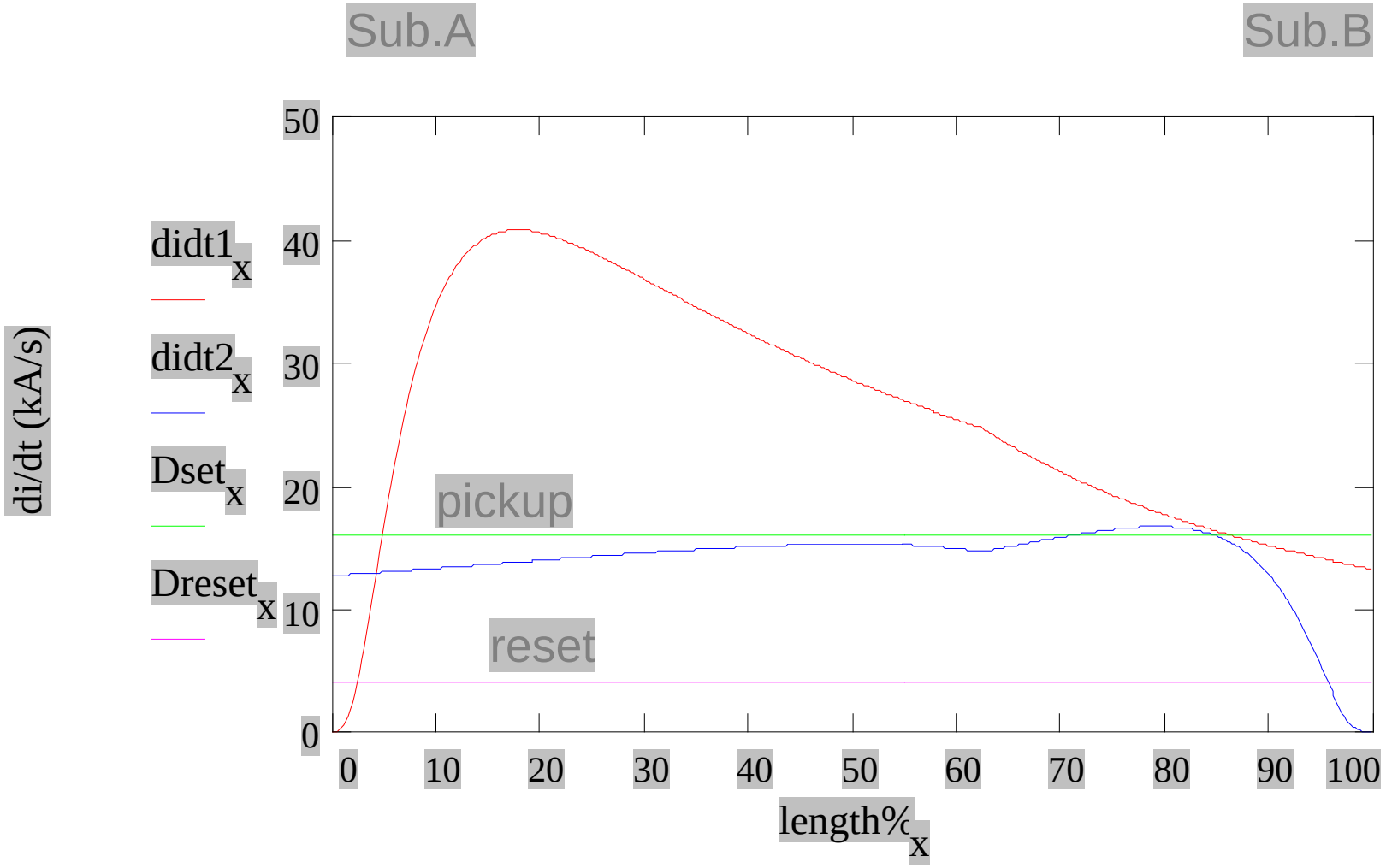
CEGELEC

D.C. System Protection
Fault current & DA setting band



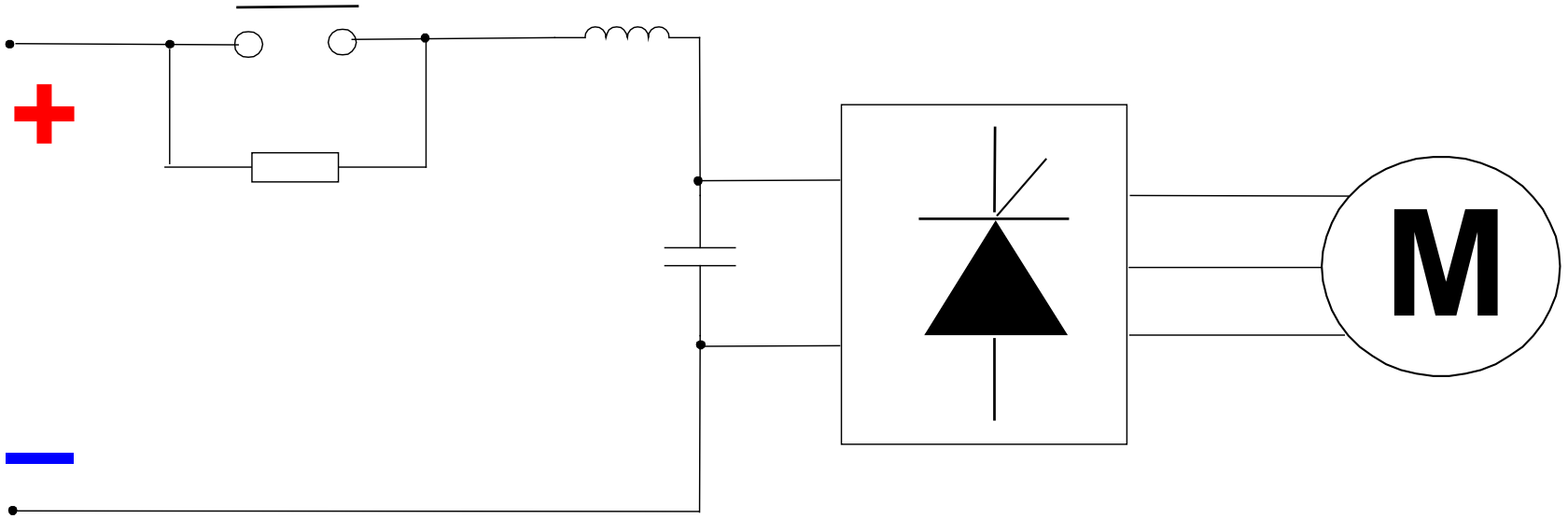
CEGELEC

D.C. System Protection
di/ dt of fault current at time setting



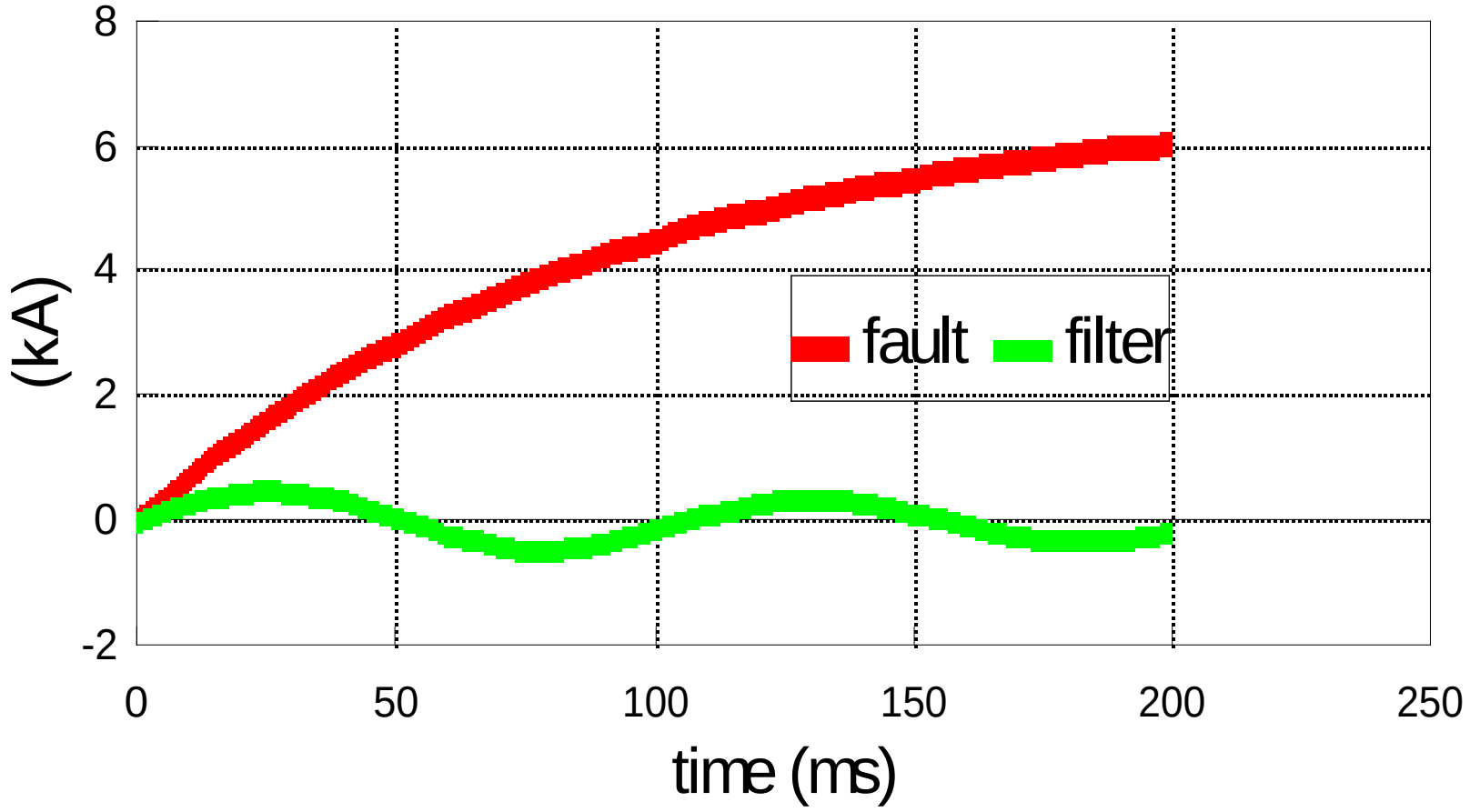
CEGELEC

D.C. System Protection
Train Filter Charging



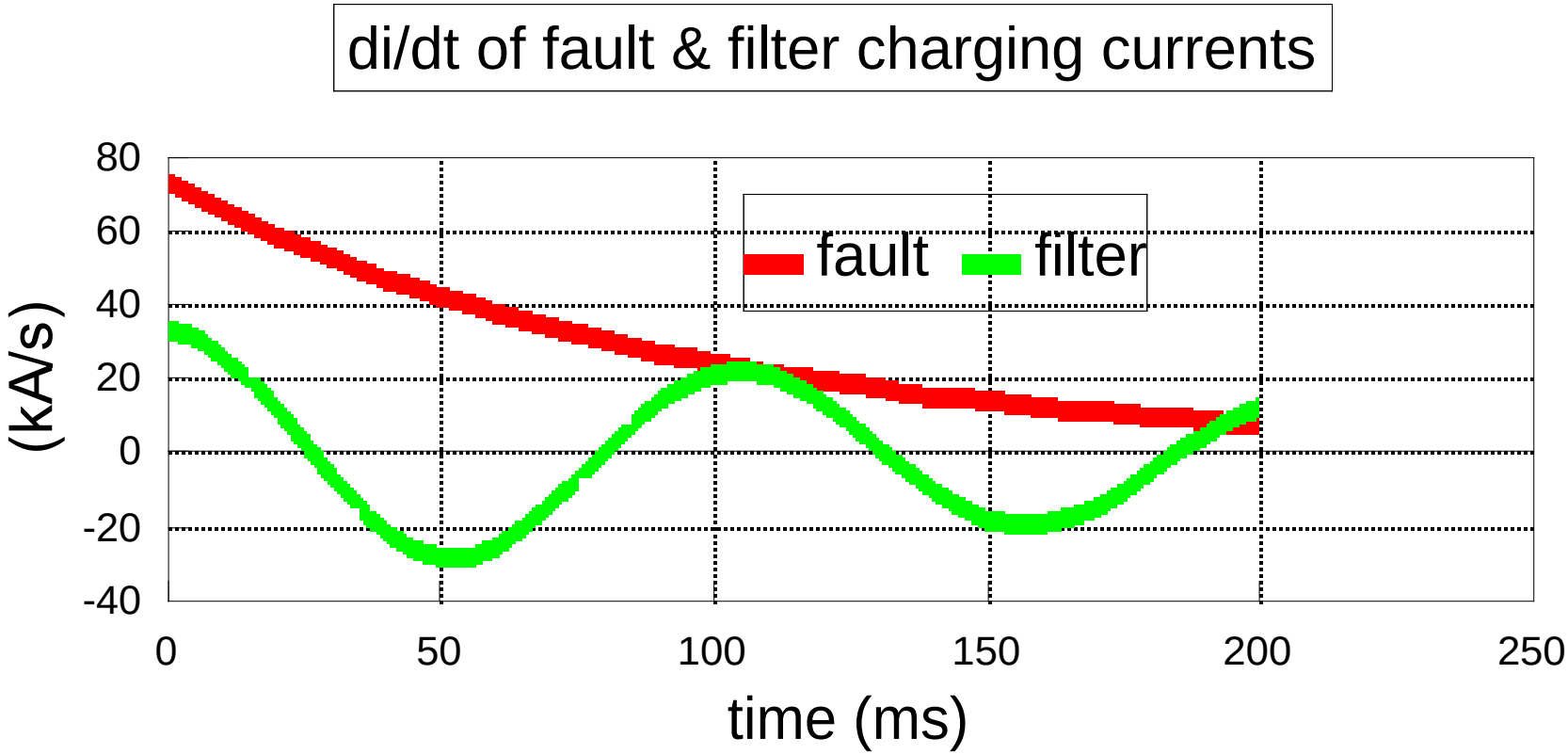
CEGELEC

D.C. System Protection
Fault & Filter Charging Current



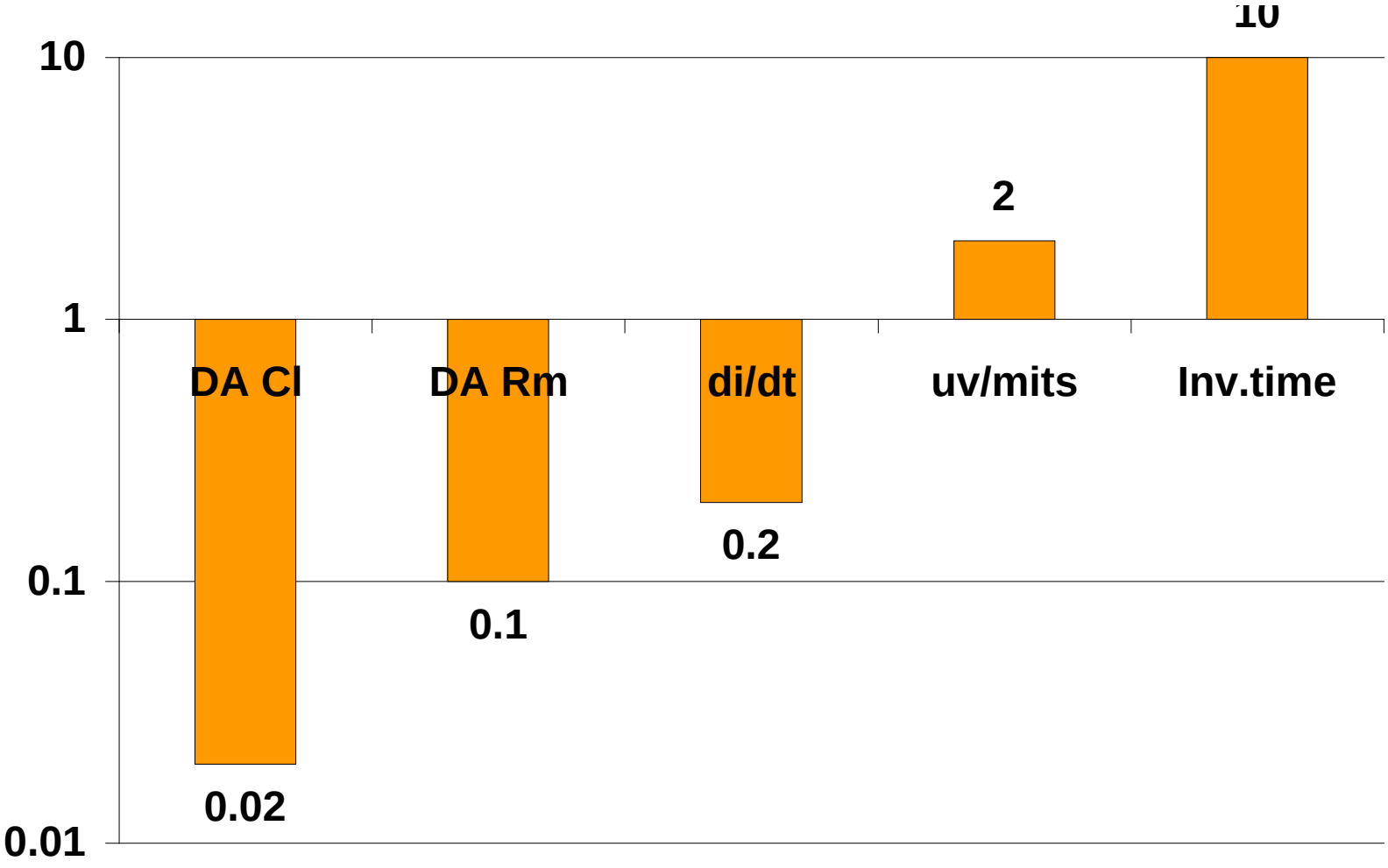
CEGELEC

D.C. System Protection
Fault & Filter Charging Current



CEGELEC

D.C. System Protection
Fault Clearance Times



Drop Short Tests (transparencies)

CEGELEC

Jubilee Line Extension
Information in the Internet

- Jubilee Line Extension Project Home Page:-
  http://www.jle.lul.co.uk/

- Cegelec Projects Limited Home Page:-
  http://www.cegelecproj.co.uk/

Thank You.