

# Simulation report

Reference: 2865DT

Version: C

Code AYD0000064518

Date: 04.08.2011



## CHENNAI METRO RAIL LIMITED

Reference **10000280** - Electrical Traction & Brake Dimensioning

Version C

### Objective

This document shows the contractual requirements, the performances and the journey time for Chennai metro.



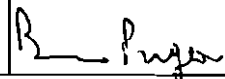
### Application Scope

The scope is to verify that the traction equipment meet the specified performance requirements.

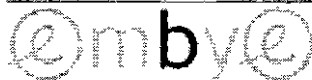
### Responsibilities

Alstom SES

### Signatures

	Name	Position	Date	Signature
Created:	D. Colombo	Power Engineer	04.08.2011	
Verified:	C. Vacca	Power Skill leader	04.08.2011	
Approved:	P. Pregara	TLE	04.08.2011	

CHENNAI METRO RAIL PROJECT



— GENERAL CONSULTANT —

TRANSPORT | **ALSTOM**

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Ref: AYD0000064518

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## Contents

Simulation report .....	1
Section 1 – Introduction .....	5
Section 2 – Commercial Characteristics .....	5
Section 3 – Environmental Characteristics .....	5
Section 4 – Input Data .....	6
4.1 Line Characteristics .....	6
4.1.1 Corridor 1 – “Washermanpet” to “Chennai Airport” .....	6
4.1.2 Corridor 2 - ” Chennai Central” to “St. Thomas Mount” .....	8
4.1.3 Train Composition .....	9
4.1.4 Weights .....	9
4.1.5 Wheels Diameter .....	10
4.1.6 Gearbox .....	10
4.1.7 Resistance To Motion (RTM) .....	10
4.2 Supply system .....	11
4.3 Data taken into account in the simulations .....	11
Section 5 – Required Performance / Simulations .....	12
5.1 Contract Requirements – Performance .....	12
5.2 Contract Requirements – Train failure operation capability .....	12
Section 6 – Traction / Braking Characteristics .....	13
6.1 Train Characteristics .....	13
6.1.1 Normal mode – Traction – 22.5kV <sub>AC</sub> – AW4 load .....	13
6.1.2 Normal mode – ED Brake + MB brake 25Kv <sub>AC</sub> – AW4 load .....	14
6.1.3 Rescue mode: – AW4-AW4 load gradient = 35‰ – 22.5kV <sub>AC</sub> .....	15
6.1.4 Rescue mode: – AWO-AWO load – gradient = 40‰ – 22.5kV <sub>AC</sub> .....	16
6.1.5 Other graphs .....	17
Section 7 – Performance on Corridor 1 and Corridor 2 (round trip) .....	20
7.1 Preliminary assumptions .....	20
7.2 Simulations on track profile .....	21
7.2.1 K01: Normal mode – COR1 .....	21
7.2.2 K02: Normal mode – COR2 .....	24

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## Simulation report

<b>Ref: AYD0000064518</b>	<b>2865DT</b>	<b>Version: C</b>	<b>Date: 04/08/2011</b>
7.2.3	K03: Degraded mode 75%– COR1 .....		27
7.2.4	K04: Degraded mode 75%– COR2 .....		30

## Section 8 – Conclusions ..... 33

### Figures

Figure 1 – “Gradient” [%] vs. Distance [m] (round-trip) .....	6
Figure 2 – “Relative Altitude” [m] vs. Distance [m] (round trip).....	6
Figure 3 – “Speed Limit” [km/h] vs. Distance [m] (round trip) .....	7
Figure 4 – “Curves radius” vs. Distance [m] (round trip).....	7
Figure 5 – “Gradient” [%] vs. Distance [m] (round-trip) .....	8
Figure 6 – “Relative Altitude” [m] vs. Distance [m] (round trip).....	8
Figure 7 – “Speed Limit” [km/h] vs. Distance [m] (round trip) .....	8
Figure 8 “Curves radius” vs. Distance [m] (round trip) .....	9
Figure 9 – Train Traction Effort .....	13
Figure 10 – Train Braking Effort .....	14
Figure 11 – Rescue mode (push-out) Train Traction Effort .....	15
Figure 12 – Rescue mode AW4-AW4 speed profile .....	15
Figure 13 – Rescue mode (Push-out) Train Traction effort .....	16
Figure 14 – Rescue mode AWO-AWO speed profile .....	16
Figure 15 – Power factor in traction .....	17
Figure 16 – Power factor in braking.....	17
Figure 17 – PMCF and Inverter Efficiency in traction .....	18
Figure 18 – PMCF and Inverter Efficiency in braking.....	18
Figure 19 – Catenary current in traction .....	19
Figure 20 – Catenary current in braking.....	19
Figure 21 – “Speed” [km/h] vs. Distance [m] .....	21
Figure 22 – “Acceleration” [m/s <sup>2</sup> ] and “Effort” [kN] vs. Distance [m] .....	22
Figure 23 – “Rms Catenary Current” [A] vs. Distance [m] .....	22
Figure 24 – “Speed” [km/h] vs. Distance [m] .....	24
Figure 25 – “Acceleration” [m/s <sup>2</sup> ] and “Effort” [kN] vs. Distance [m] .....	25
Figure 26 – “Rms Catenary Current” [A] vs. Distance [m] .....	25
Figure 27 – “Speed” [km/h] vs. Distance [m] .....	27
Figure 28 – “Acceleration” [m/s <sup>2</sup> ] and “Effort” [kN] vs. Distance [m] .....	28
Figure 29 – “Rms Catenary Current” [A] vs. Distance [m] .....	28
Figure 30 – “Speed” [km/h] vs. Distance [m] .....	30
Figure 31 – “Acceleration” [m/s <sup>2</sup> ] and “Effort” [kN] vs. Distance [m] .....	31
Figure 32 – “Rms Catenary Current” [A] vs. Distance [m] .....	31

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## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

## Tables

Table 1 – Inter-station running time for Corridor 1 normal mode .....	23
Table 2 – Inter-station running time for Corridor 2 normal mode .....	26
Table 3 – Inter-station running time for Corridor 1 degraded mode .....	29
Table 4 – Inter-station running time for Corridor 2 degraded mode .....	32

## Appendix

<b>A –</b>	<b>Definitions and References .....</b>	<b>34</b>
A-1	Definitions & Abbreviations .....	34
A-2	Reference Documents.....	34
<b>B –</b>	<b>Control Sheet .....</b>	<b>35</b>

## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

## Section 1 – Introduction

This document describes the traction performance for Chennai metro.

The journey simulations and all curves and results are obtained from ALSTOM software: CITHEL v.3.02.00.

## Section 2 – Commercial Characteristics

– Vehicle Type	- Suburban Metro
– Train Formations	- 4 car: DMC – T – T - DMC
– Train set total length	- 87.9 m;
– Track width (gauge)	- 1435 mm
– Catenary Voltage	- 25 kV <sub>ac</sub> (nominal)
– Service Speed	- 80 km/h max
– Commercial Speed	- 34kph for both Corridor 1 and Corridor 2 in normal mode
– Dwell time	30 s
– Return time	120 s

## Section 3 – Environmental Characteristics

– Maximum Ambient Temperature	- +44 °C
– Minimum Ambient Temperature	- +16 °C
– Maximum Relative Humidity	- 100% saturation during rainy season (3-4 months). Other time 82% of humidity (paragraph 2.11 of <b>REF DOC 1</b> in <b>A-2</b> )
– Pollution	- Extremely dusty during hot season
	- SO <sub>2</sub> level in atmosphere: 5 to 20 micro g/m <sup>3</sup>
	- NO <sub>x</sub> level in atmosphere: 10 to 40 micro g/m <sup>3</sup>
	- Respiratory Suspended Particles Matter in atmosphere (RSPM): 45 to 100 micro g/m <sup>3</sup>
	- Total Suspended Particles Matter in atmosphere (TSPM): 150 to 320 micro g/m <sup>3</sup>

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## Simulation report

Ref:AYD0000064518

2865DT

Version: C

Date: 04/08/2011

## Section 4 – Input Data

## 4.1 Line Characteristics

## 4.1.1 Corridor 1 – “Washermanpet” to “Chennai Airport”

- Nr. of stations: - 17
- Round trip distance: - 44.6 km

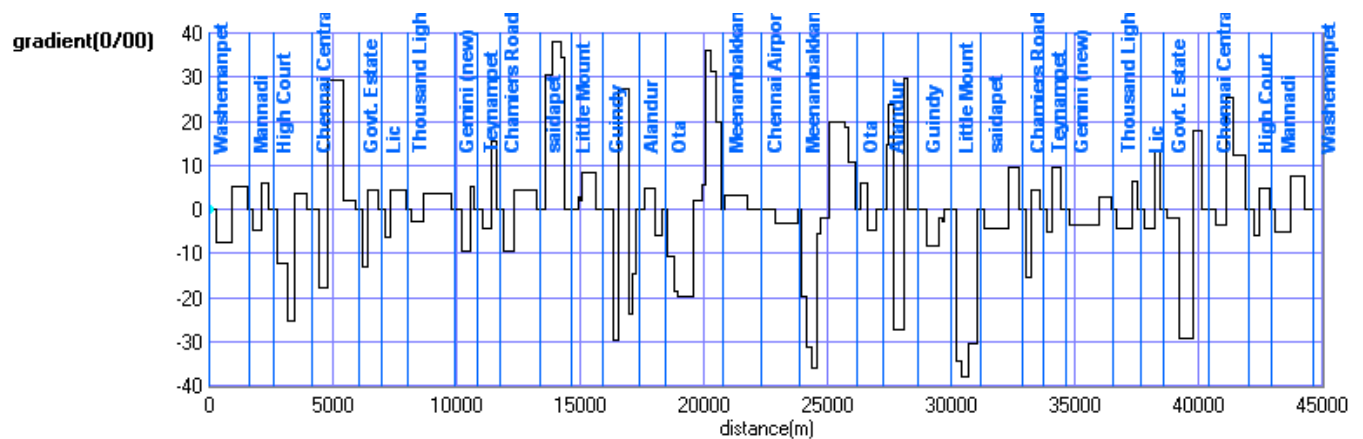


Figure 1 – “Gradient” [%] vs. Distance [m] (round-trip)

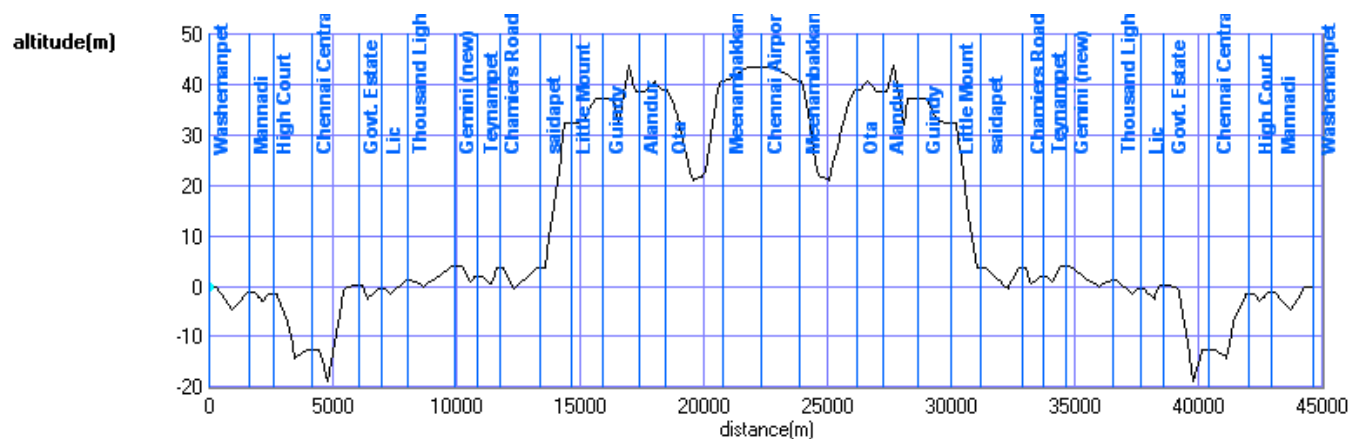


Figure 2 – “Relative Altitude” [m] vs. Distance [m] (round trip)

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Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

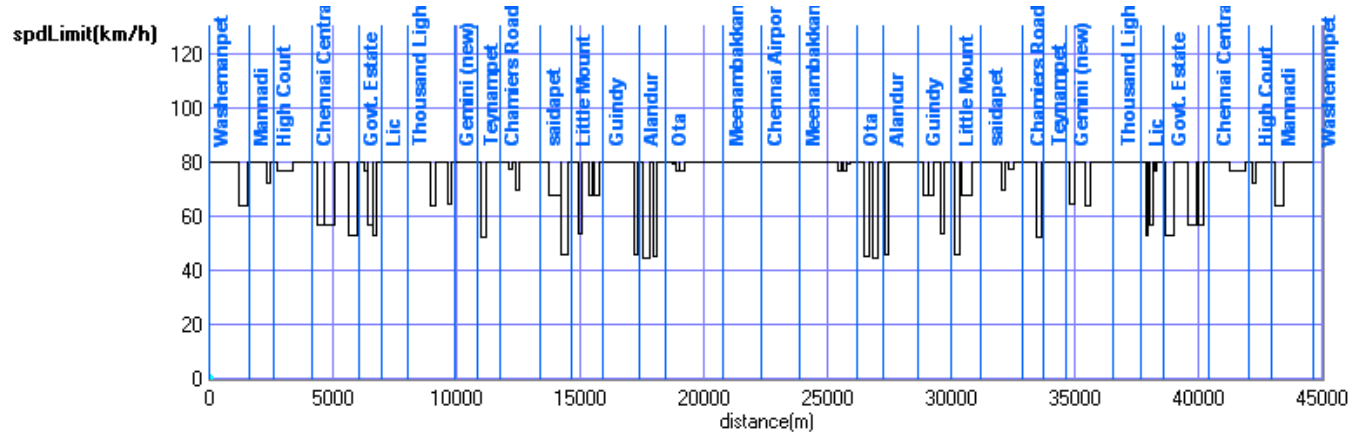


Figure 3 –“Speed Limit” [km/h] vs. Distance [m] (round trip)

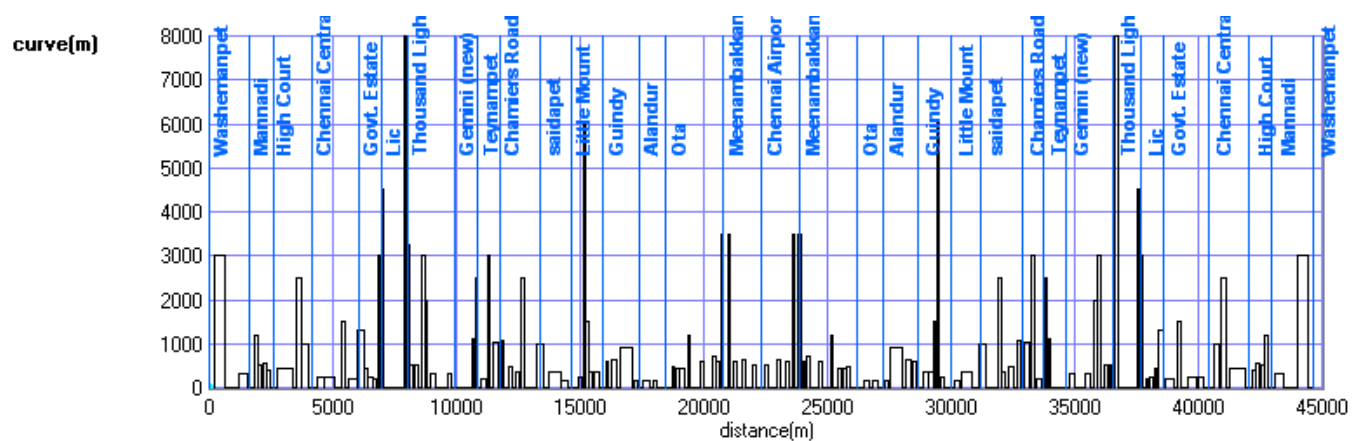


Figure 4 –“Curves radius” vs. Distance [m] (round trip)

CHENNAI - Corridor  
1.xls

Numeric data are collected in following EXCEL file:

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## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

## 4.1.2 Corridor 2 - "Chennai Central" to "St. Thomas Mount"

- Nr. of stations: - 17
- Round trip distance: - 42.7km

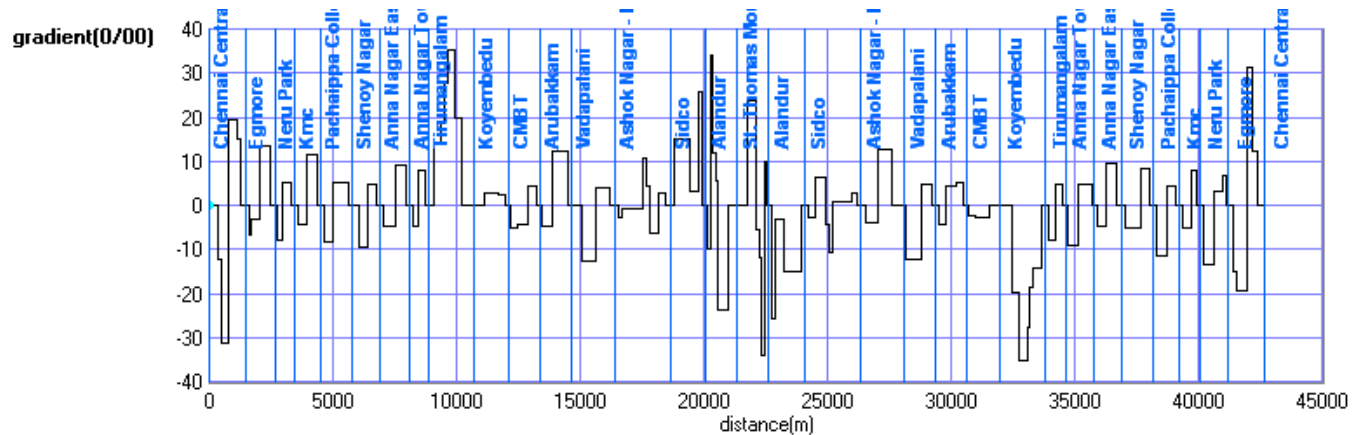


Figure 5 - "Gradient" [%] vs. Distance [m] (round-trip)

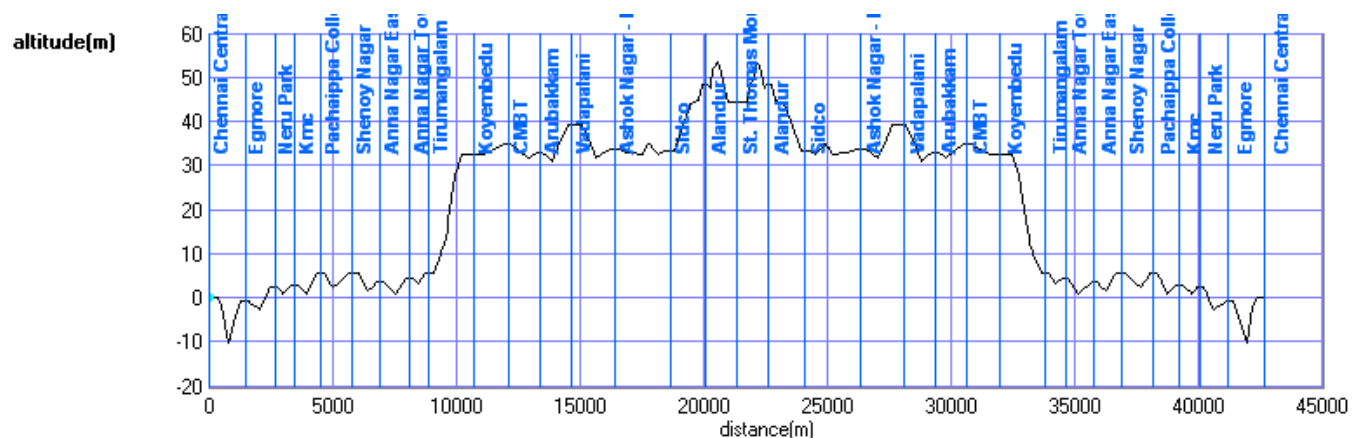


Figure 6 - "Relative Altitude" [m] vs. Distance [m] (round trip)

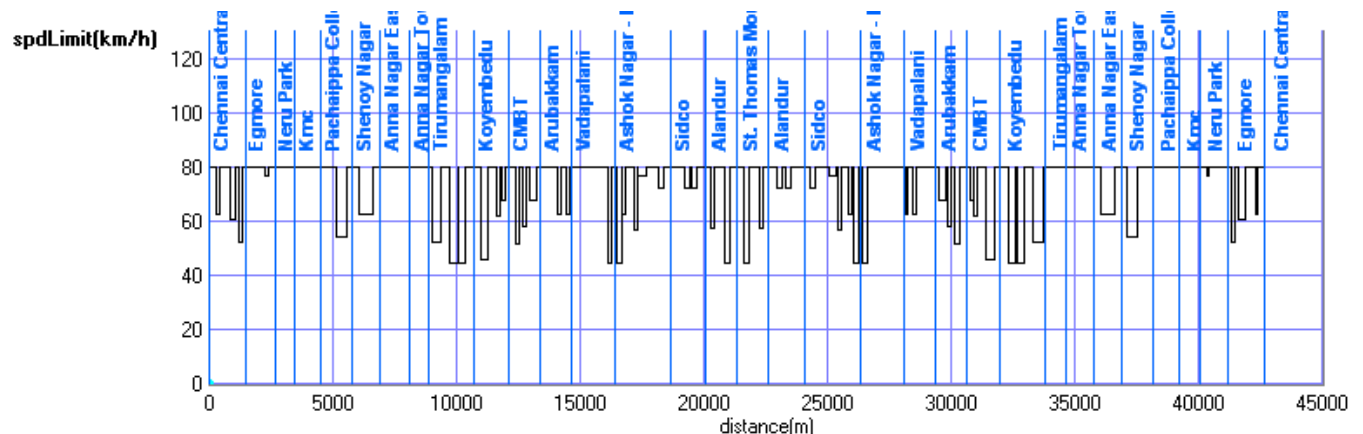


Figure 7 - "Speed Limit" [km/h] vs. Distance [m] (round trip)

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2865DT

Version: C

Date: 04/08/2011

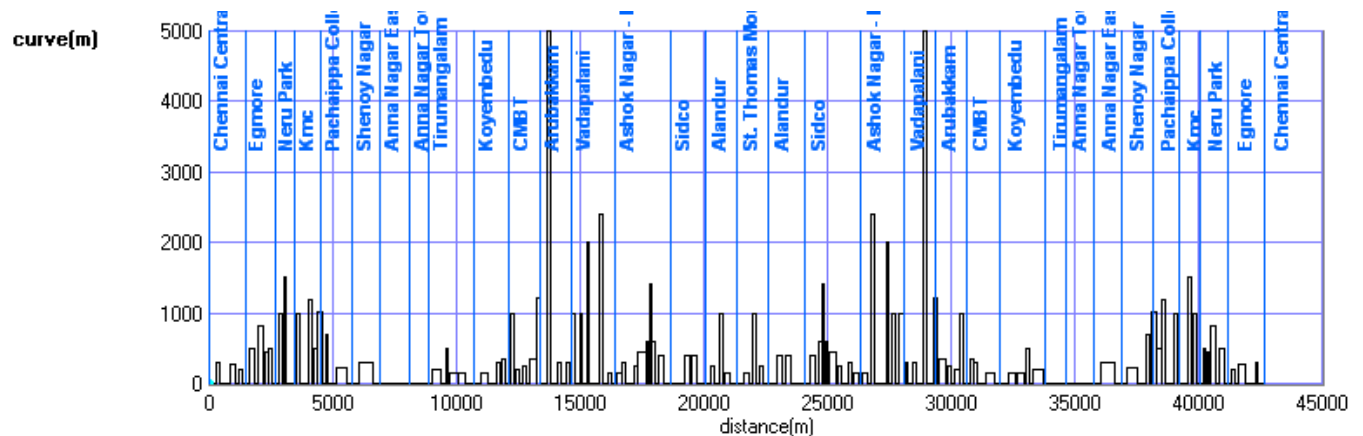


Figure 8 "Curves radius" vs. Distance [m] (round trip)

CHENNAI - Corridor  
2.xls

Numeric data are collected in following EXCEL file:

## 4.1.3 Train Composition

The metro consists of two motor vehicles (DMC) and two trailers (TC) forming a train with the following arrangement (DMC-TC-TC-DMC):

**DMC:** Motor Car with driver cab (2 propulsion converter, 2 traction motors for each converter)

**TC:** Trailer Car with pantograph

## 4.1.4 Weights

Static masses:

[kg]	DMC	TC	TC	DMC	Total
<b>AW0(empty)</b>	40535	40146	40146	40535	<b>161362</b>
<b>AW2( 4p/m<sup>2</sup>)</b>	51910	52366	52366	51910	<b>208552</b>
<b>AW3( 6p/m<sup>2</sup>)</b>	56330	56916	56916	56330	<b>226492</b>
<b>AW4( 8p/m<sup>2</sup>)</b>	60685	61466	61466	60685	<b>244302</b>

Rotational inertia (equivalent mass):

trailer axle	595 kg
motor axle	934 kg
<b>4 car train tot</b>	<b>12232 kg</b>

Average passenger weight:

65 [kg]

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## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

**4.1.5 Wheels Diameter**

•	new	860 mm
•	half worn	820 mm
•	full worn	780 mm

**4.1.6 Gearbox**

•	Gear Ratio	6.2 :1
•	Gear efficiency	97 %

**4.1.7 Resistance To Motion (RTM)**

Davis formula:  $R [N] = 6.4 \cdot M + 130 \cdot n + 0.14 \cdot M \cdot V + [0.046 + 0.0065 \cdot (N-1)] \cdot A \cdot V^2$

where:  $M$  = static train mass in tons  
 $n$  = number of axles  
 $V$  = speed in km/h  
 $N$  = number of cars  
 $A$  = front section in  $m^2$  ( $10 m^2$ )

## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

## 4.2 Supply system

- Voltage supply (normal variation):
  - 25 kV (nominal)
  - 27.5 kV (maximum permanent)
  - 19 kV (minimum)
  - 22.5 kV (nominal performance in traction mode)
  - 25 kV (nominal performance in regenerative braking)
- Line current limit: not limited

## 4.3 Data taken into account in the simulations

- Maximum speed 80 km/h (in normal operation)
- Average acceleration  $\geq 0.82 \text{ m/s}^2$  in the speed range  $0 \div 30 \text{ km/h}$ ; With 22.5kV voltage in traction AW4 load, half worn wheel, on a dry, clean and flat track, jerk included, delay time included)
- Delay time (traction) 0.5s
- Average deceleration  $\geq 1.00 \text{ m/s}^2$  in the speed range  $80 \div 0 \text{ km/h}$ . (AW4 load, half worn wheel, on a dry, clean and flat track, jerk and delay time included. Blending between electrical brake and mechanical brake in the whole speed range)
- Jerk  $0.70 \text{ m/s}^3$  maximum (traction and braking).
- Rail adhesion coefficient  $\geq 20\%$  (traction);  $\geq 16\%$  (braking)
- Traction motor type 4 ECA 2142 (specific version for Chennai metro)
- Braking Electrical Regenerative and Mechanical brake. When the line is not receptive friction brake shall be applied.
- Delay time (braking) 0.5s
- Commercial speed 34km/h for both Corridor 1 and Corridor 2 in normal mode
- Stop time at intermediate stations 30s
- Stop time at terminals 0s

Electrical and Thermal Validation have done at:

- $22.5\text{kV}_{\text{ac}}$  in traction mode;
- $25\text{kV}_{\text{ac}}$  in regenerative braking mode;
- $+45^\circ\text{C}$  of ambient temperature and inlet air temperature;
- new wheels (860mm);
- AW4 load
- Normal conditions with % of coasting.

It is assumed that during coasting mode the traction motor torque is null but the inverter is kept on.

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## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

## Section 5 – Required Performance / Simulations

### 5.1 Contract Requirements – Performance

§ 2.14.1.5: TRACTION: when the train is running on straight and flat track (gradient = 0%), in AW4 load, with 22.5kV and half-worn wheels:

Average starting acceleration [0÷30km/h] 0.82m/s<sup>2</sup>  
(jerk included and delay time included)

Jerk limit: 0.70m/s<sup>3</sup>

Adhesion coefficient ≤20%

§ 2.14.1.5: BRAKING: the service braking performances of an AW4 loaded train on straight and flat (gradient = 0%) line, with nominal voltage (25kV) and half-worn wheels, are according to the following:

Average deceleration [80÷0km/h] 1.00m/s<sup>2</sup>  
(delay and jerk included. Blending between Electric brake and Mechanical brake in the whole speed range)

Jerk limit: 0.70m/s<sup>3</sup>

Adhesion coefficient ≤20%

### 5.2 Contract Requirements – Train failure operation capability

As required by REF DOC 1 in A-2

§2.14.2.3: An assisting rake (under AW4 loading condition) shall be capable of starting and running the coupled consist up the worst case grade specified for the Main Line (3.5%) at a minimum speed of 20 km/h, with brakes released on the failed rake (with AW4 loading) to enable the defective rake to be removed from service.

§2.14.2.4: A rake shall be capable of pushing (or pulling) another rake up to an inclination of 4% with the parking brake released on the rake being pushed (or pulled) with both rakes in the Tare Loading Condition AW0. The Contractor shall submit calculations verifying compliance with this requirement.

§2.14.2.5: The design of the traction control system and the associated traction motors shall ensure that in the event of an inverter (plus associated control equipment) or bogie failure, at Crush Loading Condition AW4, the rake shall continue to operate as far as its scheduled destination without incurring a delay of greater than five (5) minutes.

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## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

## Section 6 – Traction / Braking Characteristics

## 6.1 Train Characteristics

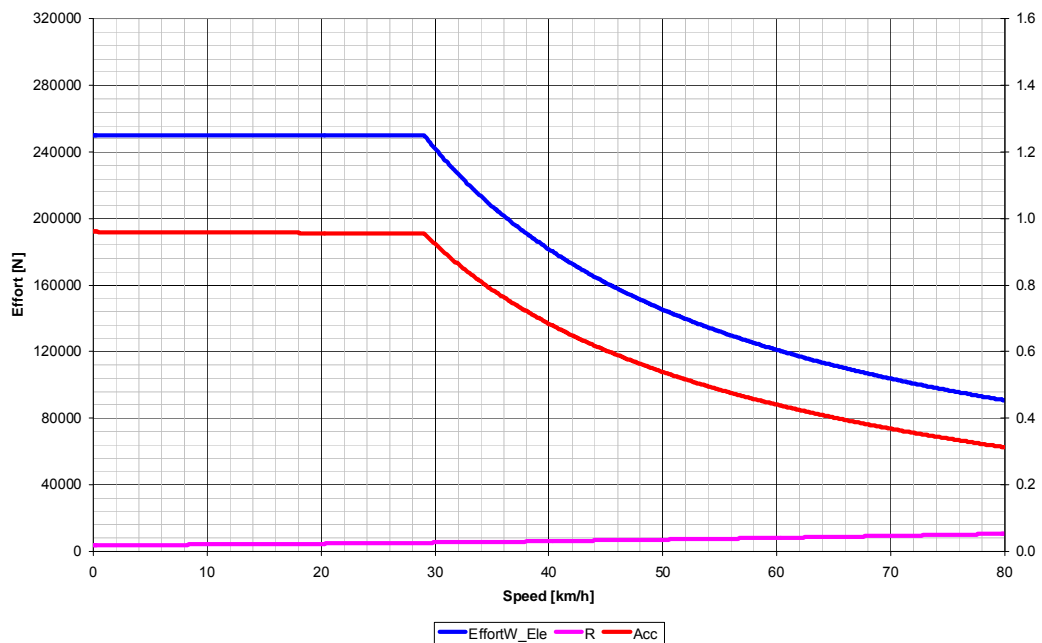
6.1.1 Normal mode – Traction – 22.5kV<sub>AC</sub> – AWW4 load

Figure 9 – Train Traction Effort

Average acceleration with jerk and with delay time (SJ + D)

Delay time	0.5 [s]
Jerk	0.7 [m/s <sup>3</sup> ]
A_time [0-30km/h + SJerk]	9.39 [s]
A_time [0-30km/h + SJ + D]	9.89 [s]
Acc[AVG 0-30km/h + SJerk]	0.89 [m/s <sup>2</sup> ]
Acc[AVG 0-30km/h + SJ + D]	0.84 [m/s <sup>2</sup> ]

## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

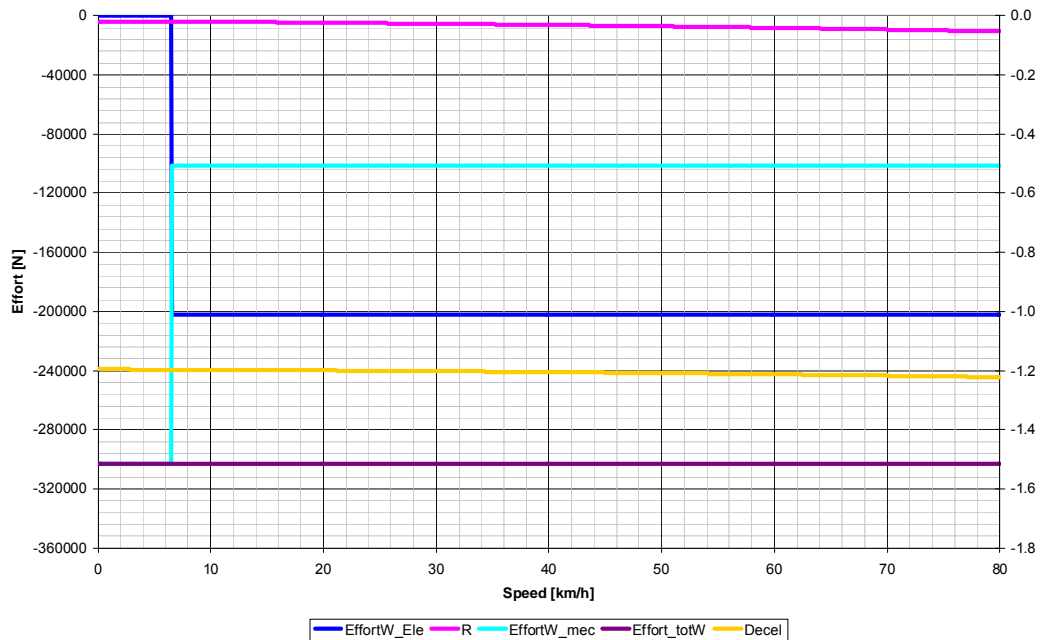
6.1.2 Normal mode – ED Brake + MB brake 25Kv<sub>AC</sub> – AWW4 load

Figure 10 – Train Braking Effort

Average deceleration with jerk and with delay time (mechanical brake blended with electric brake in the whole speed range).

Delay time	0.5	[s]
Jerk	0.7	[m/s <sup>3</sup> ]
D_brak. [80-0km/h 25kV] (not including jerk and delay time effect)	204	[m]
D_brak. [80-0km/h 25kV] (total stopping distance including jerk and delay time effect)	234	[m]
Ideal deceleration	1.21	[m/s <sup>2</sup> ]
Nominal Deceleration [80-0km/h 25kV] (theoretical constant deceleration to stop 80km/h to 0km/h in 234m)	1.05	[m/s <sup>2</sup> ]

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Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

## 6.1.3 Rescue mode: – AW4-AW4 load gradient = 35‰ – 22.5kVac

An assisting rake (under AW4 loading condition) shall be capable of starting and running the coupled consist up the worst case grade specified for the Main Line (3.5%) at a minimum speed of 20 km/h, with brakes released on the failed rake (with AW4 loading) to enable the defective rake to be removed from service.

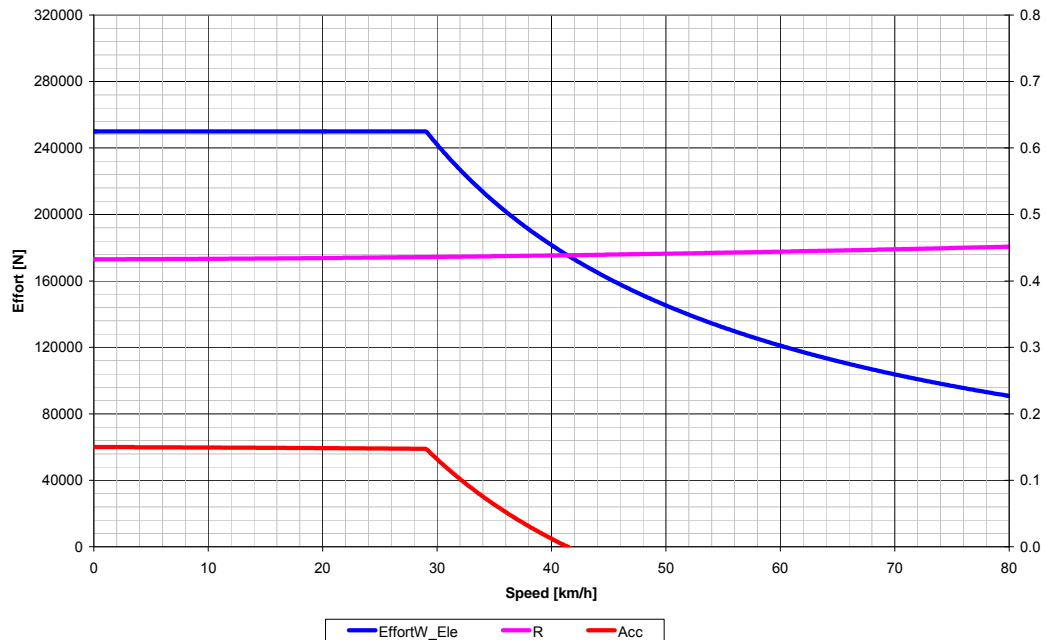


Figure 11 – Rescue mode (push-out) Train Traction Effort

The coupled metro can start on 35‰ of slope with a starting acceleration of more than  $0.1 \text{ m/s}^2$ .

Simulation made on 1300m (average interstation distance for Corridor 1 and Corridor 2) with gradient of 35‰ and speed limit of 20km/h:

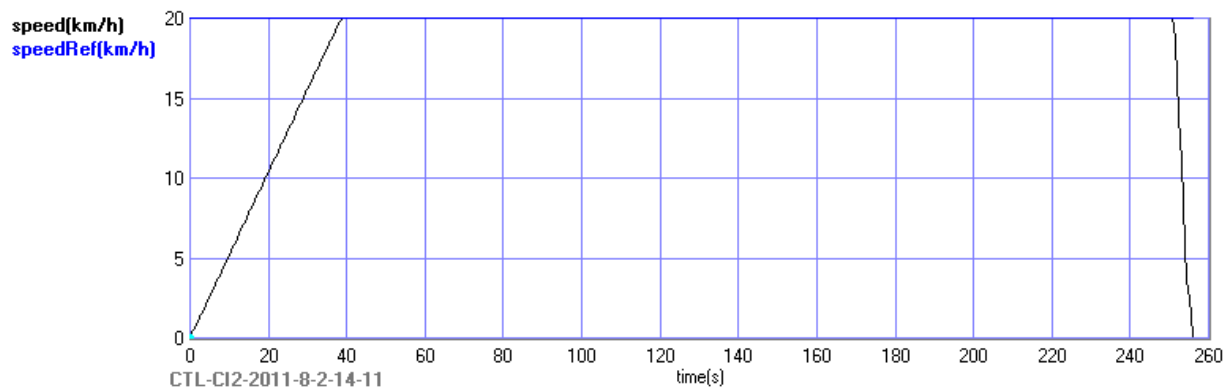


Figure 12 – Rescue mode AW4-AW4 speed profile

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Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

## 6.1.4 Rescue mode: - AW0-AW0 load - gradient = 40‰ - 22.5kVac

A train shall be capable of pushing (or pulling) another train up to an inclination of 4% with the parking brake released on the rake being pushed (or pulled) with both trains in the Tare Loading Condition AW0.

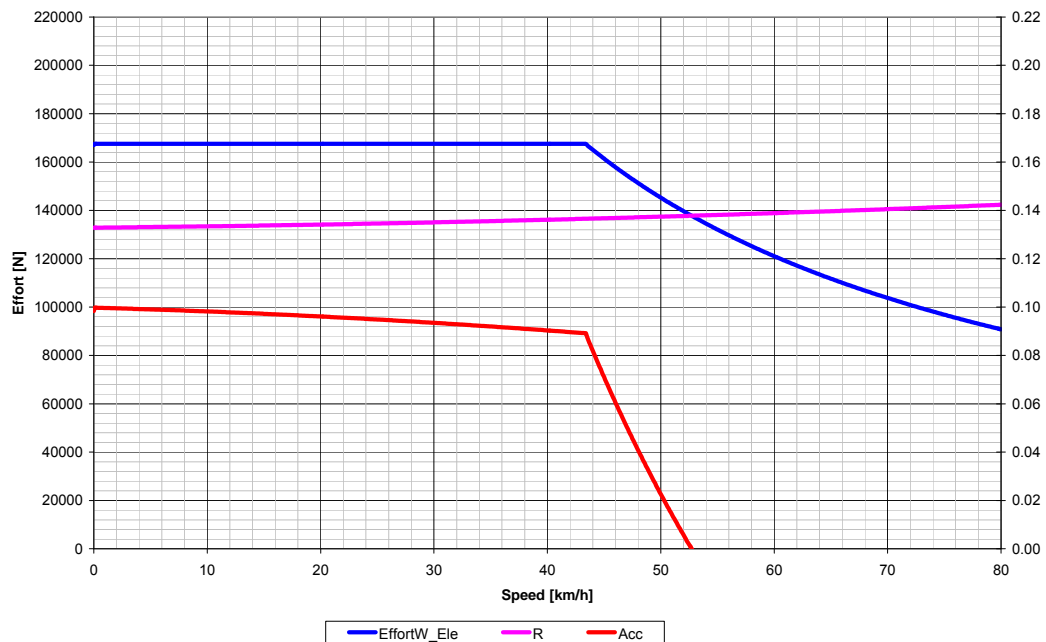


Figure 13 – Rescue mode (Push-out) Train Traction effort

The coupled metro can start on 40‰ of slope. with a starting acceleration  $\geq 0.1 \text{ m/s}^2$ .

Simulation made on 1300m (average inter-station distance for Corridor 1 and Corridor 2) with gradient of 40‰ and speed limit of 20km/h:

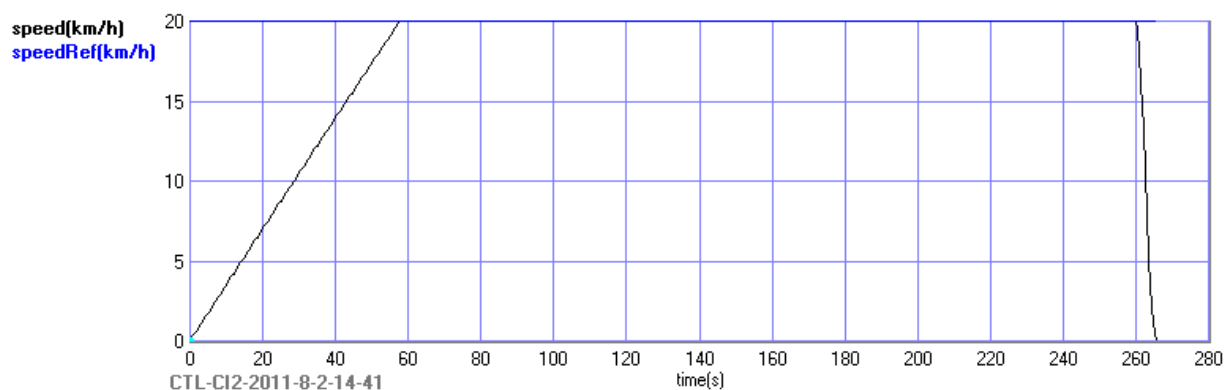


Figure 14 – Rescue mode AW0-AW0 speed profile

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## Simulation report

Ref: AYD0000064518

2865DT

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## 6.1.5 Other graphs

The curves below have been calculated in this condition:

4 cars train with all motors in service

AW4 load

Traction line voltage 22.5kV

Braking line voltage 25kV

**Power factor of the primary side of one transformer**

Traction:

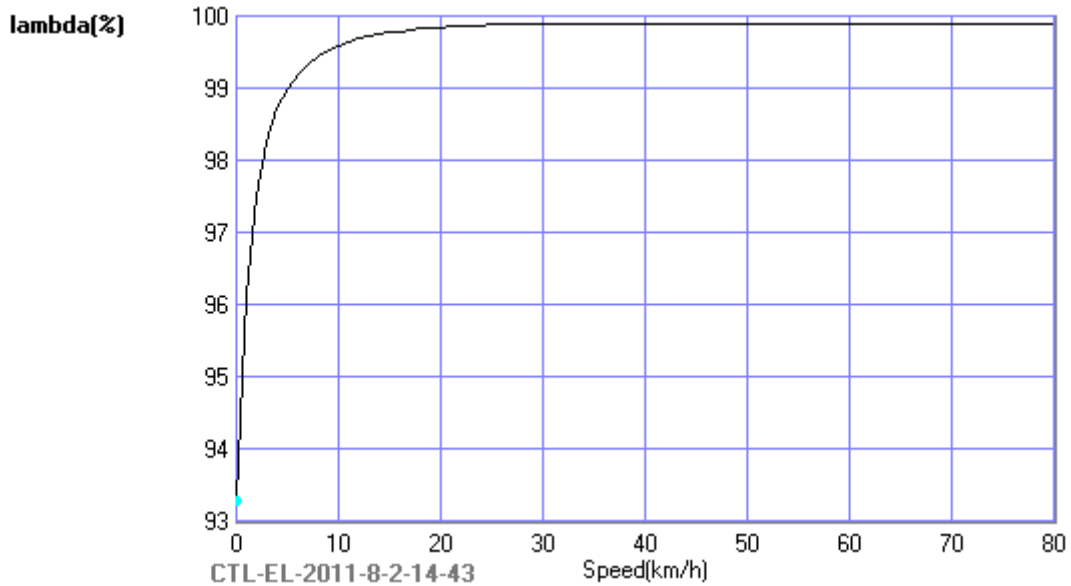


Figure 15 – Power factor in traction

Braking:

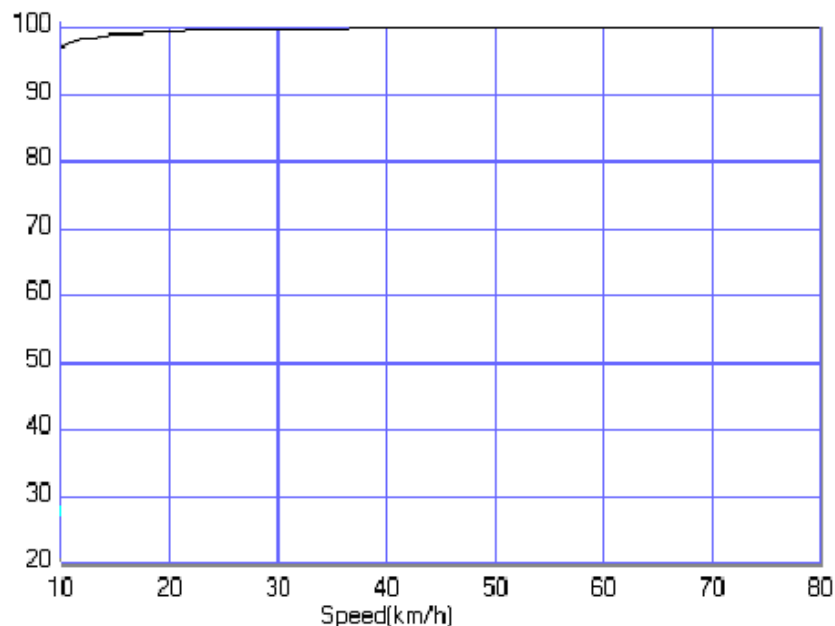


Figure 16 – Power factor in braking

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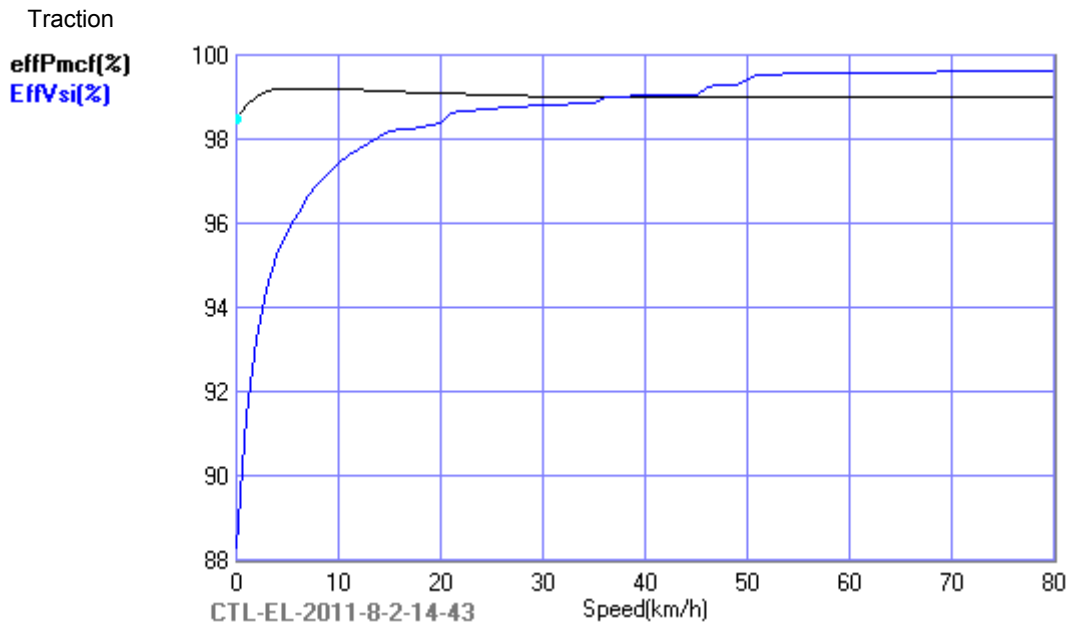
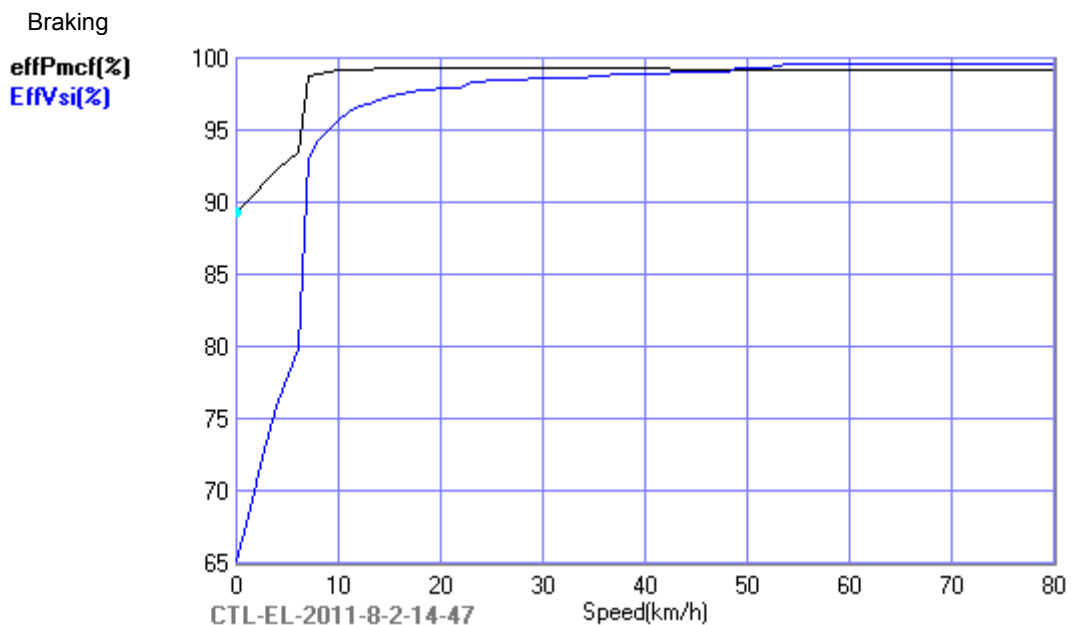
## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

**PMCF and Inverter Efficiency****Figure 17 – PMCF and Inverter Efficiency in traction****Figure 18 – PMCF and Inverter Efficiency in braking**

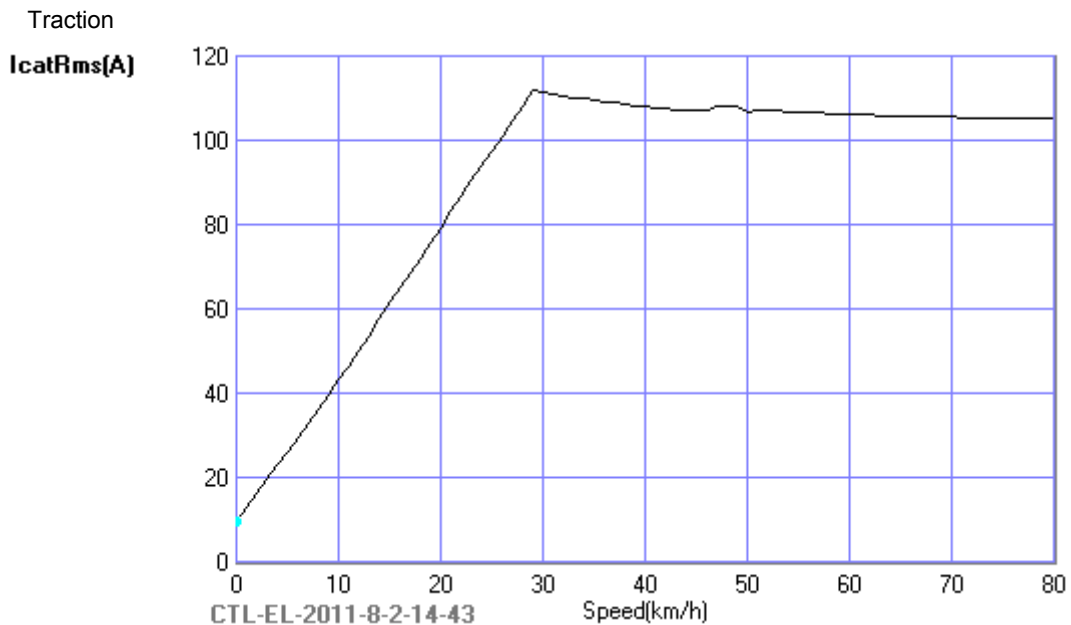
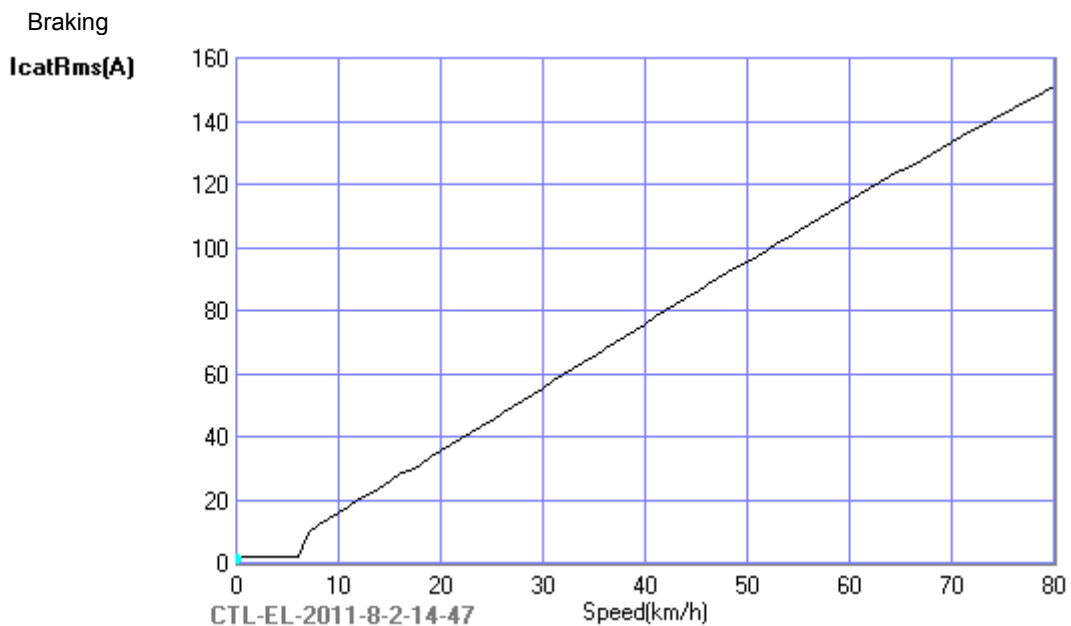
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2865DT

Version: C

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**Catenary Current****Figure 19 – Catenary current in traction****Figure 20 – Catenary current in braking**

## Simulation report

Ref: AYD0000064518

2865DT

Version: C

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## Section 7 – Performance on Corridor 1 and Corridor 2 (round trip)

## 7.1 Preliminary assumptions

The simulations are carried out with the following assumptions:

- CiThEI version 3.02.00.
- Traction/Braking curves as defined in [Section 6 –](#)  
Sharing between electrical and mechanical brake in the whole speed range.
- $T_{\text{AMBIENT}} = +45.0^{\circ}\text{C}$  with reduced ventilation for the inverter at low speed (<5km/h).
- $T_{\text{IN}} = \text{Inlet cooling air temperature} = +45.0^{\circ}\text{C}$ .
- AW4, according to table in [§4.1.4](#)
- Normal (P=100%) and degraded (1 traction converter in fault) mode analyzed.
- $V_{\text{MAX}} = 80\text{km/h}$ , Jerk =  $0.70\text{m/s}^3$ .
- Commercial speed calculated with: Dwell Time = 30s; Return Time = 0s.
- Numerical calculation settings:
  - speed interval: 2 km/h
  - handle interval: 5 %
  - time step: 0.2 s

Formula of commercial speed:

$$\text{Commercial\_Speed} = \frac{\text{Distance}}{\text{Running\_Time} + \text{Total\_Stop\_Time}}$$

Where:  $\text{Total\_Stop\_Time} = (2 * N - 4) * \text{Dwell\_Time}$

N= Number of Stations

## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

## 7.2 Simulations on track profile

## 7.2.1 K01: Normal mode – COR1

(AW4 – T=22.5kV/B=25kV – Regenerative braking – 34km/h comm. speed by coasting)

Normal Mode – all traction and brake available – Electrical brake blended with Mechanical brake in the whole speed range.

⇒ running on Corridor 1 in ETC coasting mode<sup>1</sup>

⇒  $V_{MAX} = 80\text{km/h}$ .

- AW4 load; Traction at 22.5kV<sub>AC</sub>; Reg.Braking at 25kV<sub>AC</sub>

It was applied a 26.0% of coasting, with AW4 load and nominal voltages.  
In this conditions, the commercial speed is 34km/h.

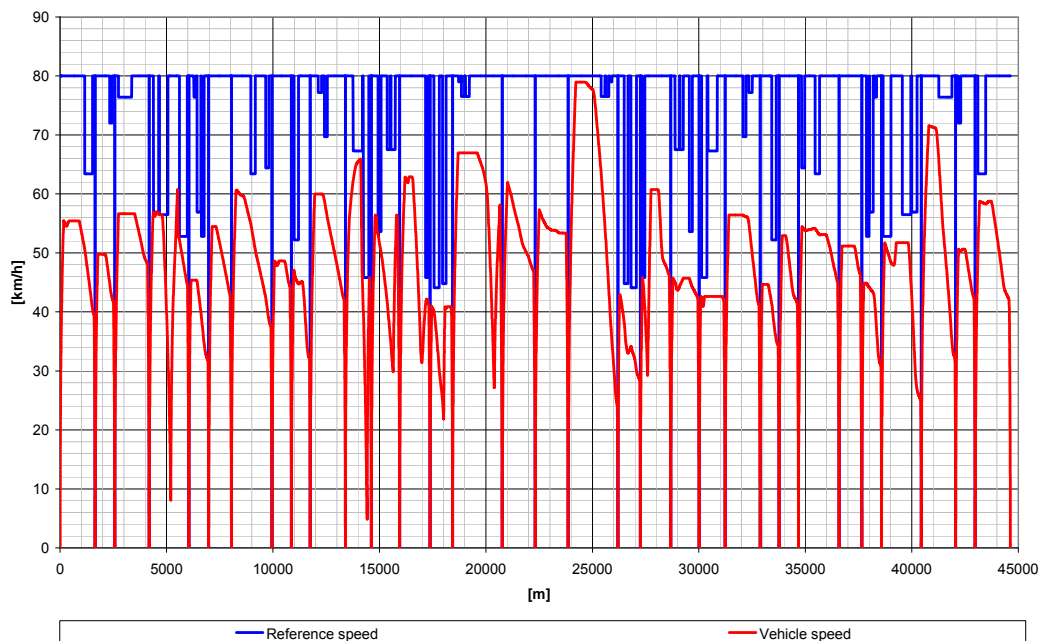


Figure 21 – “Speed” [km/h] vs. Distance [m]

$$\text{Commercial Speed: } \frac{\text{distance[m]}}{\text{time[s]}} * 3.6 = \frac{44628}{4713.2} * 3.6 = 34\text{km/h}$$

<sup>1</sup> “Extended Time Running by Coasting” consists to use coasting running on the cycle in order to obtain an extra time for each station spacing. This extra time is given by the user as a percentage of the time obtained with the all-out running.

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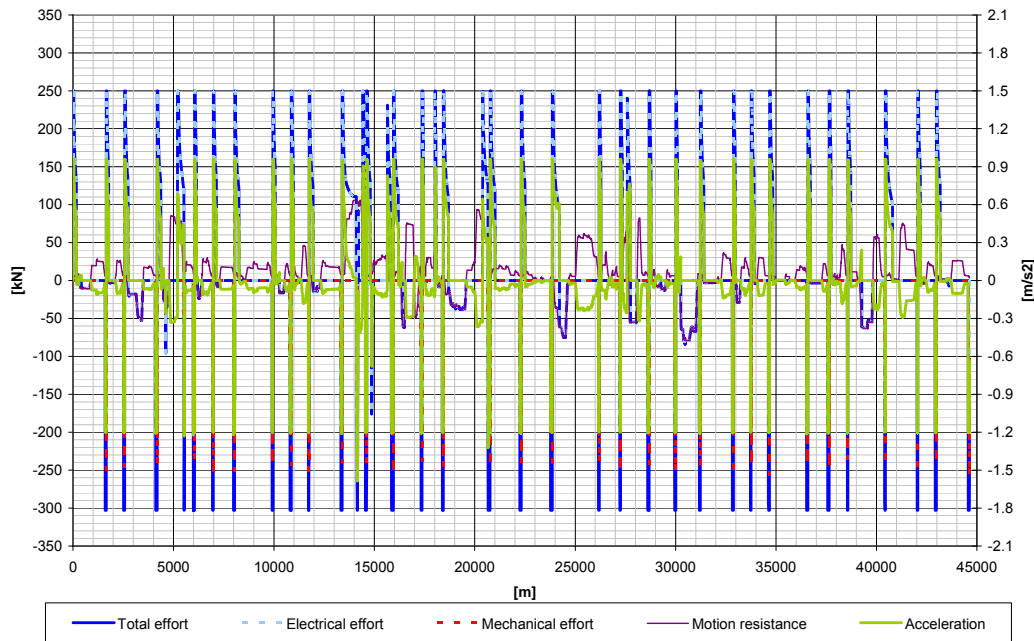


Figure 22 – “Acceleration” [m/s²] and “Effort” [kN] vs. Distance [m]

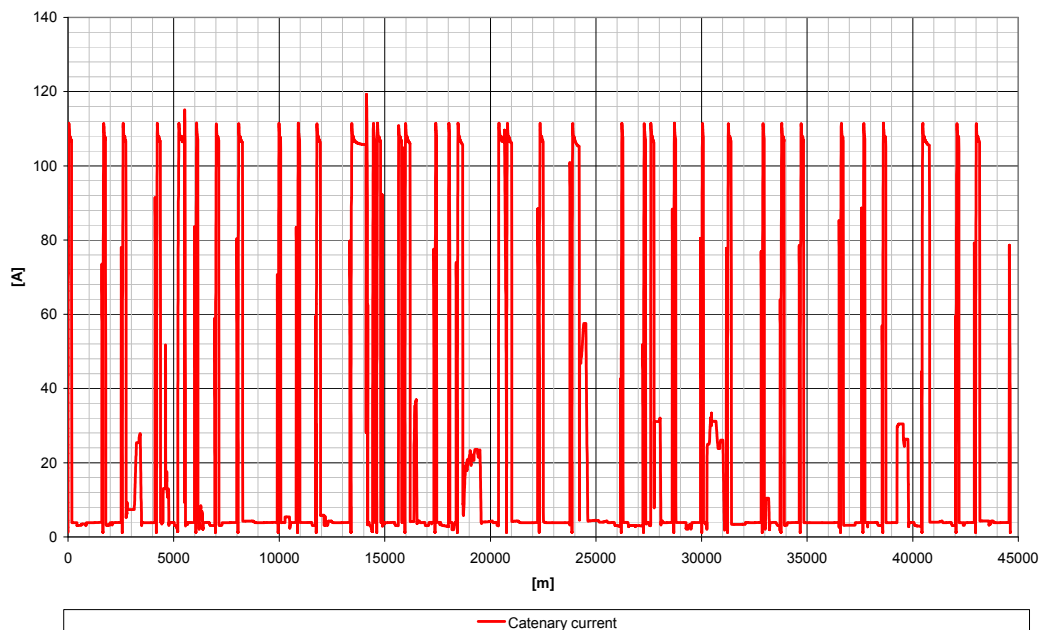


Figure 23 – “Rms Catenary Current” [A] vs. Distance [m]

	Energy (*)			
	Absorbed [kWh]	Regenerated [kWh]	Total (Abs - Reg) [kWh]	Total / km [kWh/km]
TR / ED BK	465.1	132.7	332.38	7.45

It is assumed that during coasting mode the traction motor torque is null but the inverter is kept on (to take into account the normal operation way in ATO mode).

(\*): Auxiliary consumption Excluded.

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## Simulation report

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Date: 04/08/2011

CITHEL Kinematical Calculation [CTL-CI2-2011-7-29-10-35]							
Calculation Case							
CITHEL Version	V3.02.00				Speed calculation step	2.(km/h)	
Project Name	CHENNAI CITHEL 4.00.00				Handle calculation step	5.(%)	
Calculation Case Name	CHN 4C8M NEW AW4 COR1-AR ELB+PNB ETC-STD 16%BR				Time calculation step	0.2(s)	
Calculation ID	CTL-CI2-2011-7-29-10-35						
Date	2011 July 29,10h35m22s						
Energy Balance							
Interstation Name	Run Time (s)	Wheel Total Energy (kWh)	Wheel Traction Energy (kWh)	Wheel Electrical Braking Energy (kWh)	Catenary Total Energy (kWh)	Catenary Energy in Consumption (kWh)	Catenary Energy in Regeneration (kWh)
Washemanpet to Mannadi	131.4	4.6409	8.7044	4.0635	9.5724	12.404	2.8314
Mannadi to High Court	84	3.7044	6.9388	3.2344	7.357	9.8563	2.4992
High Court to Chennai Central	123.4	-1.1388	8.7996	9.9384	4.1261	11.933	7.8068
Chennai Central to Govt. Estate	169.4	17	24.383	7.3826	25.69	31.645	5.9548
Govt. Estate to Lic	96.4	3.0632	5.8537	2.7905	6.5826	8.586	2.0034
Lic to Thousand Lights	91.8	4.8349	8.3316	3.4967	8.8807	11.561	2.68
Thousand Lights to Gemini (new)	150.4	7.967	10.49	2.523	13.669	15.695	2.0252
Gemini (new) to Teynampet	83.4	2.1343	6.6864	4.5521	5.8188	9.2688	3.45
Teynampet to Chamiers Road	89.4	4.4363	6.2488	1.8125	7.8641	9.2963	1.4322
Chamiers Road to saidapet	126.8	5.559	9.8547	4.2957	10.764	13.898	3.1338
saidapet to Little Mount	122.4	25.948	32.772	6.8237	34.589	40.27	5.6812
Little Mount to Guindy	120.2	9.4047	15.888	6.483	15.596	20.981	5.3852
Guindy to Alandur	121.6	6.4343	11.461	5.0271	11.676	15.795	4.1187
Alandur to Ota	120.6	4.9774	8.2662	3.2888	9.5388	12.013	2.4737
Ota to Meenambakkam	162.8	10.065	23.703	13.638	18.947	30.066	11.119
Meenambakkam to Chennai Airport	120	7.4521	11.374	3.9214	12.745	15.955	3.2098
Chennai Airport to Meenambakkam	118.6	4.3248	9.3892	5.0644	9.3415	13.522	4.1805
Meenambakkam to Ota	162.4	6.1571	13.969	7.8118	12.773	19.394	6.6209
Ota to Alandur	122	3.7685	5.1833	1.4147	7.3955	8.4971	1.1016
Alandur to Guindy	120	4.7246	13.192	8.4676	10.592	17.597	7.0043
Guindy to Little Mount	120.8	1.8639	5.8846	4.0207	6.2429	9.1637	2.9209
Little Mount to saidapet	116.2	-13.668	5.1103	18.779	-8.3729	7.0109	15.384
saidapet to Chamiers Road	128	5.4408	8.9818	3.5409	10.424	12.887	2.4632
Chamiers Road to Teynampet	90	2.093	5.6329	3.5399	5.5459	8.168	2.6221
Teynampet to Gemini (new)	83.8	4.7163	7.8931	3.1768	8.506	10.987	2.4811
Gemini (new) to Thousand Lights	146	4.8099	8.3876	3.5777	10.139	13.054	2.9148
Thousand Lights to Lic	91.2	2.8434	7.2291	4.3857	6.7989	9.9604	3.1614
Lic to Govt. Estate	95.6	4.0282	5.6955	1.6673	7.4734	8.7743	1.3009
Govt. Estate to Chennai Central	167.6	-1.9821	7.8349	9.817	3.7754	11.897	8.1214
Chennai Central to High Court	124.6	12.831	14.64	1.8084	18.287	19.715	1.4289
High Court to Mannadi	83.4	4.0423	7.3	3.2577	7.7446	10.342	2.5972
Mannadi to Washemanpet	129	6.4224	9.6957	3.2733	11.629	14.195	2.5652
-----							
Stops Data	900						
Totals	4713.2	168.9	335.77	166.87	332.38	465.05	132.67
-----							

Table 1 – Inter-station running time for Corridor 1 normal mode

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## Simulation report

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2865DT

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## 7.2.2 K02: Normal mode – COR2

(AW4 – T=22.5kV/B=25kV – Regenerative braking – 34km/h comm. speed by coasting)

Normal Mode – all traction and brake available – Electrical brake blended with Mechanical brake in the whole speed range.

- ⇒ running on Corridor 2 in ETC coasting mode<sup>2</sup>
- ⇒  $V_{MAX} = 80\text{km/h}$ .

- AW4 load; Traction at 22.5kV<sub>AC</sub>; Reg.Braking at 25kV<sub>AC</sub>

It was applied a 18.27% of coasting, with AW4 load and nominal voltages.  
In this condition, the commercial speed is 34km/h.

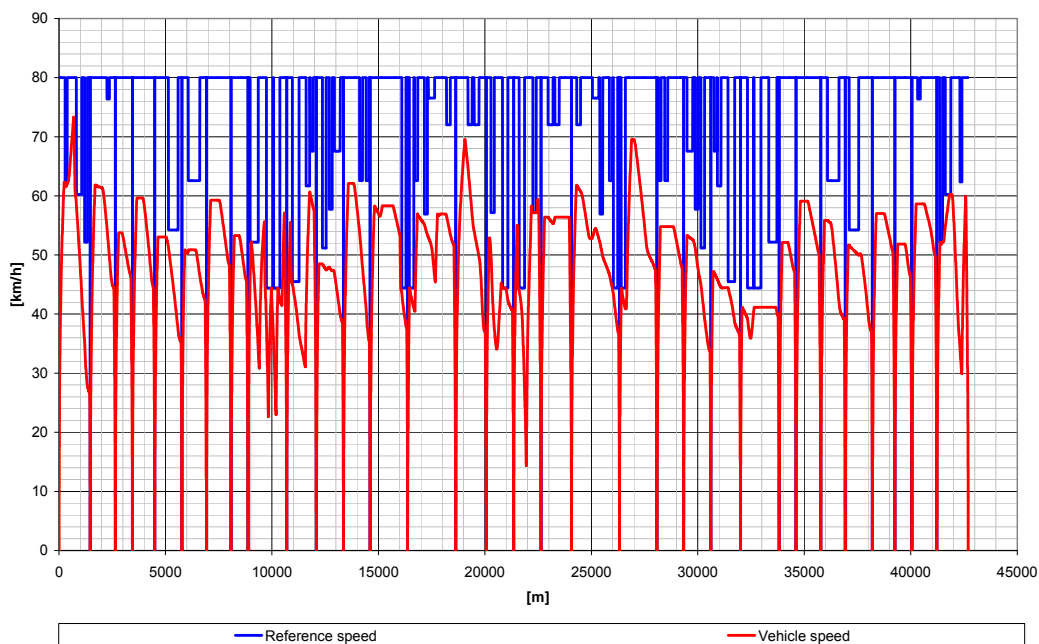


Figure 24 – “Speed” [km/h] vs. Distance [m]

$$\text{Commercial speed} = \frac{\text{distance[m]}}{\text{time[s]}} * 3.6 = \frac{42696}{4515.6} * 3.6 = 34\text{km/h}$$

<sup>2</sup> “Extended Time Running by Coasting” consists to use coasting running on the cycle in order to obtain an extra time for each station spacing. This extra time is given by the user as a percentage of the time obtained with the all-out running.

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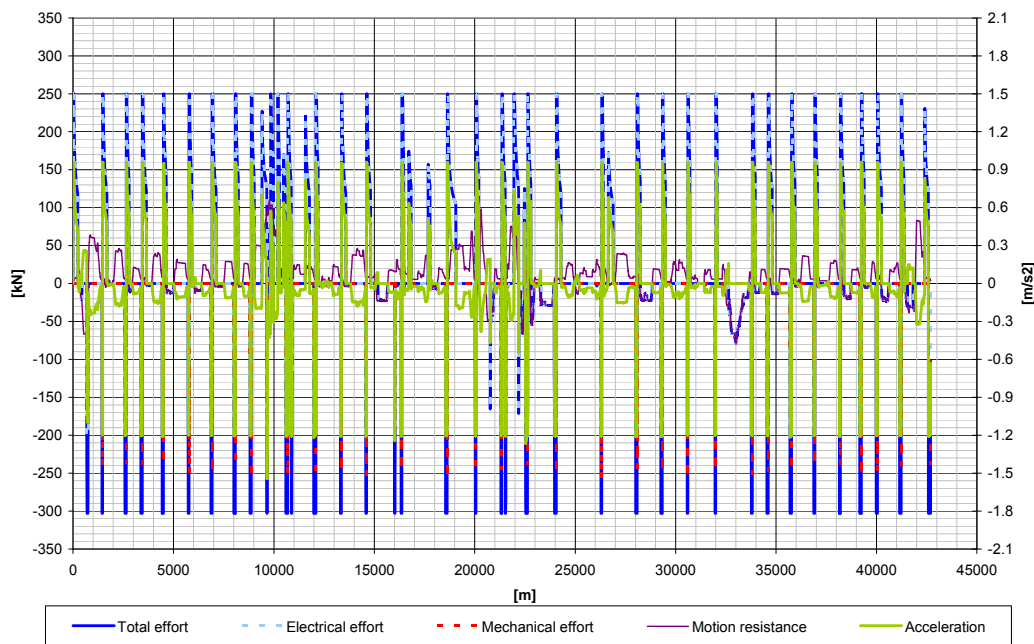


Figure 25 – “Acceleration” [m/s²] and “Effort” [kN] vs. Distance [m]

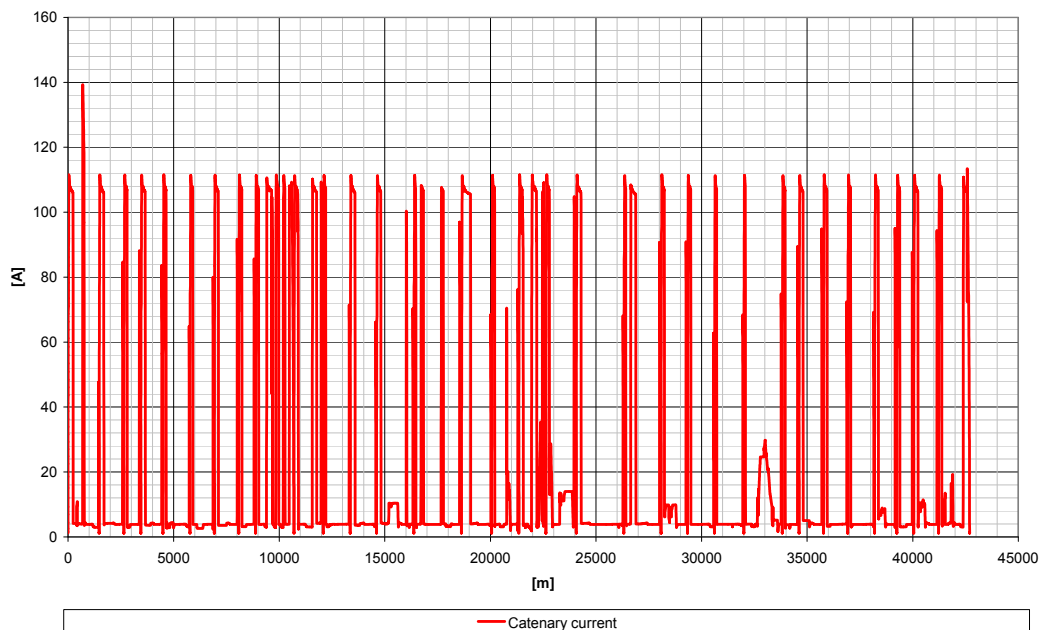


Figure 26 – “Rms Catenary Current” [A] vs. Distance [m]

	Energy (*)			
	Absorbed [kWh]	Regenerated [kWh]	Total (Abs - Reg) [kWh]	Total / km [kWh/km]
TR / ED BK	476.3	131.9	344.37	8.07

It is assumed that during coasting mode the traction motor torque is null but the inverter is kept on (to take into account the normal operation way in ATO mode).

(\*): Auxiliary consumption Excluded.

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## Simulation report

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CITHEL Kinematical Calculation [CTL-CI2-2011-7-29-14-50]							
Calculation Case							
CITHEL Version	V3.02.00				Speed calculation step	2.(km/h)	
Project Name	CHENNAI CITHEL 4.00.00				Handle calculation step	5.(%)	
Calculation Case Name	CHN 4C8M NEW AW4 COR2-AR ELB+PNB ETC-STD 16%BR				Time calculation step	0.2(s)	
Calculation ID	CTL-CI2-2011-7-29-14-50						
Date	2011 July 29,14h50m34s						
Energy Balance							
Interstation Name	Run Time (s)	Wheel Total Energy (kWh)	Wheel Traction Energy (kWh)	Wheel Electrical Braking Energy (kWh)	Catenary Total Energy (kWh)	Catenary Energy In Consumption (kWh)	Catenary Energy In Regeneration (kWh)
Chennai Central to Egmore	124.2	5.7558	11.117	5.3615	11.021	15.448	4.4265
Egmore to Neru Park	93	7.0201	10.568	3.5479	11.524	14.414	2.8904
Neru Park to Kmc	72	3.9063	8.0297	4.1233	7.5375	10.762	3.2246
Kmc to Pachaippa College	85.6	6.2915	9.9897	3.6982	10.543	13.412	2.8688
Pachaippa College to Shenoy Nagar	112.6	4.5862	7.8976	3.3114	8.8994	11.179	2.2793
Shenoy Nagar to Anna Nagar East	99.8	3.4259	7.3261	3.9002	7.5222	10.328	2.8055
Anna Nagar East to Anna Nagar Tower	91.4	5.1571	9.6767	4.5197	9.5964	12.978	3.3819
Anna Nagar Tower to Tirumangalam	71.6	4.043	7.9496	3.9066	7.6313	10.645	3.0136
Tirumangalam to Koyembedu	175.2	28.3	35.668	7.3677	39.167	45.287	6.1199
Koyembedu to CMBT	128	9.5418	17.382	7.8405	16.285	22.805	6.5198
CMBT to Arubakkam	113.6	3.9155	6.6263	2.7108	8.1403	10.254	2.1134
Arubakkam to Vadapalani	102.8	8.2196	10.613	2.3934	12.762	14.527	1.765
Vadapalani to Ashok Nagar - kk Nagar	134.8	2.8633	9.8162	6.9529	8.474	13.811	5.3369
Ashok Nagar - kk Nagar to Sidco	170.6	9.2335	14.335	5.1017	16.215	20.168	3.9525
Sidco to Alandur	111.6	14.837	17.228	2.3908	20.515	22.428	1.9135
Alandur to St. Thomas Mount	123	2.5277	7.5175	4.9898	7.2082	11.148	3.9394
St. Thomas Mount to Alandur	124.2	10.129	21.029	10.9	17.728	26.664	8.9354
Alandur to Sidco	108.8	-3.7455	8.4716	12.217	1.3387	11.05	9.7112
Sidco to Ashok Nagar - kk Nagar	173.4	8.3994	10.787	2.3877	14.621	16.532	1.9104
Ashok Nagar - kk Nagar to Vadapalani	133.4	10.244	14.263	4.0189	16.225	19.519	3.2939
Vadapalani to Arubakkam	100.6	1.1433	8.3084	7.1651	5.5999	11.055	5.4547
Arubakkam to CMBT	115.2	6.0696	8.0681	1.9984	10.382	11.969	1.5871
CMBT to Koyembedu	130	3.8823	6.2505	2.3682	8.3743	10.269	1.8945
Koyembedu to Tirumangalam	173.8	-10.026	4.7488	14.775	-3.9305	7.5284	11.459
Tirumangalam to Anna Nagar Tower	71.6	2.863	7.5367	4.6737	6.4345	10.008	3.5736
Anna Nagar Tower to Anna Nagar East	91	3.9575	9.5546	5.5971	8.4306	12.708	4.2772
Anna Nagar East to Shenoy Nagar	100.2	5.8869	8.7293	2.8423	10.137	12.317	2.1808
Shenoy Nagar to Pachaippa College	110.8	5.0581	7.4868	2.4287	9.3323	11.253	1.9208
Pachaippa College to Kmc	85.2	2.8196	8.9554	6.1358	7.0558	11.802	4.7464
Kmc to Neru Park	72.2	3.3331	7.5377	4.2047	6.8904	10.033	3.1426
Neru Park to Egmore	92.2	3.3194	9.6953	6.3759	7.8796	12.826	4.9465
Egmore to Chennai Central	123.2	7.8146	15.578	7.7631	14.155	20.483	6.3284
-----							
Stops Data	900						
Totals	4515.6	180.77	348.74	167.97	344.37	476.28	131.91

Table 2 – Inter-station running time for Corridor 2 normal mode

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## 7.2.3 K03: Degraded mode 75%– COR1

(AW4 – T=22.5kV/B=25kV – Regenerative braking – 34km/h comm. speed by coasting)

Degraded Mode – one inverter (2 traction motors) out of service –

⇒ running on Corridor 1 in ETC coasting mode<sup>3</sup>

⇒  $V_{MAX} = 80\text{km/h}$ .

- AW4 load; Traction at 22.5kV<sub>AC</sub>; Reg.Braking at 25kV<sub>AC</sub>

It was applied a 20.6% of coasting, with AW4 load and nominal voltages.

In this condition the request of paragraph §5.2 item 2.14.2.5 is respected.

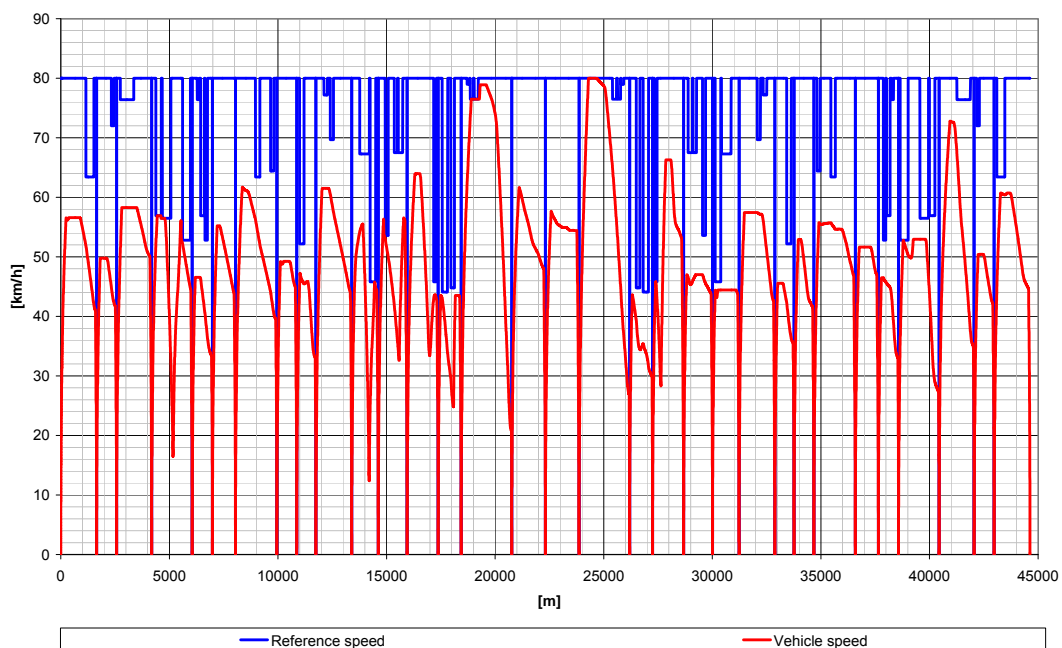


Figure 27 – “Speed” [km/h] vs. Distance [m]

$$\text{Commercial Speed: } \frac{\text{distance[m]}}{\text{time[s]}} * 3.6 = \frac{44628}{4719.4} * 3.6 = 34\text{km/h}$$

<sup>3</sup> “Extended Time Running by Coasting” consists to use coasting running on the cycle in order to obtain an extra time for each station spacing. This extra time is given by the user as a percentage of the time obtained with the all-out running.

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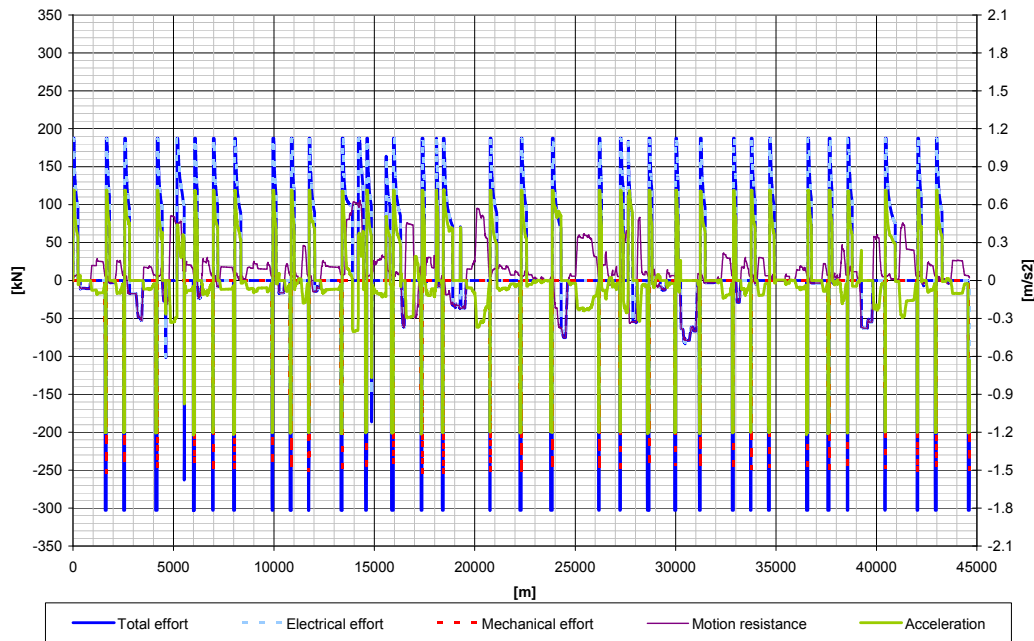


Figure 28 – “Acceleration” [m/s²] and “Effort” [kN] vs. Distance [m]

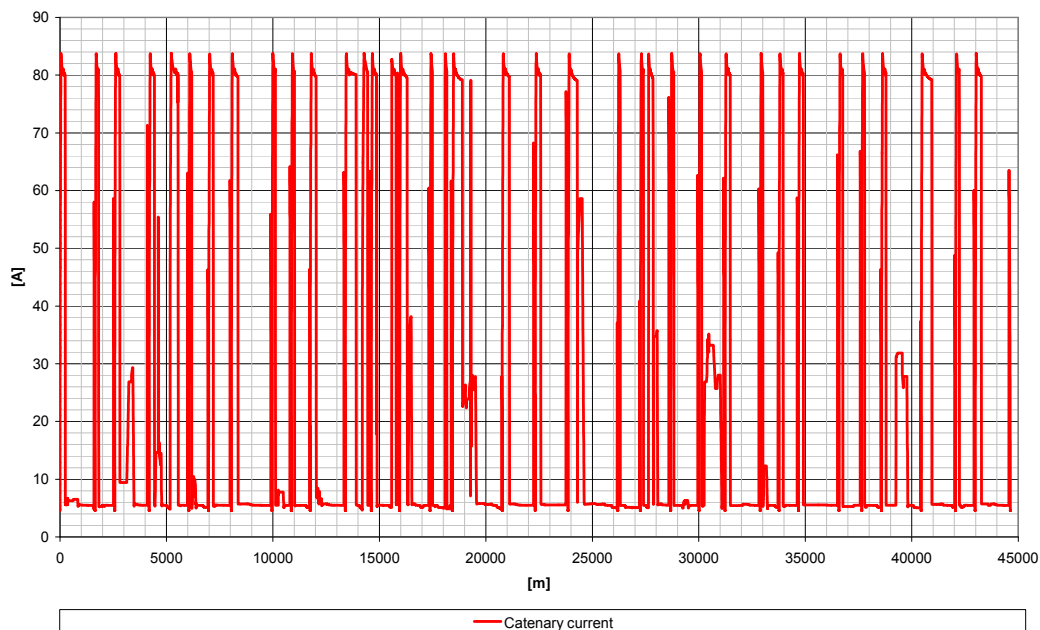


Figure 29 – “Rms Catenary Current” [A] vs. Distance [m]

	Energy (*)			
	Absorbed [kWh]	Regenerated [kWh]	Total (Abs - Reg) [kWh]	Total / km [kWh/km]
TR / ED BK	440.4	107.7	332.75	7.46

It is assumed that during coasting mode the traction motor torque is null but the inverter is kept on (to take into account the normal operation way in ATO mode).

(\*): Auxiliary consumption Excluded.

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## Simulation report

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Date: 04/08/2011

CITHEL Kinematical Calculation [CTL-CI2-2011-7-29-16-12]							
Calculation Case							
CITHEL Version	V3.02.00				Speed calculation step	2.(km/h)	
Project Name	CHENNAI CITHEL 4.00.00				Handle calculation step	5.(%)	
Calculation Case Name	CHN 4C6M NEW AW4 COR1-AR ELB+PNB ETC-STD 16%BR				Time calculation step	0.2(s)	
Calculation ID	CTL-CI2-2011-7-29-16-12						
Date	2011 July 29,16h12m29s						
Energy Balance							
Interstation Name	Run Time (s)	Wheel Total Energy (kWh)	Wheel Traction Energy (kWh)	Wheel Electrical Braking Energy (kWh)	Catenary Total Energy (kWh)	Catenary Energy in Consumption (kWh)	Catenary Energy in Regeneration (kWh)
Washemanpet to Mannadi	131.8	5.5526	9.2031	3.6506	9.7998	12.411	2.611
Mannadi to High Court	86.4	4.4557	6.9187	2.463	7.577	9.4689	1.8919
High Court to Chennai Central	123.4	0.15609	9.0029	8.8468	4.7545	11.89	7.1353
Chennai Central to Govt. Estate	166.2	17.497	23.16	5.6622	24.933	29.496	4.5624
Govt. Estate to Lic	96.2	3.6801	6.1365	2.4565	6.7103	8.5489	1.8386
Lic to Thousand Lights	93.6	5.6919	8.4336	2.7418	9.1862	11.353	2.1664
Thousand Lights to Gemini (new)	150	8.8641	10.937	2.0732	13.689	15.36	1.671
Gemini (new) to Teynampet	85	3.0921	6.9176	3.8255	6.2749	9.2243	2.9494
Teynampet to Chamiers Road	90.4	4.9784	6.4278	1.4494	7.9287	9.0775	1.1487
Chamiers Road to saidapet	128	6.5742	10.018	3.4437	10.972	13.602	2.6307
saidapet to Little Mount	127.2	25.55	28.182	2.6312	32.974	35.118	2.1438
Little Mount to Guindy	120.4	10.954	15.999	5.045	16.36	20.55	4.1899
Guindy to Alandur	122.4	7.3938	12.08	4.6866	12.034	15.918	3.8843
Alandur to Ota	118.2	6.0422	8.9011	2.8589	9.9699	12.157	2.1874
Ota to Meenambakkam	161.4	8.222	14.437	6.2148	13.757	18.931	5.1746
Meenambakkam to Chennai Airport	122	8.5616	11.649	3.0873	13.124	15.657	2.5327
Chennai Airport to Meenambakkam	119.2	5.7448	9.7267	3.9819	10.033	13.325	3.2925
Meenambakkam to Ota	161.4	6.6164	12.997	6.3801	12.121	17.565	5.444
Ota to Alandur	120.2	4.26	5.4472	1.1872	7.3147	8.2462	0.93148
Alandur to Guindy	118.6	6.6991	13.467	6.7682	11.777	17.457	5.6802
Guindy to Little Mount	120	2.8614	6.2895	3.4281	6.5185	9.052	2.5335
Little Mount to saidapet	114.6	-12.654	5.6369	18.291	-7.8393	7.4171	15.256
saidapet to Chamiers Road	129	6.4073	9.2322	2.8249	10.695	12.639	1.9442
Chamiers Road to Teynampet	90.6	2.6893	5.8196	3.1303	5.6679	8.0842	2.4164
Teynampet to Gemini (new)	86.2	5.4791	7.8344	2.3553	8.7302	10.573	1.8428
Gemini (new) to Thousand Lights	145.6	5.9214	8.867	2.9456	10.412	12.824	2.4122
Thousand Lights to Lic	93	3.9017	7.311	3.4093	7.2654	9.6682	2.4028
Lic to Govt. Estate	94.8	4.6284	6.137	1.5086	7.6062	8.7572	1.151
Govt. Estate to Chennai Central	165.2	-1.4839	8.3462	9.8301	3.5477	11.818	8.2708
Chennai Central to High Court	124.2	13.509	15.122	1.613	18.349	19.634	1.2848
High Court to Mannadi	86	4.7812	7.3137	2.5325	7.9634	9.8922	1.9287
Mannadi to Washemanpet	128.2	7.588	10.361	2.7732	12.039	14.193	2.1535

Stops Data	900						
Totals	4719.4	194.22	328.31	134.1	332.75	440.41	107.66

Table 3 – Inter-station running time for Corridor 1 degraded mode

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## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

## 7.2.4 K04: Degraded mode 75%– COR2

(AW4 – T=22.5kV/B=25kV – Regenerative braking – 34km/h comm. speed by coasting)

Degraded Mode – one inverter (2 traction motors) out of service –

⇒ running on Corridor 2 in ETC coasting mode<sup>4</sup>

⇒  $V_{MAX} = 80\text{km/h}$ .

- AW4 load; Traction at 22.5kV<sub>AC</sub>; Reg.Braking at 25kV<sub>AC</sub>

It was applied a 13.45% of coasting, with AW4 load and nominal voltages.  
In this condition the request of paragraph §5.2 item 2.14.2.5 is respected.

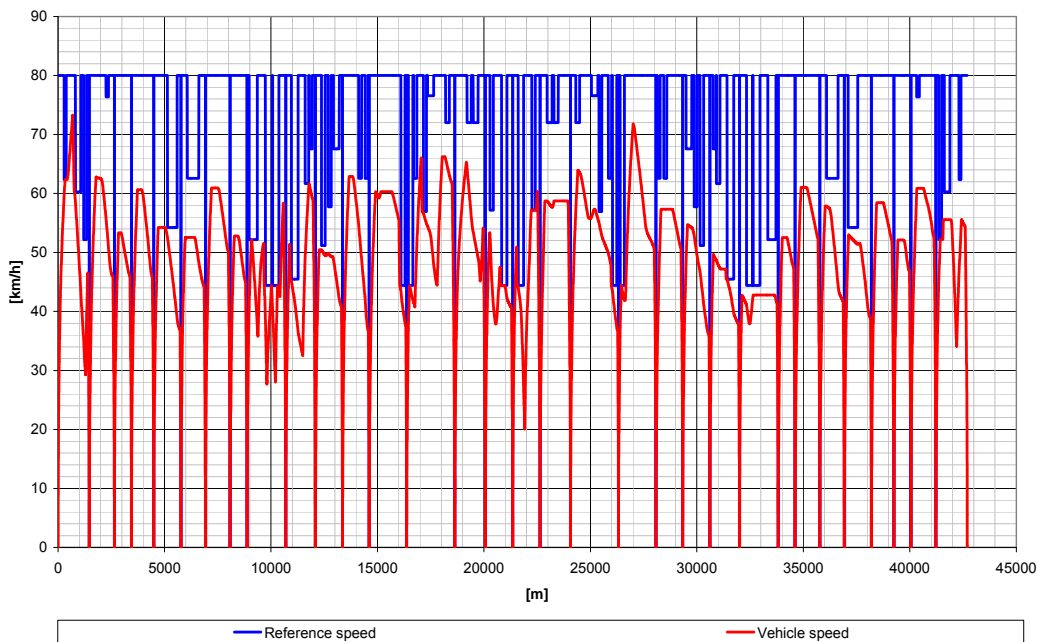


Figure 30 – “Speed” [km/h] vs. Distance [m]

$$\text{Commercial Speed: } \frac{\text{distance[m]}}{\text{time[s]}} * 3.6 = \frac{42696}{4514.6} * 3.6 = 34\text{km/h}$$

<sup>4</sup> “Extended Time Running by Coasting” consists to use coasting running on the cycle in order to obtain an extra time for each station spacing. This extra time is given by the user as a percentage of the time obtained with the all-out running.

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## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

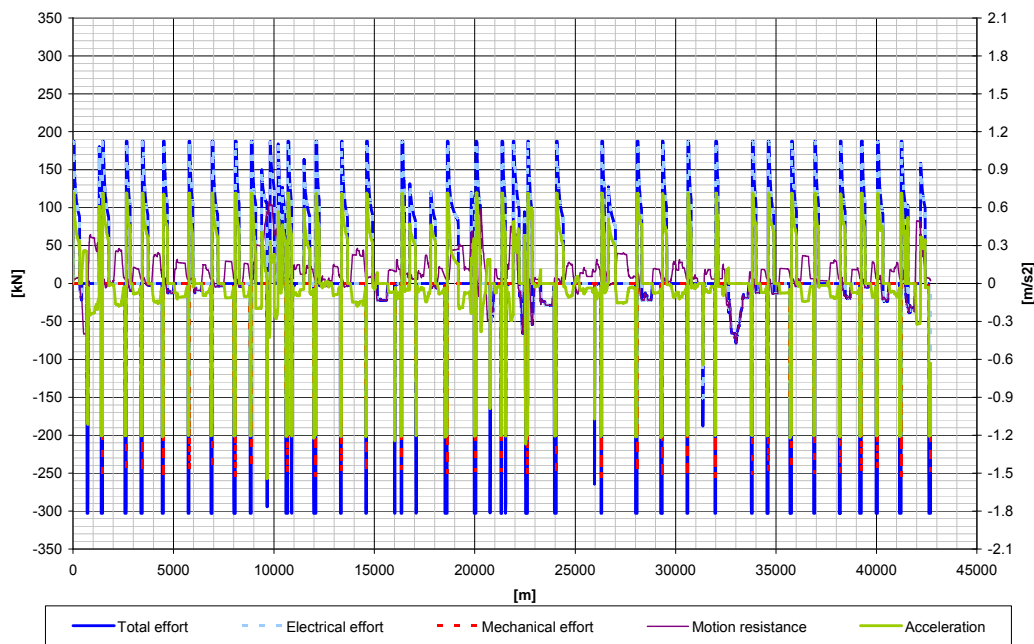


Figure 31 – “Acceleration” [m/s²] and “Effort” [kN] vs. Distance [m]

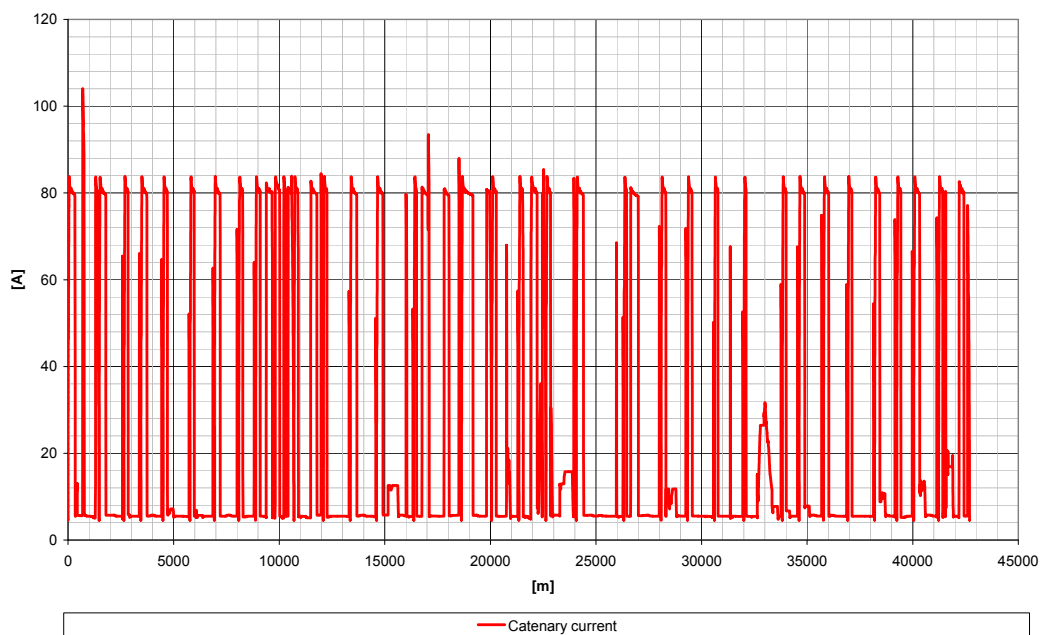


Figure 32 – “Rms Catenary Current” [A] vs. Distance [m]

	Energy (*)			
	Absorbed [kWh]	Regenerated [kWh]	Total (Abs - Reg) [kWh]	Total / km [kWh/km]
TR / ED BK	485.6	118.6	367.07	8.60

It is assumed that during coasting mode the traction motor torque is null but the inverter is kept on (to take into account the normal operation way in ATO mode).

(\*): Auxiliary consumption Excluded.

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## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

CITHEL Kinematical Calculation [CTL-CI2-2011-7-29-17-25]							
Calculation Case							
CITHEL Version	V3.02.00				Speed calculation step	2.(km/h)	
Project Name	CHENNAI CITHEL 4.00.00				Handle calculation step	5.(%)	
Calculation Case Name	CHN 4C6M NEW AW4 COR2-AR ELB+PNB ETC-STD 16%BR				Time calculation step	0.2(s)	
Calculation ID	CTL-CI2-2011-7-29-17-25						
Date	2011 July 29,17h25m17s						
Energy Balance							
Interstation Name	Run Time (s)	Wheel Total Energy (kWh)	Wheel Traction Energy (kWh)	Wheel Electrical Braking Energy (kWh)	Catenary Total Energy (kWh)	Catenary Energy In Consumption (kWh)	Catenary Energy In Regeneration (kWh)
Chennai Central to Egmore	122.2	9.0288	15.311	6.2823	14.486	19.655	5.1689
Egmore to Neru Park	94.8	8.1202	10.921	2.8009	12.058	14.344	2.2866
Neru Park to Kmc	74.8	4.7311	7.7963	3.0652	7.8494	10.287	2.4372
Kmc to Pachaippa College	87.8	7.3094	10.237	2.9277	11.035	13.327	2.2918
Pachaippa College to Shenoy Nagar	111.6	5.307	8.0661	2.7591	9.0083	11.031	2.023
Shenoy Nagar to Anna Nagar East	100	4.4467	7.9098	3.4631	8.0055	10.553	2.5472
Anna Nagar East to Anna Nagar Tower	92.4	6.4356	10.114	3.6788	10.317	13.106	2.7887
Anna Nagar Tower to Tirumangalam	74.4	4.8773	7.7494	2.8721	7.9571	10.156	2.1984
Tirumangalam to Koyembedu	169.2	29.656	35.131	5.4748	39.172	43.705	4.5334
Koyembedu to CMBT	128.2	10.935	16.58	5.6455	16.597	21.286	4.6884
CMBT to Arubakkam	112.4	4.8404	7.1529	2.3125	8.4256	10.24	1.8139
Arubakkam to Vadapalani	104.4	8.8699	10.788	1.9179	12.834	14.286	1.4522
Vadapalani to Ashok Nagar - kk Nagar	135.4	4.0649	10.641	6.5764	8.9778	14.211	5.2337
Ashok Nagar - kk Nagar to Sidco	168.6	13.093	20.294	7.2001	20.209	26.165	5.9559
Sidco to Alandur	113.6	17.52	21.408	3.8887	23.45	26.65	3.2001
Alandur to St. Thomas Mount	121.8	3.5957	8.2903	4.6947	7.7328	11.527	3.7939
St. Thomas Mount to Alandur	123.4	11.652	19.898	8.2459	18.132	24.957	6.8248
Alandur to Sidco	108.4	-1.9515	8.4001	10.352	2.4776	10.842	8.3646
Sidco to Ashok Nagar - kk Nagar	170.8	9.2963	11.711	2.4149	14.61	16.566	1.9555
Ashok Nagar - kk Nagar to Vadapalani	132.6	11.708	15.153	3.4449	16.958	19.795	2.8363
Vadapalani to Arubakkam	100.4	2.579	8.6975	6.1184	6.4927	11.294	4.8015
Arubakkam to CMBT	114.2	6.8323	8.5414	1.7091	10.567	11.933	1.3655
CMBT to Koyembedu	128.2	4.649	6.9681	2.3191	8.4898	10.362	1.8726
Koyembedu to Tirumangalam	170.6	-9.0713	5.1833	14.255	-3.8621	7.6011	11.463
Tirumangalam to Anna Nagar Tower	73.8	3.888	7.4937	3.6057	6.9706	9.7895	2.8189
Anna Nagar Tower to Anna Nagar East	92.2	5.351	9.8769	4.5259	9.2525	12.835	3.5821
Anna Nagar East to Shenoy Nagar	100	6.9013	9.2783	2.377	10.631	12.512	1.8806
Shenoy Nagar to Pachaippa College	111.6	5.8722	7.861	1.9888	9.5144	11.114	1.5993
Pachaippa College to Kmc	86.6	4.1573	9.0997	4.9424	7.864	11.781	3.9173
Kmc to Neru Park	74.6	4.3538	7.5742	3.2204	7.4427	9.8452	2.4025
Neru Park to Egmore	93.2	4.8257	10.008	5.1826	8.8037	12.961	4.1578
Egmore to Chennai Central	122.4	8.5118	16.229	7.7169	14.102	20.41	6.3075
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Stops Data	900						
Totals	4514.6	222.39	370.36	147.98	367.07	485.63	118.56

Table 4 – Inter-station running time for Corridor 2 degraded mode

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## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

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**Section 8 – Conclusions**

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**Normal mode:**

- Acceleration target on flat track and AW4 ( $0.82\text{m/s}^2$ ) met: reached  $0.84\text{m/s}^2$ .
- Deceleration target on flat track and AW4 ( $1.00\text{m/s}^2$ ) met: reached  $1.05\text{ ms}^2$ .
- A Commercial speed of 34km/h is possible in both Corridor 1 and 2.

**Degraded mode:**

- A Commercial speed of 34km/h is possible even in degraded mode in both Corridor 1 and 2.

**Rescue mode:**

- An AW4 train with all motors in service can push or pull another AW4 train with all motors out of service and brake released on a slope of 3.5%.
- An AW0 train with all motors in service can push or pull another AW0 train with all motors out of service and brake released on a slope of 4%.
- In case of four motors lost on eight motors the passengers must get off and the metro must go to depot in empty state.

Mechanical brake performance must be confirmed by the brake system supplier.

Traction equipment thermal performance will be demonstrated in specific documentation.

## Simulation report

Ref: AYD0000064518

2865DT

Version: C

Date: 04/08/2011

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**A – Definitions and References**

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**A-1 Definitions & Abbreviations****A-2 Reference Documents****REF DOC 1:**

GCC-400-000-090059-B Contract Are-01 Tender documents- Volume 3-Technical specification Rev. CO  
date /08/09/2010

## Simulation report

Ref:AYD0000064518

2865DT

Version: C

Date: 04/08/2011

**B – Control Sheet**

Ver	Date	Revision description	Author
A	Feb/04/2011	First issue.	B.Pregara
B	May/15/2011	§1: used edition of Cithel v.3.02.00. §3: updated relative humidity according contract. §4.1.1: Track data (line extension to Airport) updated and modified stop time at terminals; introduced speed limitation in curve dependig on curve radius. §4.1.2: Track data updated and modified stop time at terminals; introduced speed limitation in curve dependig on curve radius. §4.1.4: updated train masses. §4.1.5: simulations done at new wheels. §4.3: return time =0. §6.1: updated Traction/Braking Characteristics (Figure 9, 10, 11, 13) according increase of weight and performances with new wheels. §6.1.2: values re-calculated with new masses and clarification on meaning of variables §7.2 performance simulations re-done with new track data; all Figures modified. §7.2.2 added Figure 26. §8: updated conclusions.- RM81789	L.Bianchi
C	Aug/02/2011	§4.1.1 and §4.1.2 Added numerical data in EXCEL format. §4.1.4 Updated static mass table header and masses values. §4.3 Updated adhesion coefficients. Updated inverter status during coasting mode. §6.1.1 and §6.1.2 Updated diagrams and tables. §6.1.3 and §6.1.4 Updated Degraded mode in Rescue mode. Updated diagrams. §6.1.5 Updated diagrams. §7.1 Updated calculation time step and total stop time formula. §7.2.1, §7.2.2, §7.2.3 and §7.2.4 Updated results.(inverter kept on in coasting) §8 Updated conclusions. RM81891	D.Colombo

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