

# SIMINE<sup>CIS</sup> TR Trolley Assist



## Contents

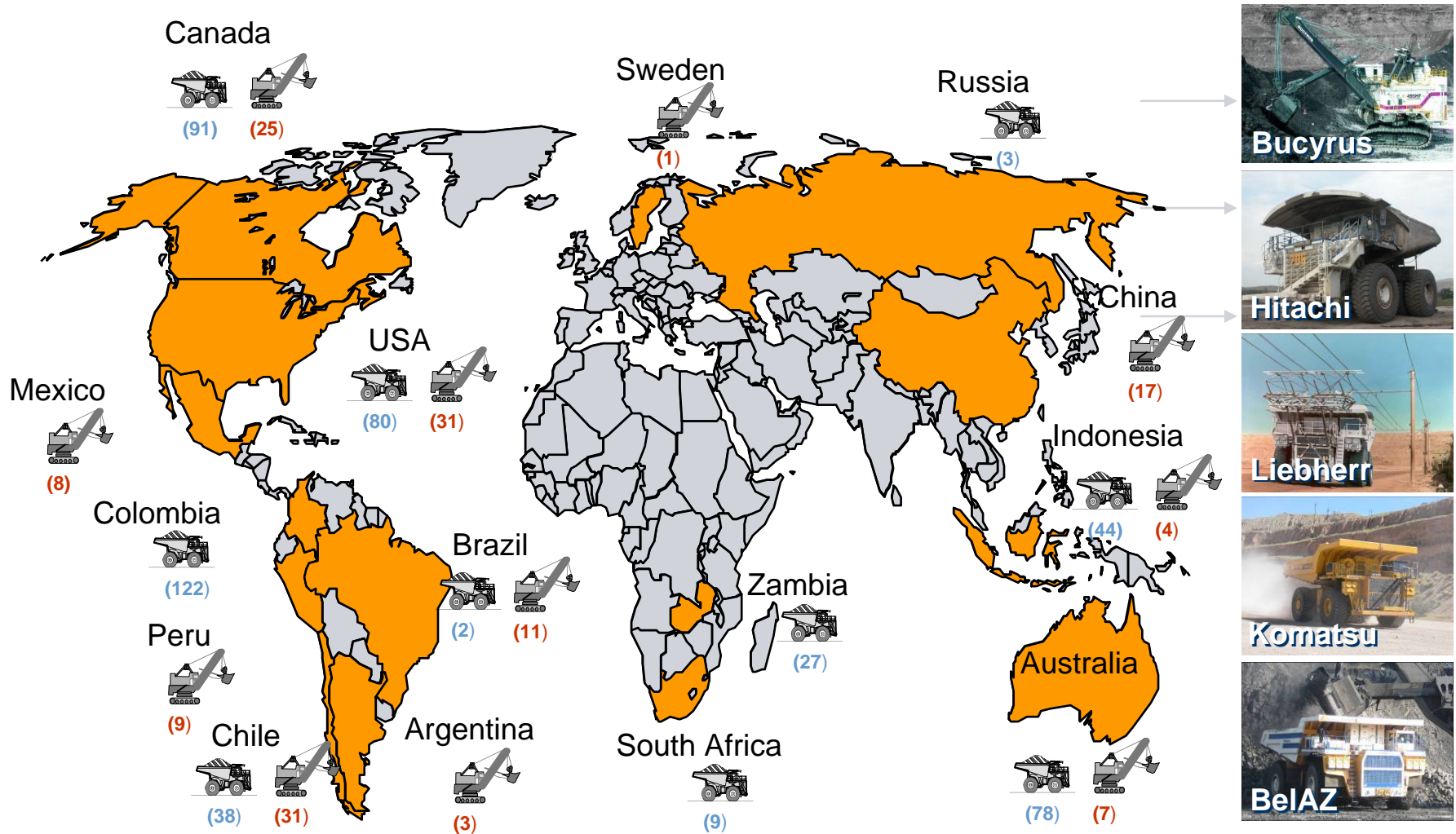
- History of Siemens dump trucks and trolley systems
- Truck IGBT system
- Trolley system
- Power supply
- Benefits of trolley vs. pure diesel electric
- Duty cycle calculation
- Benefits calculation
- Summary

## History of Siemens Dump Trucks and Trolley Systems

- Werner von Siemens built the first electric train in 1879 and the first trolley bus in 1882.
- Starting in 1991 Siemens pioneered AC technology on locomotives in North America and equipped more than 1500 heavy freight locomotives in North America alone
- Derived from the locomotive drives, the AC haul truck drive was developed and presented at MinExpo 1996
- Tens of thousands of commutator traction motors and more than 40,000 AC traction motors, hundreds of truck equipments and several truck trolley installations have been built by Siemens

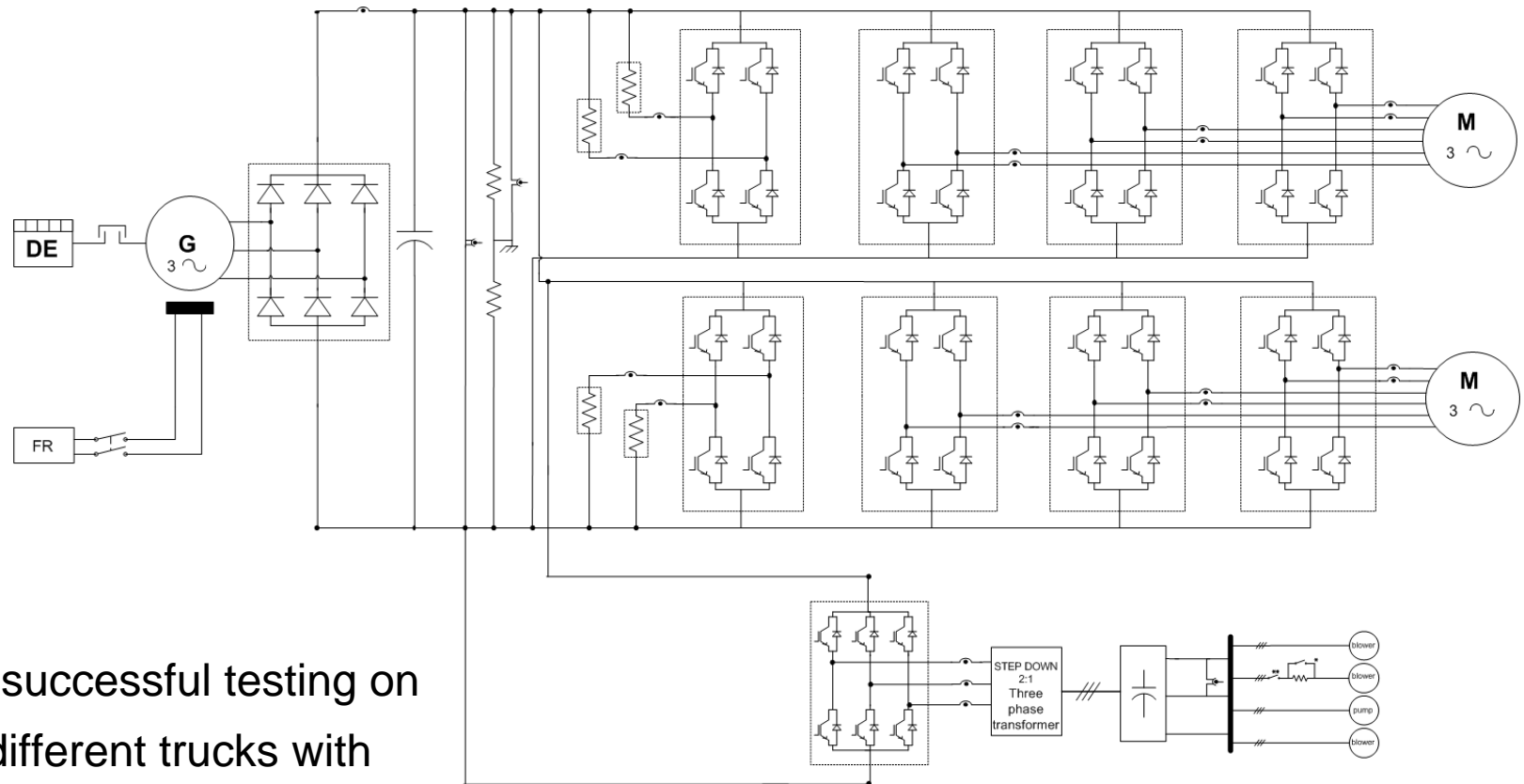


## Siemens Truck (540) and Excavator (140) Population



Issue: 3/2009

## Siemens IGBT Drive System

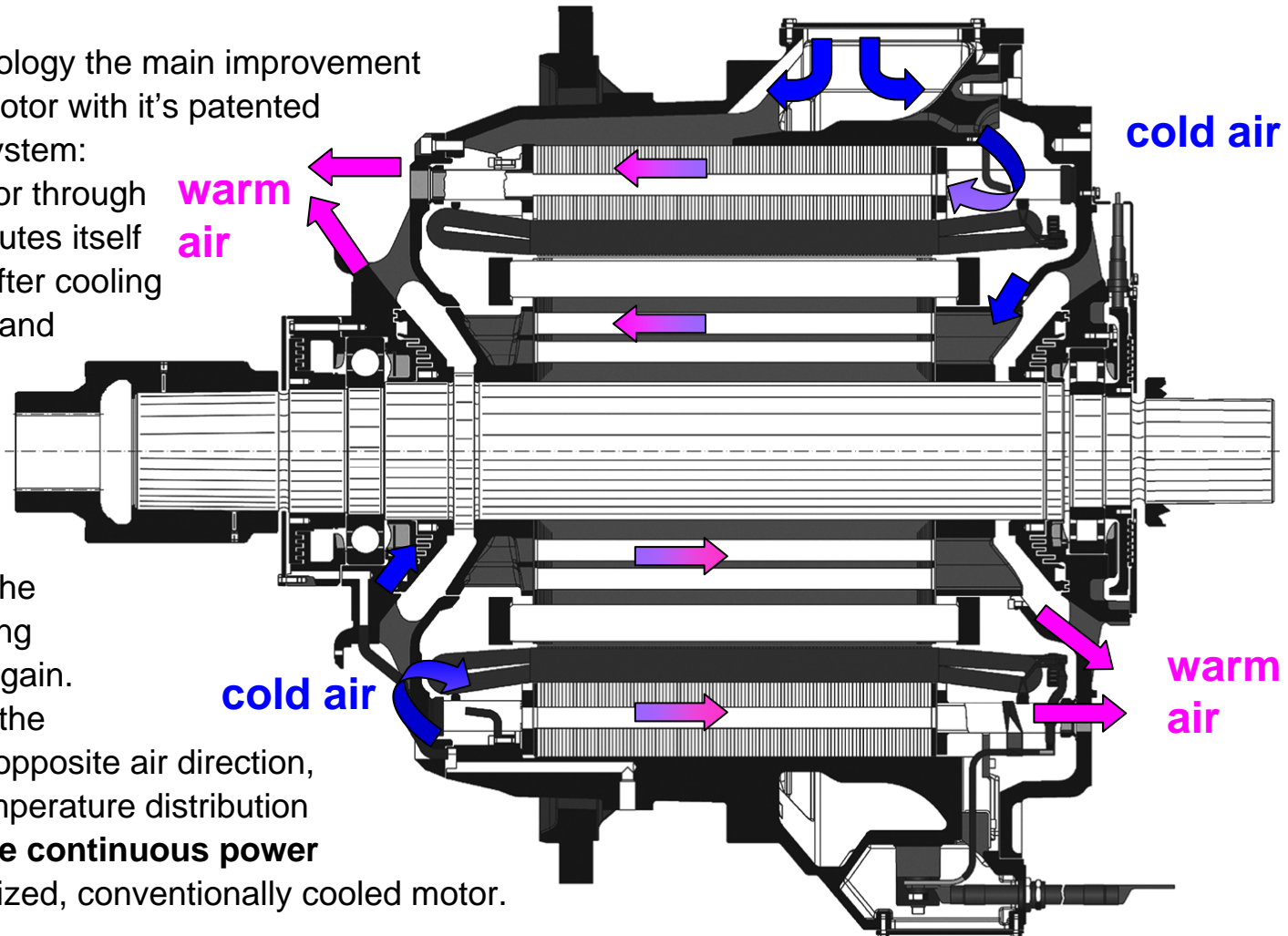


After successful testing on  
four different trucks with  
two truck manufacturers

Siemens' IGBT truck drive system was released for series production in 2009.

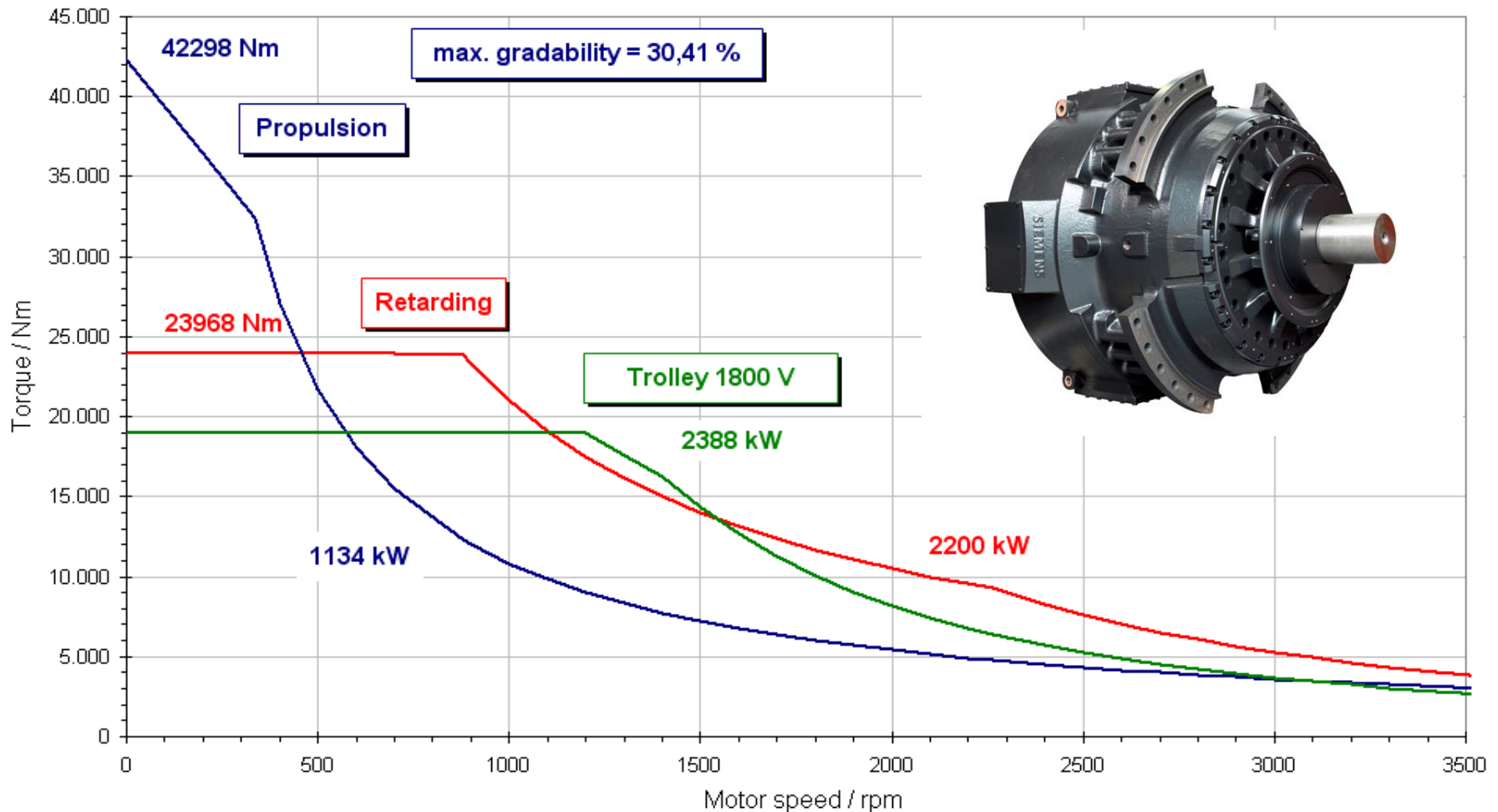
## Siemens Truck Wheel Motor

Next to the IGBT technology the main improvement is the stronger wheel motor with its patented double-sided cooling system: Cold air enters the motor through an inlet duct and distributes itself 50 : 50 to both sides. After cooling the winding overhangs and the short-circuit rings the air runs through holes in the stator and rotor lamination and exits the motor through pipes and channels at the other side without striking the winding overhang again. Every other hole along the circumference has the opposite air direction, resulting in an even temperature distribution and allowing **50 % more continuous power** compared to a same- sized, conventionally cooled motor.



## Torque – Speed Characteristics of Truck Motor 1TB3030

1TB3030-xGA03



## Siemens Trolley System

### MAIN COMPONENTS:

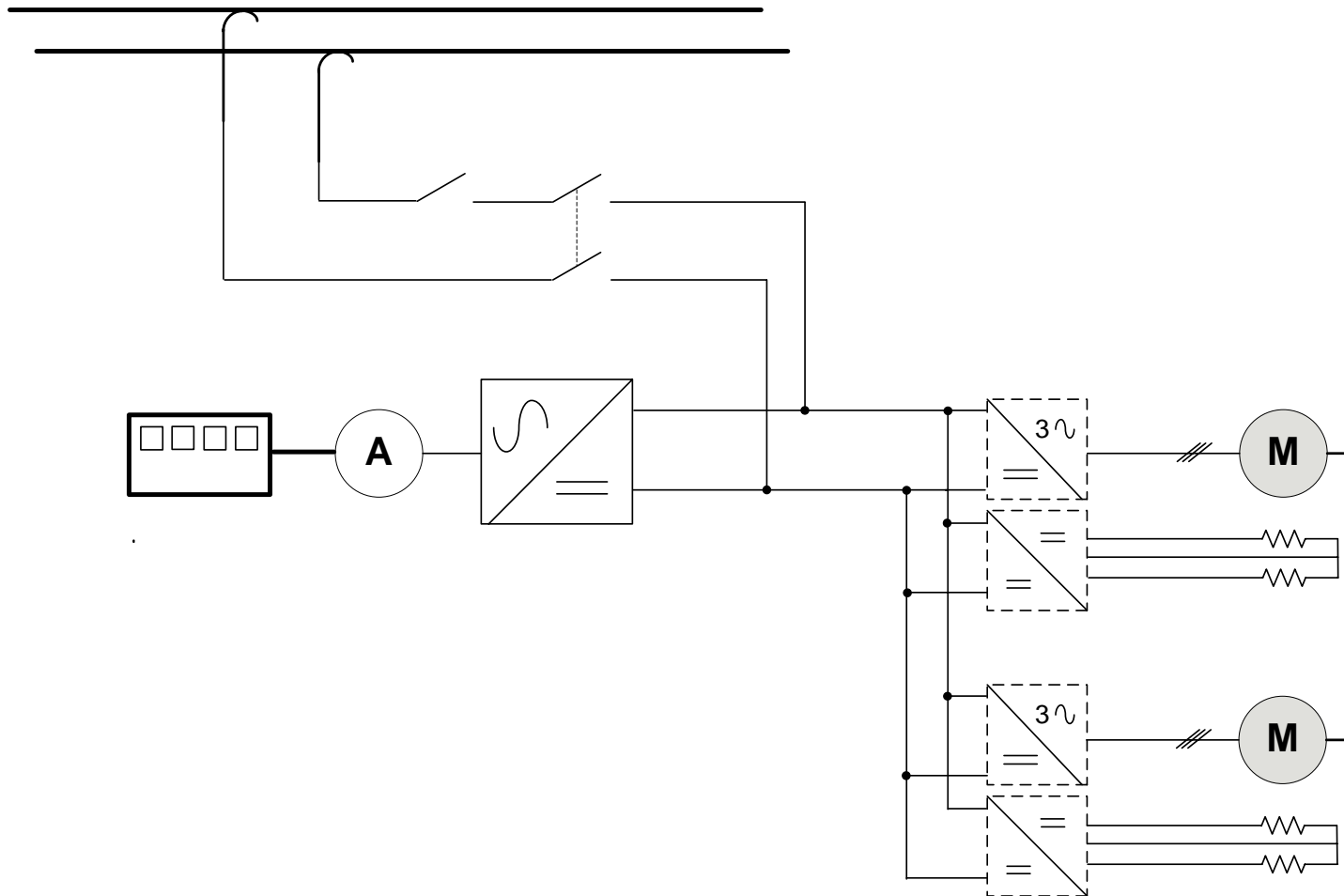
- Substation modules
- Catenary system
- Truck equipment
  - Pantographs
  - Switchgear
  - Position sensor
  - Software

### PLUS:

- Erection
- Commissioning
- Profitability studies
- Truck conversion / Truck equipment deliveries (GTO and IGBT)
- Relocations (optionally)
- Maintenance (optionally)
- Turn-key system (optionally)

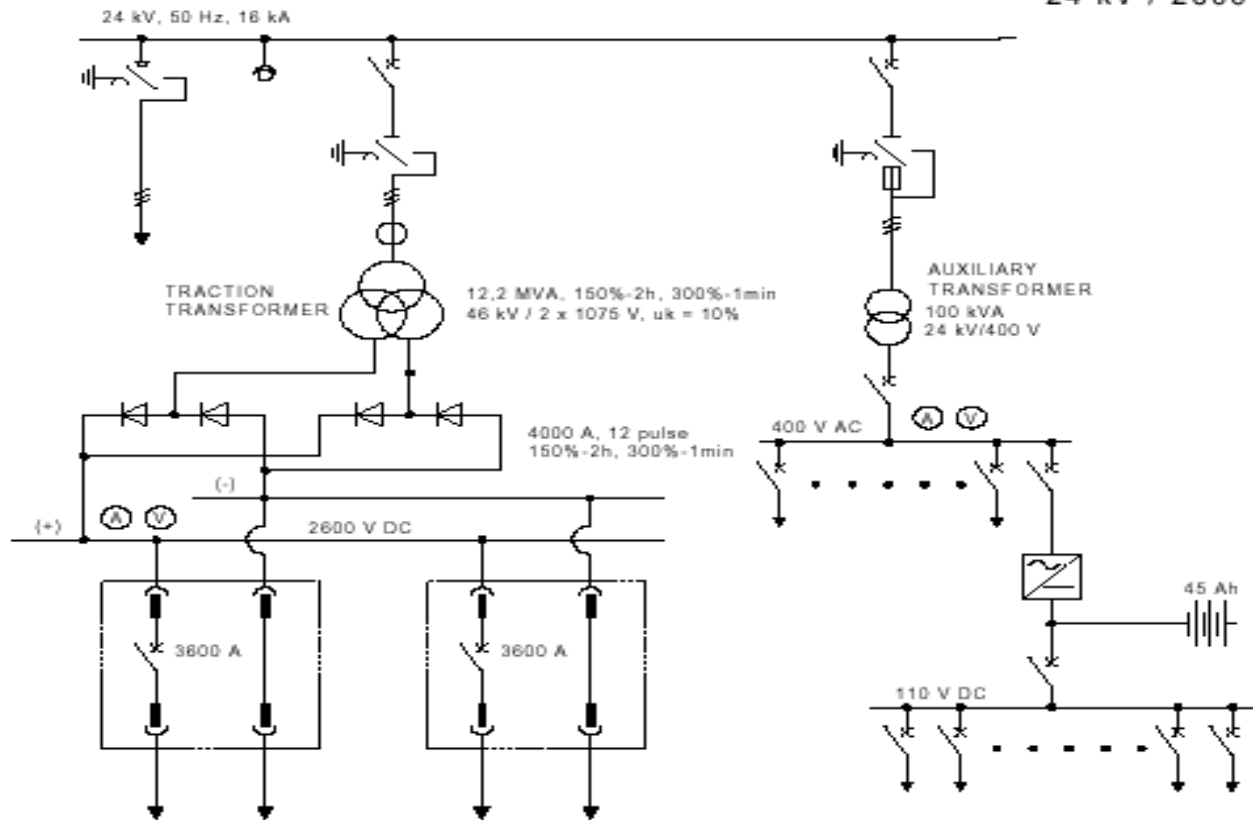


## Siemens Trolley System

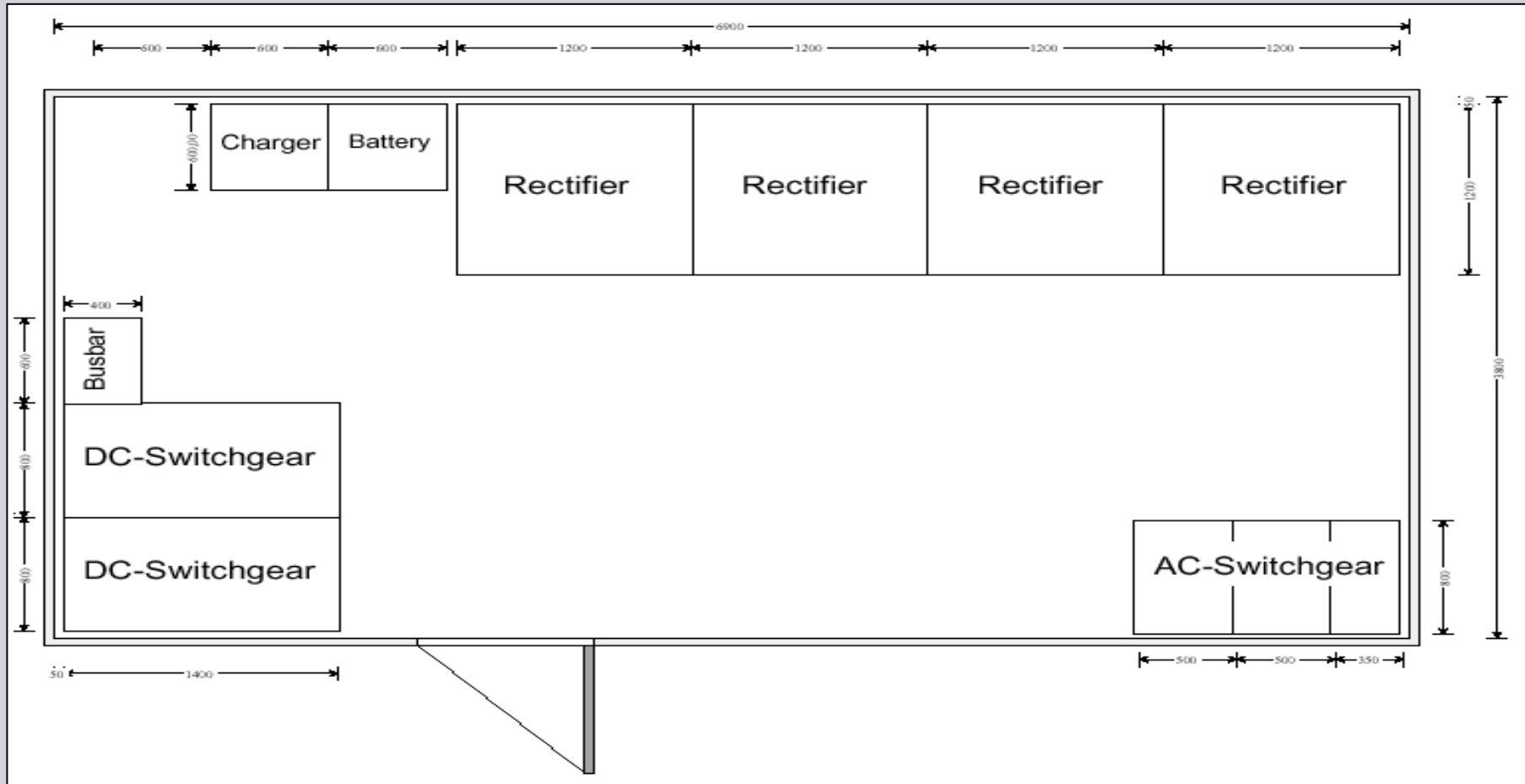


## Pre-Engineered Modular Substation

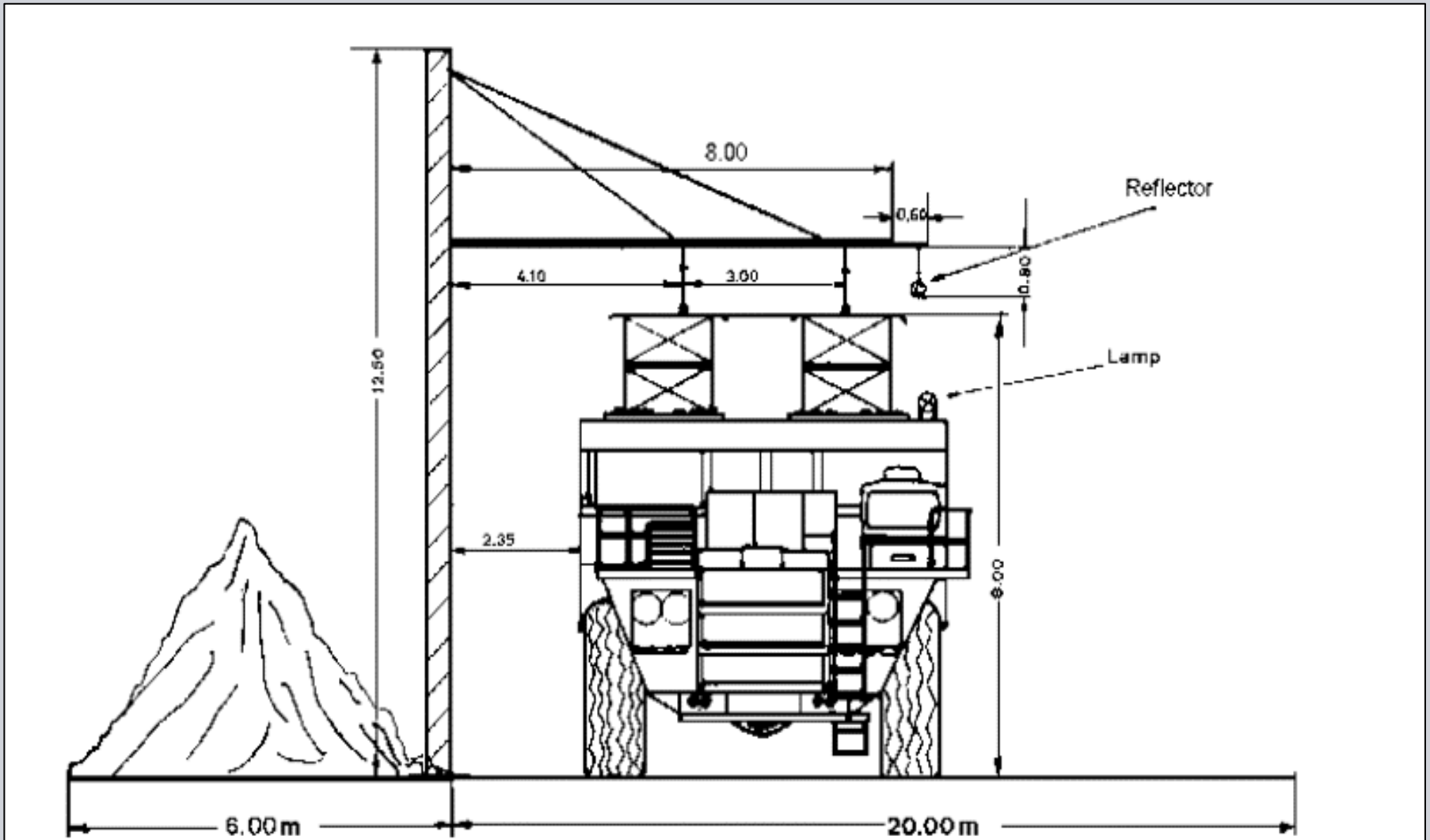
### TRUCK TROLLEY SYSTEM Substation / Subestacion / Unterwerk 24 kV / 2600 V DC / 10,4 MW



## Substation Container



## Flexible Catenary Design



## Pantograph with Integrated Line Position Sensor

- Pantographs have been designed and built for mining duty:
  - large extension range
  - able to withstand rolling and bouncing motions
  - optimized for hauler operating speeds
  - current ratings up to 2500 A ( \* 1800 V = 4500 kW power / IGBT truck)  
( \* 2600 V = 6500 kW power / GTO truck)
- Position sensor with dash-mounted display allows operator to easily monitor the pantograph position on the line while continuously watching the road.
- Position sensor can be incorporated into vehicle guidance system to assist operator or for autonomous operation.
- Transition from diesel to trolley operation and back occurs quickly under full diesel power with no coasting, no jerk and with automatic connection.

## Trolley System Design

- The overall trolley system design criteria includes
  - Truck characteristics
  - Gradients
  - Spacing between truck
  - Speed of truck
  - Ambient conditions (derating)
  - Total line length
  - Number of segments

## Catenary System

- The substations have to be designed according to
  - Truck system voltage
  - Load cycle
  - Conductor/ line limitations
  
- The catenary system with 2 x RiS 150mm<sup>2</sup> contact wires and 2 x 150mm<sup>2</sup> hard drawn Copper Wires are suitable for
  - Current Carrying Capacity of Trolley Line (New) : 2805 A
  - Current Carrying Capacity of Trolley Line (wear -10%) : 2522 A
  - Current Carrying Capacity of Trolley Line (wear -20%) : 2239 A

## Trolley System – References

### Siemens Trolley Systems:

Mine	Route Length	Substation Rating	Number of Substations	Converted Trucks	Commissioning Year
Palabora, South Africa	8,0 km	5,0 MVA	7	80	1981
Rössing, Namibia	8,5 km	3,0 MVA	5	30	1986
Gecamines, Congo	3,5 km	2,4 MVA	4	22	1986
Barrick Gold, USA	5,5 km	6,5 MVA	7	11	1994

### Trolley Trucks with Siemens Drives:

Mine	Technology	Trucks	Commissioning Year
Grootegeeluk Coal, South Africa	GTO	4	2001
Sishen Iron, South Africa	IGBT	2	2008
Lumwana Copper, Zambia	GTO	27	2009

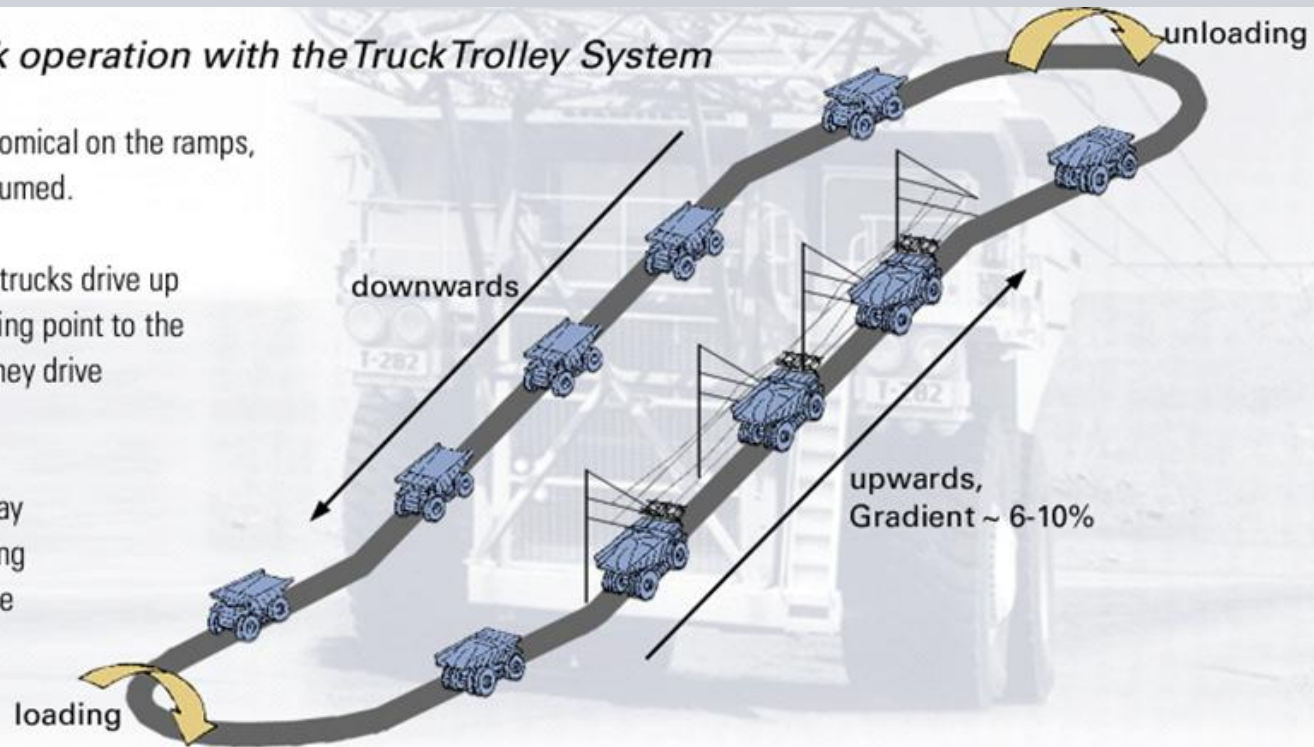
## Advantages of Trolley Operation vs. Pure Trolley

### *Simplified example of truck operation with the Truck Trolley System*

The Truck Trolley System is mostly economical on the ramps, where most of the total energy is consumed.

The drawing shows the best case, the trucks drive up the ramp a high gradient from the loading point to the place where they get unloaded. Then they drive down empty the same gradient/ramp.

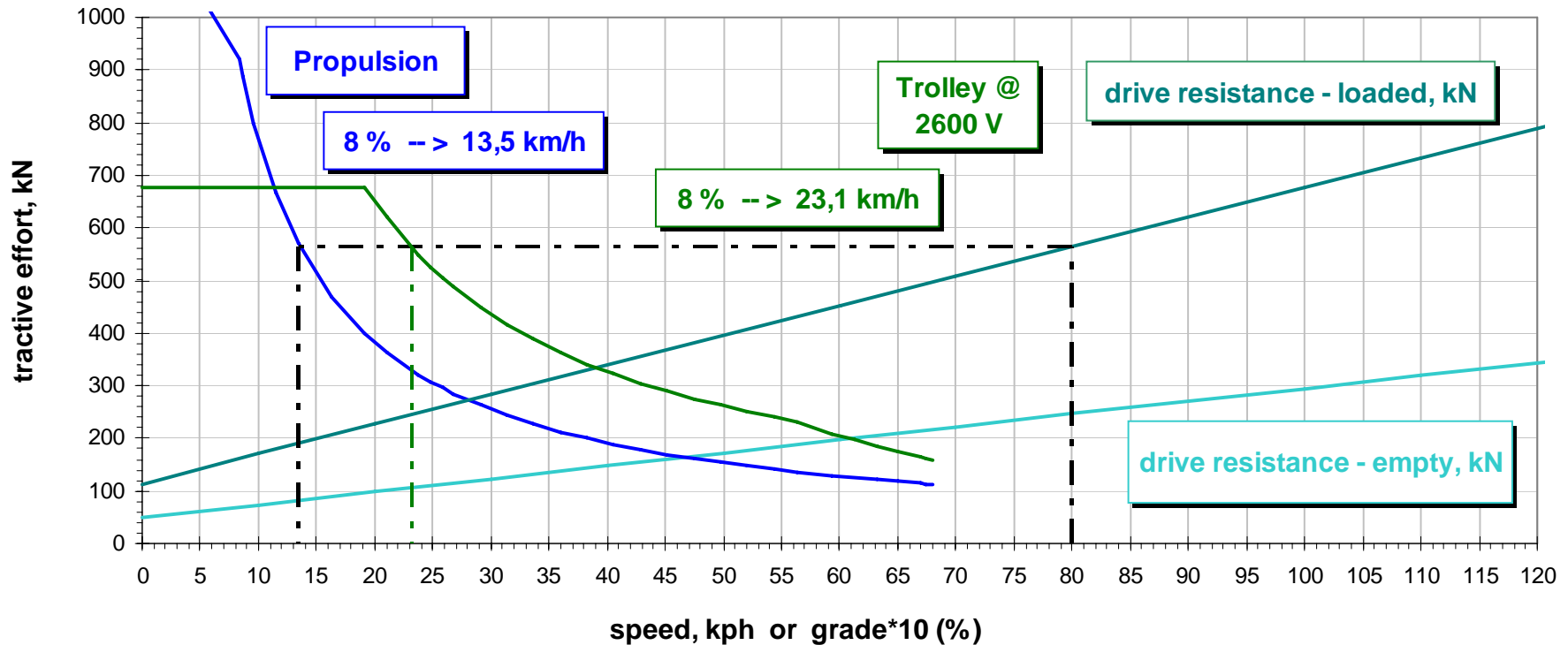
The catenary is installed only on the way up-hill. In the loading zone, the unloading zone and on the way down, the win due to the save of fuel or the increase of speed are superfluous.



- Faster uphill haul → shorter cycle time, higher productivity
- Fuel savings, electrical energy less expensive
- Longer engine life, lower maintenance costs

**More  
tons / \$**

## Trolley Assist – Faster Uphill Haul



- Truck speed increases because the trolley line can supply more power than existing diesel engines.
- Higher speed on trolley means shorter cycle time and higher production or fewer trucks for the same production.

**maximizes  
productivity**

## Trolley Assist – Savings

- Without trolley, 70-80% of fuel is consumed on grade.
- Trolley assist dramatically reduces engine power demand on grade (engine idles on direct trolley).
- Electrical energy produced in a conventional power plant is less expensive than diesel-electric energy.
- Engine overhaul intervals are proportional to the amount of fuel burned (typically 1 engine overhaul for every 2 million liter of fuel).

**reduces fuel costs  
and  
engine maintenance costs**

- Trolley assist reduces environmental impact (noise, exhaust fumes)

## Costs of Trolley System

- Substation costs depend on installed power and number of substations
  - two substations at the end points of the trolley line and one approximately every 800 m
  - approx. US\$ 600,000 / 4 MVA, 1800 V substation
  
- Trolley line
  - approx. US\$ 1.2 Million / km
  
- Trolley Equipment for Truck / new or conversion
  - approx. US\$ 300,000 / Truck
  
- **Additional costs for Trolley system minus savings result in a typical payback time of 2-5 years !**

## Relocation of Roadside Equipments

- Relocation costs
  - easy to move substation container with switchgear, transformer and rectifier
  - flexible catenary design for easier moves
  - depend on local staff costs and condition of material to be reused

## Economic Analysis with Trolley Calculator

- Provides an easy-to-understand, fundamental feasibility analysis.
- Inputs are mine-specific system parameters such as
  - cycle length,
  - grade,
  - production requirements,
  - prices of diesel fuel and electricity etc.
- Outputs are
  - investment costs
  - energy costs
  - maintenance costs
  - production values
  - payback time

## Duty Cycle Calculation (GTO Truck)



# Economic Analysis with Trolley Calculator

## ECONOMIC FEASIBILITY FOR TROLLEY ASSIST

Proj. : Mine Sample

Date: October 14, 2008

INPUT

CALCULATION

Length of total round-trip loop	11200.00 m
Length of trolley ramp	3500.00 m
Actual speed of trucks on ramp - Diesel only	11.90 km/h
Actual speed of trucks on ramp - Trolley	18.97 km/h
Actual time of trucks on ramp - Diesel only	1058.82 s
Actual time of trucks on ramp - Trolley	664.21 s
Total time for round trip - Diesel only	2041.52 s
Total future time of round trip with trolley	1646.90 s
Average truck speed for total round trip - Diesel only	19.75 km/h
Average truck speed for total round trip - Trolley	24.48 km/h
Average speed increase with Trolley	23.96 %

Diesel consumption per truck loaded	630.00 l/h
Diesel consumption per truck empty	34.40 l/h
Electric energy use per truck on trolley	3900.00 kW
Diesel consumption per ramp without trolley	185.29 l
Diesel consumption per ramp with trolley	6.35 l
Diesel savings per ramp with trolley	178.95 l
Electric energy use per truck per ramp with trolley	757.43 kWh

Cost of Diesel fuel per liter	1.00 US\$/l
Cost of electrical energy per kWh	0.042 US\$/kWh
Actual Diesel cost per ramp driven	185.29 US\$
Future Diesel costs per ramp driven	6.35 US\$
Electric energy costs per ramp driven	31.81 US\$
Total diesel/electricity cost per ramp driven	38.16 US\$
<b>Savings per ramp using trolley</b>	<b>147.14 US\$</b>

### Hours of Operation

Hours of operation per day	20.00 h
Days of operation per year	365.00 days/year
Total number of trucks used now	20.00 trucks
Round trips per truck per day - Diesel only	35 round trips
Round trips all trucks per day - Diesel only	700 round trips
Round trips all trucks per year - Diesel only	255,500 round trips
<b>Fleet Diesel cost on ramp per year</b>	<b>47,342,647 US\$</b>

# AC Trolley Assist

## ECONOMIC FEASIBILITY FOR TROLLEY ASSIST

### Costs for Trolley

Scenario 1 : Same production with fewer trucks		Scenario 2:Incr. production w. same # of trucks	
Conversion costs per truck ( switchgear, pantogr.+struct)	300,000 US\$/truck	Conversion / truck ( switchgear, pantogr.+struct)	300,000 US\$/truck
Number of trucks to convert	17 trucks	Number of trucks to convert	20 trucks
<b>Total conversion costs for truck fleet</b>	<b>5,100,000 US\$</b>	<b>Total conversion costs for truck fleet</b>	<b>6,000,000 US\$</b>
Cost of overhead line per km incl. Installation	1,200,000 US\$/km	Cost of overhead line per km incl. Installation	1,200,000 US\$/km
Cost of rectifier substation ( 4 MVA, 1800V per 0.5 km)	625,000 US\$/km	Cost of rectifier substation ( 2,625V, 4,000 Amp)	625,000 US\$/km
Length of ramp	3,500 m	Length of ramp	3,500 m
Number of substations for ramp ( 1 / 500m)	7	Number of substations for ramp ( 1 / 900 m )	7
<b>Total cost roadside equipment</b>	<b>8,575,000 US\$</b>	<b>Total cost roadside equipment</b>	<b>8,575,000 US\$</b>
Spares, Tools, Training	600,000 US\$	Spares, Tools, Training	600,000 US\$
Distribution system up grade	180,000 US\$	Distribution system up grade	180,000 US\$
			US\$
<b>TOTAL CAP. COST TROLLEY CONVERSION</b>	<b>14,455,000 US\$</b>	<b>TOTAL CAP. COST TROLLEY CONV.</b>	<b>15,355,000 US\$</b>
<b>Annual Maintenance Costs</b>		<b>Annual Maintenance Costs</b>	
Add. maintenance truck trolley equipment ( \$1.80/truck/hour)	223,380 US\$/year	Add. maint. truck trolley equipment ( \$ 1.00 / hour)	223,380 US\$/year
Reduced maintenance Diesel engine ( \$ -1.8 / truck / hour)	-223,380 US\$/year	Reduced maintenance Diesel engine ( \$ 2 / hour)	-223,380 US\$/year
<b>Total change in truck maintenance costs with trolley</b>	<b>0 US\$/year</b>	<b>Total change in truck maintenance costs with trolley</b>	<b>0 US\$/year</b>
Maintenance cost - Trolley Support Group	566,000 US\$/year	Maintenance cost - Trolley Support Group	566,000 US\$/year
Maintenance cost - Roadside Equipment Mat. ( \$ .5 /tr. km)	447,125 US\$/year	Maintenance cost - Roadside Equipment Mat. ( \$ .5 /tr. km)	1,124,200 US\$/year
Additional maintenance haul road	75,000 US\$/ year	Additional maintenance haul road	75,000 US\$/year
<b>TOTAL ADD. ANNUAL MAINTENANCE COS</b>	<b>1,088,125 US\$/year</b>	<b>TOTAL ADD. ANNUAL MAINT. COSTS</b>	<b>1,765,200 US\$/year</b>

# Economic Analysis with Trolley Calculator

## ECONOMIC FEASIBILITY FOR TROLLEY ASSIST

### Advantages with trolley assist

#### Scenario 1 : Same production with fewer trucks

<b>Energy cost savings on ramp w.trolley &amp; fewer trucks:</b>	
Number of trucks required	<b>17 trucks</b>
Round trips per truck per day with trolley	<b>44 round trip</b>
Round trips required for same production	<b>700 round trip</b>
Round trips required per year for same production	<b>255,500 round trip</b>
Fleet Diesel / electricity costs on ramp per year	<b>9,749,590 US\$</b>
<b>Total energy cost savings on ramp / a</b>	<b>37,593,057 US\$/year</b>
<b>Additional benefits per year :</b>	
Maintenance cost per truck per year (\$30/h, 6,000 h/a)	<b>180,000 US\$</b>
Maint. cost savings due to fewer trucks per year	<b>540,000 US\$</b>
Hourly wages for truck driver	<b>14.00 US\$/h</b>
Fringes / other cost per driver per hour	<b>14.00 US\$/h</b>
Drivers per truck	<b>4.00 drivers</b>
Paid hours per driver per year (incl. vacation, sick, holiday)	<b>2,000.00 hours</b>
Reduction in trucks	<b>3 trucks</b>
Personnel cost savings due to fewer trucks per year	<b>672,000 US\$</b>
<b>Total additional benefits per year</b>	<b>1,212,000 US\$/year</b>
<b>One Time Capital Cost Savings ( fewer trucks)</b>	
Capital cost savings per truck NOT acquired	<b>4,500,000 US\$/truck</b>
<b>Total one time capital cost savings</b>	<b>13,500,000 US\$</b>

#### TOTAL BENEFITS SCENARIO 1 - FEWER TRUCKS

Yearly savings	<b>38,805,057 US\$</b>
One time savings	<b>13,500,000 US\$</b>

#### Scenario 2:Incr. production w. same # of trucks

<b>Energy cost savings on ramp :</b>	
Same number of trucks - increased production	<b>20 trucks</b>
Round trips per truck per day with trolley	<b>44 round trip</b>
Fleet trips per day / increased production	<b>880 round trip</b>
Fleet trips per year / increased production	<b>321,200 round trip</b>
Fleet Diesel / electricity costs on ramp per year	<b>12,256,628 US\$</b>
<b>Fleet Diesel / electricity costs on ramp per year</b>	<b>35,086,019 US\$/year</b>
<b>Benefits due to higher production per year :</b>	
Payload per truck	<b>400.00 short tons</b>
Number of round trips without trolley	<b>255,500 round trip</b>
Theoretical fleet capacity per year without trolley	<b>102,200,000 t/year</b>
Number of round trips with trolley per year	<b>321,200 round trip</b>
Future fleet capacity with trolley per year	<b>128,480,000 t/year</b>
Additional fleet capacity with trolley per year	<b>26,280,000 t/year</b>
Estimated benefits for each additional ton moved	<b>1.000 US\$/ton</b>
<b>Benefits from additional production</b>	<b>26,280,000 US\$/year</b>

#### TOTAL BENEFITS SCENARIO 2 - KEEP SAME # OF TRUCKS

Yearly benefits fuel/production	<b>61,366,019 US\$</b>
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## Summary

- Greatly increased power, speed and productivity
- Significantly reduced energy costs
- Reduced engine wear and greatly extended engine service intervals
- Minimal environmental impact with very low noise and diesel exhaust emissions
- Improved line and pantograph systems to maximize reliability and minimize capital outlay
- Siemens offers
  - profitability studies
  - electrical drive (GTO and IGBT) and trolley equipment for BelAZ trucks
  - conversion of existing trucks
  - mine trolley electrification with substations and catenary system
  - erection, commissioning, turn-key systems (optionally)
  - relocations and maintenance (optionally)

## Thank You for Your Attention

For more information please contact:

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