Traction inverter, Power Supply, Emergency ventilation inverter for Light rail train

Qingdao Zener Electric Co., Ltd
Part 1
Power Supply for the Overhead Traction Line
Introduction

Conventional power supply solution

- Diode Rectifiers offer a simple and robust construction
- Energy flow in one direction only
- Braking energy *only sometimes* used by other cars
- Unused braking energy wasted in resistors
Operating Features

The new Sine Saver system provides for reversible electrical power flow. It can:

- Supply the overhead line with DC power, consuming from the utility line, clean electrical power, COS (Ø) = 1.
- Regenerate (feedback) the braking power of the electrical vehicles back to the utility line.
Operating Features

- Produce reactive power for the utility line.
- Stabilise the utility line voltage.
- Act as an active filter
  - Reducing the line THD (Total Harmonic Distortion) produced in the utility line by other users e.g. existing diode rectifiers thus improving the power quality of the utility line.
Technical Characteristics

- Line reactor
- AC Line
- DC Line Link
  - Slow charge control
  - SKiiP signals
- DC Link Voltage
- Power Interface
  - Control Board + LCD display + keypad
  - Switch mode Power Supply

User Interface
Current & Voltage

Motoring Mode

\[ v, i \]

\[ t \]
Current & Voltage

Generating Mode
Technical Characteristics

- Rated DC voltage: 750V + 20%, -30%
- Can be applied to 600V systems
- Maximum operating DC voltage: 1200V
- Maximum sustaining voltage (without IGBT switching): 1500V
- Maximum surge voltage: 1700V
Technical Characteristics

- Utility line voltage 3 x 380 ~ 690V +/- 10%
- Utility line frequency 50 or 60 Hz +/- 5%
- Current total harmonic distortion < 3%
- Typical rated power
  - 1 stack = 350kW
  - 3 stacks = 1.05MW
  - 4 stacks = 1.4MW
Technical Characteristics

- In case of fault condition Sine Saver can operate with a rating of:
  - \((N-1) \times \text{stack power}\)
  - \((N \text{ is total number of stacks in parallel})\)
- Efficiency > 99% up to 50% rated power
  - > 98% for rated power
Technical Characteristics

- Cooling
  - Forced air (Ambient temperature 45°C)
  - Liquid cooling with heat exchanger
Operating Conditions

Four operation modes are considered

- For new systems
- Improvement to existing system
- Power quality improvement
- Additional power source
Operating Conditions

- Parallel operation of many Sine Saver assemblies
- Constant output voltage with current limit
- Rectifier or inverter mode selected automatically
  - Lower DC voltage gives rectifier mode
  - Higher DC voltage gives inverter mode
Operating Conditions

Power quality improvement

- In parallel operating mode using diode rectifiers the Sine Saver is not required 100% of the time
- Spare Sine Saver capacity can be used to improve power quality
  - Reactive power generation
  - AC line voltage stabilization
  - Active filter operation
Harmonics – B6 – Sine Saver

Harmonic Number

%
DSP Controller Board

More than 15000 pieces in use
System power supply & power interface board
Power Stacks

Power stacks: 10kW ~ 1MW or more
Part 2
Light Rail Traction

The Zener Traction Drive System (ZTDS)
Light Rail

- 600 or 750VDC supply
- City use
- Frequent stop / start
- Typically 30 tonne / unit
Introduction

The use of inverters is well known, but there are special requirements for rail

- Electrical
- Mechanical
- System

All these must be met to make a reliable system
Introduction

Electrical Requirements…

- Powered from DC overhead line or 3rd rail
- Wide voltage range, typically –30% to +20%
- Large, high energy transients on the DC supply
- Interface to the train system
- Torque control by steps
- Large overload capacity
Introduction

Mechanical Requirements…

- Space is always a problem on a train
  - Compact design essential
- Equipment must withstand shock and vibration
Introduction

Other System Requirements…

- High reliability is essential
- Running costs must be minimized by efficient energy use
- Capital cost must be as low as possible
The System

- Overhead line
- Distributed L, R
- Pantograph
- Lightning Arrestor
- Circuit breaker
- Regenerative braking
- Resistive braking
- Slow charge circuit
- Track return circuit
- Rectifier sub-station
  
  750VDC Nominal
  
  (20kA short circuit)

- IGBT INVERTER
- INDUCTION MOTOR

- Rectifier
- Lightning Arrestor
- Circuit breaker
- Regenerative braking
- Resistive braking
- Slow charge circuit
- Track return circuit

Distributed L, R

- Track return circuit

- Rectifier sub-station
  
  750VDC Nominal
  
  (20kA short circuit)
Technology

- Control system specially designed by Zener for traction drive applications
- Power semiconductor (IGBTs, diodes) sub-systems
- Allows 150% and 200% overload
Most Commonly applied standard is

International Electrotechnical Commission (IEC) standard

1287-1 *Power converters installed on board rolling stock*

The equipment presented here meets this and other standards.
Power source

- Supply voltage range for contentious operation - 30% to +20%. For a 750VDC system this is 525 - 900V
  
  - Low voltage limit is necessary for emergency operation of the railway when some of the track side power supplies (rectifier sub-stations) are not working
  
  - High voltage limit is to allow the use of energy saving regenerative braking with the least use of wasteful resistive or mechanical braking
Electrical Transients

- High inductance in overhead wire (~1.5mH/km)
- High fault currents possible
- Large stored energy ($0.5 \times L \times I^2$)
- Proper design for transient voltages is essential for a reliable system
Electrical Transients…

From figure 4, IEC 1287-1

- **No damage curve**
- **Voltage at inverter capacitors from "no damage" transient**
- **Limit for single IGBT (1700V)**
- **Over voltage trip point (1300V)**

**Figure 1**
Interface to the train controls system

ZTDS provides two kind of interface

- 24VDC control interface using relay contacts and electronic relay "coils" that allows control of the driving or braking torque step as well as signalling of fault conditions

- Industry standard MODBUS serial communications protocol

- Allows access to a wider range of control features and reporting of operating conditions including fault status, currents, voltages and power measurements in real time
ZTDS Control System

- High performance Texas Digital Signal Processor (DSP)
- Driving / braking in multiple steps
- Slow charge control for inverter DC link
- 2 line LCD display & keypad for testing / maintenance and parameter setting
ZTDS Control System

- RS-485 serial interface (MODBUS protocol)
- Relay contacts for status signals
- Highly reliable hardware
- Can drive two AC traction motors in parallel - Reduce the overall cost
Outline

- The traction application – mechanical overview
- Traction motor environment - bogie construction
- Induction motor performance
- Torque production
- Decoupling flux and torque
- Sensorless operation
- Control topology, description
Traction requirements

The traction system needs to provide sufficient force parallel to the rail (tractive effort) for:

- Acceleration
- Climbing slopes
- Friction
- Windage

A regenerative capability is normally required for energy efficiency
Light Rail Bogie

Figure 2 Light rail bogie
Light Rail Bogie – from below
Wheel and Rail

Axle weight

Torque applied by traction drive

Traction effort
\[ F = \text{Torque \times radius} \]

Maximum tractive effort
\[ F = \mu \times \text{axle weight} \]

\( \mu = \text{coefficient of adhesion} \)

Reaction force on rail

Basic Forces

Figure 1
Advantages of AC Traction

- More rugged traction motors
  - Environment is very harsh - vibration, shock, water
  - Impact on the motor case, obstruct ventilation openings etc.

- Low maintenance
  - No brushgear
  - Usually no ventilation openings

- Multiple motors may be driven by one inverter
  - Economy
  - Improved wheel slip performance conditions
Challenges of AC Traction

- More complex control
  - Digital Signal Processors (DSP) allow complex control structures to be implemented economically and reliably
- Speed sensor usually required on the motor
  - Lowers reliability
  - Adds cost
  - Takes space

  Speed-sensorless control can avoid this!
Speed-sensorless control

Figure 4 Sensorless control scheme
Torque Production – DC Machine

DC machine
• Torque is produced by the force on a current carrying wire in a magnetic field

• Current in the wire is quite separate to the method of producing the magnetic field (field coil, permanent magnet etc)
Torque Production – Induction Machine

1. Rotating magnetic field

2. Current induced in rotor conductors

3-phase AC supply

4 pole machine shown
Induction Motor Characteristics

- **Torque**
  - (+) (driving)
  - (-) (regeneration)

- **Breakdown torque**
  - Synchronous speed
  - Shaft speed = stator frequency
  - No rotor current
  - No torque produced

- **Motor shaft speed**
Induction Motor Characteristics

Figure 3 Induction machine operating regions

- Constant torque
- Constant power
- Reduced power

Torque

Speed

Breakdown torque

Rated torque
Decoupling

- Decoupling

- Separates torque and magnetic flux production by “untangling” the stator current information

- Simplifies the control structure
  (so that it can be like a DC machine)

- Key element of field oriented control.
Decoupled Control

- By definition:
  - Decoupled control
  - = separate flux and torque control

- By implication:
  - Separate (constant) flux control
  - $\rightarrow$ decoupled control $\rightarrow$ torque control
# Typical Specification

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>450-900VDC</td>
</tr>
<tr>
<td>Maximum operating input voltage</td>
<td>1200V</td>
</tr>
<tr>
<td>Exceptional peak input voltage</td>
<td>1500V</td>
</tr>
<tr>
<td>Output voltage</td>
<td>480V RMS</td>
</tr>
<tr>
<td>Output current</td>
<td>Depending on actual requirement</td>
</tr>
<tr>
<td>cos(\phi)</td>
<td>0.85 to 0.9</td>
</tr>
<tr>
<td>Output frequency</td>
<td>0.5Hz to 150Hz</td>
</tr>
<tr>
<td>Overload</td>
<td>Depending on actual requirement</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>1 kHz</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>25 to +40°C</td>
</tr>
<tr>
<td>Capacitors lifetime</td>
<td>-100,000 hours at 1000V at 70°C without over voltages</td>
</tr>
<tr>
<td>Cooling fluid</td>
<td>Filtered air</td>
</tr>
<tr>
<td>Altitude</td>
<td>&lt;1200m above sea level</td>
</tr>
<tr>
<td>Humidity</td>
<td>Non-condensed 85%</td>
</tr>
<tr>
<td>Mechanical protection</td>
<td>IP00</td>
</tr>
</tbody>
</table>
What is our latest development?

- Now we can supply the traction inverter for the input voltage 1500VDC which is widely used for light rail train and under-ground subway system.
### Part 3
#### What else we can supply

- **Emergency ventilation inverters, battery chargers…**Please see our sales reference below:

<table>
<thead>
<tr>
<th>Qty</th>
<th>Description</th>
<th>Ratings</th>
<th>Fleet Operator</th>
<th>Zener Part number</th>
</tr>
</thead>
</table>
| 386 | Emergency ventilation inverter and output transformer | Input: 110Vdc  
Output: 55Vac/45Hz/3 ph feeding  
step-up transformer.  
Inverter based on MSC-3R30 | New Delhi DMRC              | ZM00304                        |
| 208 | Emergency ventilation inverter and output transformer | Input: 110Vdc  
Output: 55Vac/45Hz/3 ph feeding  
step-up transformer.  
Inverter based on MSC-3R30 | Hong Kong MTRC              | ZM00304                        |
| 110 | Battery charger and LV power supply       | Input: 600Vdc (from overhead line)  
Output 24Vdc / 90A             | Yarra Trams, Z1/Z2 Class passenger trams operating in Melbourne, Australia | Y0037                  |
| 22  | Battery charger and LV power supply       | Input: 415V/50Hz/3-ph/PWM  
(unfiltered from inverter)  
Output 24Vdc / 120A       | V/Line passengers, Sprinter DMU intercity railcars operating in regional Victoria, Australia | ZM00100                  |
## Sales reference further

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Type</th>
<th>Inputs/Specifications</th>
<th>Application</th>
<th>Model Numbers</th>
</tr>
</thead>
</table>
| 48   | Air conditioning inverters 10A and 24A | **Input:** 415Vac 50Hz/3-ph  
**Output:** 415V/50Hz 10A (ZM00044) and 24A (ZM00045) | Queensland Rail (QR) Rockhampton to Brisbane Tilt Train passenger vehicles  
Queensland Rail (QR) Rockhampton to Brisbane Tilt Train passenger vehicles | ZM00044 & ZM00045                   |
| 280  | Emergency ventilation inverter and output transformer | **Input:** 120Vdc  
**Output:** 61Vac/35Hz feeding step-up transformer | Millennium passenger trains operating in metropolitan Sydney, Australia | ZM00308                           |
| 900  | Emergency ventilation inverter | **Input:** 120Vdc  
**Output:** 55V/21Hz supplying fan motor | Tangara and K Class passenger trains operating in metropolitan Sydney, Australia | ZM00300                           |
Contact Information

Thank you

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