PRODUCT DATA

99 Aero Camino
Goleta, California 93117 **http://www.enerpro-inc.com**

PD767 REV E
08-03-2016

POWER CONVERTER WITH THREE-STAGE BATTERY CHARGING
FOR LOCOMOTIVE APPLICATIONS

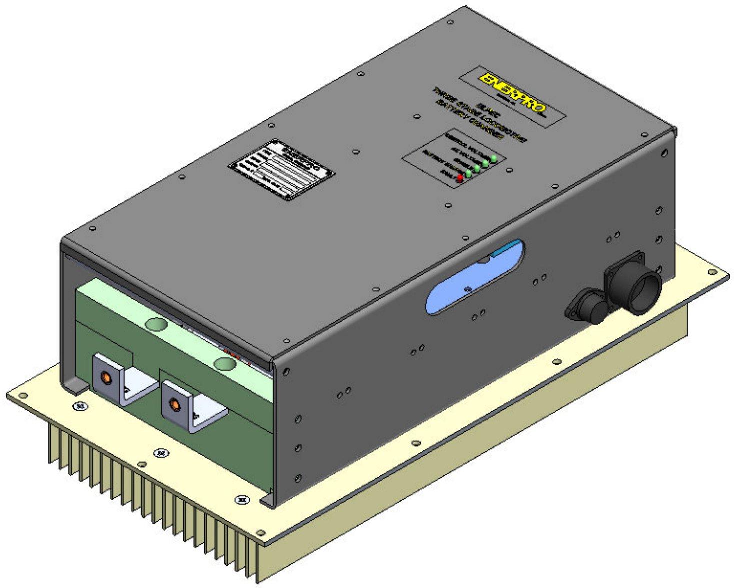

Figure 1 – ELPEC Subassembly

INTRODUCTION

The Enerpro Locomotive Power Electronics Converter, or ELPEC, is an open-frame phase-controlled rectifier (Figure 1). The converter is installed in the locomotive electrical equipment locker.

The ELPEC is supplied with constant V/Hz three-phase voltage from an isolated stator winding on the companion alternator (CA), or alternatively, from an isolation transformer fed by the CA stator winding. The rectifier converts this variable-frequency, variable-amplitude AC voltage into regulated DC voltage or current. Rectifier current passes through an external inductor and capacitor filter (capacitor filter part number CFA-1). The resultant filtered voltage supplies power to the battery and other direct current equipment; an external diode/shunt assembly (Enerpro part number PCM1DCE1768) provides blocking and reverse polarity protection diodes and an independent battery current monitoring shunt.

A three-stage charging algorithm is implemented within the voltage and current regulation circuitry to enhance battery life. This algorithm eliminates the need for battery-based temperature compensation.

THREE-STAGE CHARGE PROFILE

High fuel costs and restrictive air pollution regulations have preciptated a fundamental shift in locomotive operations. Units that previously ran nearly continuously are now started multiple times per day, resulting in a premature loss of battery capacity and higher cell failure rate due to the single-stage charge profile provided by conventional chargers. With single-stage charging, the initial current immediately after engine start is limited only by generator output and battery circuit resistance. Most locomotive battery charging circuits incorporate a current limiting resistor to reduce the charge current. Even with this resistor, the initial current can greatly exceed the battery manufacturer’s recommended maximum charging current and shorten battery life. The single-stage charger transitions from the high initial first-stage current when the battery voltage rises to reach the nominal voltage setpoint of 74 V and then maintains constant nominal 74 V on the battery until the engine is shut down.

According to battery experts, 74 V is insufficient to convert all of the battery's active material during the engine run time if the engine is shut down several times per day. The result is a progressive loss of capacity.

The three-stage charge profile produced by the ELPEC regulates the first, or bulk stage, current to the manufacturer's typically recommended 20% of capacity. In the second, or absorption stage, the rectifier voltage is regulated to typically 78 V. This elevated voltage converts the maximum amount of active battery material while equalizing the charge in each cell, thus minimizing sulfation and capacity loss. In the final float stage, the ELPEC reverts to a constant-voltage regulation mode (nominally 72 V).

Bulk Stage
Upon engine start, the unit enters the 90 A constant-current bulk stage. The battery behaves as a capacitor in that the constant charging current results in battery voltage increasing linearly with time. The bulk stage ends when the voltage reaches a converter-imposed limit of typically 78 V (2.44 Volts per cell). The transition to the next stage is accomplished by the characteristics of the ELPEC's current and voltage regulation circuits.

Absorption Stage
The constant-voltage absorption stage begins with the battery charged to about 80% total capacity. The absorption stage current decays exponentially with time from the initial 90 A until it reaches one of two conditions:

1. The steady-state absorption stage current decays to 25 A, or
2. The second derivative of battery charge (d^2Q/dt^2) falls below a predetermined threshold value.

Enerpro's proprietary, patent-pending d^2Q/dt^2 float force method ensures that a shorted or defective cell will not result in continuous operation at elevated voltage. Examining the current profile in this manner additionally ensures that the maximum charge enters the battery during the absorption stage regardless of temperature. The net result is the maximum charge and optimum conditioning effect in the minimum amount of time with a very high safety margin.

Float Stage
During the regulated 72V float stage, the battery current gradually decays to the steady-state self-discharge current. This maintains a full battery charge as long as the engine is running.

It is important to note that all steady-state load power is supplied by the ELPEC while the unit is powered by the companion alternator. During normal operation, the battery supplies power only for the few milliseconds required for the ELPEC to respond to load changes.

BLOCK DIAGRAM

The ELPEC is configured in a locomotive system as shown in Enerpro drawing E1735. The conversion is achieved by means of a six-thyristor rectifier bridge that is connected to an isolated winding on the companion alternator. If an isolated Companion Alternator winding is not available, the ELPEC may be powered through an appropriate isolation transformer. Thyristor firing, voltage regulation, current regulation, and control interfacing is achieved by a charge control and thyristor firing board as shown. The DC output is filtered with a typical series inductor/shunt capacitor arrangement and fed to a diode/shunt assembly. The battery current shunt feedback signal is isolated from the firing/regulator board by means of a precision isolation amplifier. Critical and non-critical loads may be split as needed by using the appropriate terminal lug on the diode/shunt assembly.

ENVIRONMENTAL SPECIFICATIONS

The ELPEC is an open-frame assembly. Environmental specifications that are enclosure-dependent, such as salt fog and dust infiltration, are deferred to the customer-supplied enclosure requirements. Any responsibility for environmental qualification rests with the customer.

Cooling Air Temperature

- -40° C to 65° C continuous at rated current
- 100° C for 15 minutes at reduced current (tunnel operation)
- -40° C to 65° C storage

The ELPEC incorporates a temperature sensor circuit that forces the output to the float stage when the heatsink temperature exceeds a preset limit of 120 C and reports a soft fault. This scheme preserves the ELPEC's DC output at a safe level.

Assembly Specifications
The Enerpro-designed and manufactured combination regulator, gate trigger, and controller circuit board and snubber board, along with the thyristor modules, bus bars/terminals, current shunt and thyristor temperature sensor are mounted on a finned-on-one-side aluminum extrusion and adaptor plate. These components form an open frame assembly with envelope dimensions of 22.75 in. (578 mm) length x 11.44 in. (291 mm) width x 8.65 in. (220 mm) depth. The assembly is attached to a panel with the heat sink fins protruding into the air stream behind the panel as seen in Drawing M1888.

Altitude
-100 to +11000 feet above sea level.

Shock and Vibration
The ELPEC is designed to withstand continuous high shock and vibration in both directions of all three planes at an as-yet to be determined frequency.

Maintenance
Occasional cleaning of the heat sink fins may be required to maintain full rated current capability. Clean, dry cooling air should be used

EMI Compatibility
Compatibility with the following EMI tests has been tested in similar projects with excellent results per established EN standards. The customer assumes all responsibility for EMI certification testing as configured in a specific application.

- Conducted Susceptibility
- Radiated Susceptibility
- Conducted Emissions
- Electrostatic Discharge

Failure Rate
The useful design life is 16 years in freight locomotive service with a critical failure rate of less than 2% per year. The ELPEC is unit-serviceable in event of failure.

ELECTRICAL SPECIFICATIONS--REFERENCE DRAWING E1735

AC Input From Companion Alternator

- Carbody connection — No
- Phase sequence — Positive or Negative
- Frequency: — 30 Hz to 60 Hz (or as specified by customer)
- Volts per cycle:
  maximum short term — 8.50 V/Hz
  maximum continuous — 8.00 V/Hz
  nominal — 7.67 V/Hz
- Minimum voltage for regulation — 60 Vac
- Maximum current (5 seconds) — 800 A_{RMS}

DC Output Current and Voltage

- Total current — 425 A @ 70 C air temperature, 500 LFM through heatsink fins (absolute maximum)
- Bulk stage charge current — 90 A (typical setpoint, maximum allowable is C/5)
- Absorption stage voltage — 78 V @ 20 C battery temperature for FLA batteries (standard)
  76 V @ 20 C for AGM/VRLA batteries (optional)
- Float stage voltage — 72 V

Efficiency
The ELPEC efficiency is greater than 95% from 20% to 100% of rated load.

Load Filter
An LC filter reduces the ripple current voltage applied to the battery and other loads. The filter resonant frequency selected should be less than six times the lowest generator frequency. The filter attenuation should limit the ripple

voltage to less than 5% of the dc voltage. The Enerpro Capacitor Filter Assembly (CFA-1) provides 0.1 F (200 working VDC, 250 VDC surge) of capacitance in a compact, ruggedized package suitable for rail applications and fulfills these requirements when paired with an inductor of sufficient value and rating.

Control (Enable Command) Power
All control and enable command power is derived directly from the locomotive battery.

Low Voltage Electronics Power

• Source	Locomotive battery
• Carbody ground referenced	No
• Type	Isolated DC/DC converter with Zener pre-regulator
• Input Voltage range	60 to 90 VDC

Command and Status Signals (See Drawing E1735)

- *Enable Command*: a floating, current-limited photodiode input filtered for noise immunity to prevent unwanted enable or inhibit. The ELPEC is enabled when the input is connected to the locomotive battery bus in the polarity indicated.
- *Status Signal:* the status signal is a floating phototransistor output that is on when the unit is enabled. The customer must observe polarity and current-limit this output to no more than 250 mA at 74 VDC. Do not exceed a current-voltage product of 25 V-A as applied across the output and current limit resistor.
- *Soft Fault Signal:* The soft fault signal is electrically identical to the status signal and is on when any of the following fault conditions are present: low AC input voltage, low DC output voltage, heat sink overtemperature. Battery charging output may be compromised if this fault signal is active as the output voltage is indeterminate in the low voltage conditions. The unit is forced into the float stage in the heat sink overtemperature condition.
- *Hard Fault Signal:* The hard fault signal is electrically identical to the status signal and is on when any of the following fault conditions are present: phase loss, high DC voltage, loss of shunt signal. The unit self-inhibits under the phase loss and high DC voltage conditions and stays inhibited until the fault is corrected. If the enable command is asserted, the status signal will not be asserted when this fault is indicated. If the shunt signal is lost, then the unit is forced into the 72 V float stage.
- *Fault Signal Blanking*: The soft and hard fault signals are blanked for a period of 10 seconds after the enable command is asserted. This avoids reporting false faults to the locomotive control computer associated with startup transients. Faults are not reported when the ELPEC is manually inhibited.

ELECTRICAL CONNECTIONS

AC and DC Power	Terminations are by threaded inserts in the ends of the six bus bars.
DC Power Terminals (2)	Positive and negative DC output
AC Power Terminals (3)	Three-phase ac (A, B, and C)
Control and Status Signals	MIL-C-5015 bayonet connector, 24-5 insert

Thyristor Modules

• Part no.	TT250N18KOF
• I^2t	245,000 A^2s
• Rated one cycle current	7000A peak (per thyristor)
• Blocking Voltage	1600Vac
• dV/dt	1000V/μs
• di/dt (repetitive)	150A/μs
• Thermal resistance, R_{JS}	0.085° C/W

Heatsink

• Extrusion length	20.375 in.
• Specific weight	8.42 lb./ft.
• Number of fins	22
• Thermal resistance, R_{SA}	0.042° C/W with 500 LFM airflow

Firing/Regulator Board

The FCROVF6-TSCS-1 variable frequency firing/regulator board uses the field-proven elements of the rail industry-standard FCOVF6100 variable frequency firing board and the VLTLCL-1 regulator board, originally developed for a mining truck battery charger application. This board also includes custom fault monitoring, control interface, and battery current regulation features not present in other Enerpro products. The printed circuit board is a six-layer, 0.093"-thick FR-4 epoxy laminate with plated through holes and solder mask over bare copper. All bare Enerpro circuit boards conform to UL94-V0. A polyurethane conformal coating (MIL-1-46056, Type UR) is applied to the printed circuit board to provide enhanced immunity to dirt and moisture.

Snubber Board

In a thyristor converter, a high rate-of-rise in anode to cathode voltage, or dV/dt, occurs when a thyristor ceases conduction or when another thyristor in the circuit is gated into conduction. The dV/dt of the thyristor voltage must be limited to avoid erratic circuit operation and device damage. Connected anode to cathode, the snubber circuit resistors and capacitors limit this dV/dt. Specifically designed for use in high vibration environments, the TSBHG-6 board uses rail mounted TO-220 style resistors and high-quality, board mounted WIMA film capacitors. This configuration minimizes the susceptibility of the solder joints to vibration and provides a convenient heat sinking scheme for the snubber resistors.

Status LED Indicators

A set of LED indicators are mounted directly to the top cover plate of the unit, as seen in Figure 2. These provide an at-a-glance indication of the unit's status.

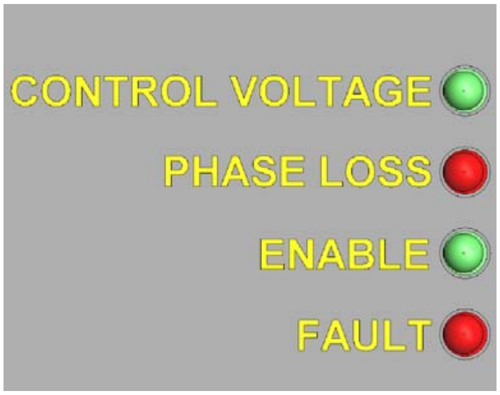

Figure 2—Front Panel LED Status Indicators

Name	Description
CONTROL VOLTAGE	Indicates that the battery is connected to the unit and providing power.
PHASE LOSS	Indicates that the CA voltage is unbalanced or absent and inhibits operation regardless of enable command.
ENABLE	Indicates that the enable command has been asserted by the locomotive control system and a hard fault has not inhibited operation.
FAULT	Indicates any of the following fault conditions: low ac voltage, low dc voltage output, high dc voltage output, heat sink over temperature, or CA phase loss.

SYSTEM CONNECTIONS AND SETUP

Connections

Refer to connection diagram E1735. All internal connections are completed at the factory. Connections for ac and dc power are made directly to the bus bars, which are fitted with captive 1/2-13 UNC threaded PEM nuts. Enable and status read-back signals are available on connector J1, which is a weather-tight, keyed, bayonet-style cylindrical connector (MIL 5015 series, 24-5 insert).

APPLICABLE DOCUMENTS

E1735, Connection Diagram, "ELPEC Controlled Rectifier & Battery Charger"

E1734, Schematic Diagram, "FCROVF6-TSCS-1, Simplified Variable Frequency Firing Circuit with Three-Stage Charging"

E459, Schematic Diagram, "High Shock 6-Circuit Snubber Board, TSBHG-6"

M1888, Mechanical Diagram, "ELPEC Phase Controller"

Document Revision History			
Revision	Date	Appr	Comments
NC	09/03/2009	jtm	Initial release
A	02/17/2010	jtm	Updated specifications per released product
B	12/10/2010	jtm	Change to voltage-regulated float stage
C	04/23/2012	jtm	Include proprietary abs/flt transition circuit, describe fault and enable interface
D	07/03/2012	jtm	Clarify nominal enable command voltage
E	08/03/2016	dli	Correct address to new Enerpro location