



**APTA PR-E-RP-015-99, Rev. 2**

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**Electrical Working Group**

# Head End Power Source Characteristics

**Abstract:** This recommended practice defines the characteristics necessary on new equipment for head end power (HEP) sources, including diesel-driven alternators, inverters and utility-supplied wayside power. The HEP source is composed of power source, switchgear, control system (incorporating trainline complete functions) and connections to vehicle HEP trainline(s).

**Keywords:** 480 Vac HEP, head end power source, TLC, trainline, trainline complete (TLC)

**Summary:** This recommended practice defines the functionality of HEP power sources and their control systems, including trainline interfaces.



## Foreword

The American Public Transportation Association is a standards development organization in North America. The process of developing standards is managed by the APTA Standards Program's Standards Development Oversight Council (SDOC). These activities are carried out through several standards policy and planning committees that have been established to address specific transportation modes, safety and security requirements, interoperability, and other topics.

APTA used a consensus-based process to develop this document and its continued maintenance, which is detailed in the [manual for the APTA Standards Program](#). This document was drafted in accordance with the approval criteria and editorial policy as described. Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

This document was prepared by the Electrical Working Group as directed by the Passenger Rail Equipment Safety Standards Policy and Planning Committee.

This document represents a common viewpoint of those parties concerned with its provisions, namely transit operating/planning agencies, manufacturers, consultants, engineers and general interest groups. The application of any recommended practices or guidelines contained herein is voluntary. APTA standards are mandatory to the extent incorporated by an applicable statute or regulation. In some cases, federal and/or state regulations govern portions of a transit agency's operations. In cases where there is a conflict or contradiction between an applicable law or regulation and this document, consult with a legal adviser to determine which document takes precedence.

This document supersedes APTA PR-E-RP-015-99, Rev. 1, which has been revised. Below is a summary of changes from the previous document version:

- Updated working group roster; format updated to latest APTA standards format.
- Addition of Summary section.
- Added new Section Foreword.
- Added applicability language in the Introduction.
- Revised figures in former section 9, Illustrations. Redistributed revised figures in appropriate places within document.
- Merged former Sections 1.1, Scope, and 1.2, Purpose, into Scope and Purpose.
- Moved former Section 2, References, to the new sections Related APTA standards and References.
- Moved former Section 3, Definitions, abbreviations and acronyms into new sections Definitions and Abbreviations and Acronyms.
- Added power car as a vehicle type throughout document.
- Renumbered former section 4, Technical Information, to Section 1.
  - Moved contents of former sections 4.1.1., HEP source recommended practice and 4.1.2, Power sources to renumbered Section 1.1, General. Eliminated sections 4.1.1. and 4.1.2.
  - Renumbered former Section 4.3, HEP trainline configurations to Section 1.2. Added reference to APTA PR-E-RP-016-99, "480 Vac Head End Power System." Moved content on single bus to new section 1.2.1, Single bus. Moved content on split bus to new Section 1.2.2, Split bus. Moved remainder of content to new Section 1.2.3, Intermixing.
  - Renumbered former section 4.2.1, Single bus HEP system attributes to Section 1.2.4.
  - Renumbered former section 4.2.2, Split bus HEP system attributes to Section 1.2.5.



- Renumbered former Section 4.3, Rating, to Section 1.3. Revised wording to include “designed and manufactured to operate reliably and without degradation.” Added examples of additional conditions which may be specified by the operating authority.
- Removed former Section 4.5, TLC trainline complete function of a train. Moved subsections within into new sections 1.5.1, Operation, 1.5.2, Active sources, 1.5.3, Indicator lights, and 1.5.4, Short-looping. Revised Figure 5, Simplified Trainline Complete (TLC) Operation-Train. Added new content on 5 mph speed function into Section 1.5.1.
- Renumbered former Section 5, Vehicle-based HEP sources, to Section 2.
  - Added content on EMC requirements and phase imbalance.
  - Renumbered former Section 5.3.2, Inverter, to Section 2.3.2. Placed existing content under new Subsection 2.3.2.1, HEP Inverter.
  - Added new Section 2.3.2.2, Backup inverter. Recommendation added on backup inverters.
  - Renumbered former Section 5.4.1, Inverter, to Section 2.4.2. placed content under new subsection 2.4.2.1, HEP inverter.
  - Added new Section 2.4.2.2, Backup inverter. Added recommendation on backup inverter.
  - Renumbered former Section 5.5.1.3, Meters, to Section 2.5.1.3. Added recommendation for the display of all 3 phases simultaneously if screen is employed.
  - Renumbered former Section 5.6.6., F-end isolation switch, to Section 2.6.6. Added rationale behind the need for a HEP F-end isolation switch. Added recommendation for control logic to prevent movement of switch unless 480 V power is removed.
- Renumbered former Section 6, Wayside power, to Section 3.
  - Renumbered former Section, 6.1, General, to Section 3.1. Added rationale for each outlet box to have its own control station and switchgear including all fault protections. Added recommendations for applications requiring more than 800 A of wayside power for a single consist. Added recommendations for outlet boxes with four receptacles.
  - Added new Section 3.1.1, Fault current interruption. Added recommendation for circuit breaker fault capacity and possible fusing with available fault current of the transformer.
  - Renumbered former Section 6.3.1.3, Meters, to Section 3.3.1.3. Added recommendation to display all three phases simultaneously on screen.
- Renumbered former Section 7, Tests, to Section 4.
  - Renumbered and renamed former Section 7.1, Wiring, to Section 4.1, Production tests. Split content into new subsections 4.1.1, Insulation, and Section 4.1.2, Continuity.
  - Added new Section 4.1.3, Functional tests. Added new subsections 4.1.3.1, Trainline complete, and 4.1.3.2, HEP power source. Added recommended procedures therein.
  - Renumbered former Section 7.2, Vehicle proof-of-design test, to Section 4.2. Placed existing recommendations in new subsection 4.2.1, New vehicle tests.
  - Added new Section 4.2.2, Functional tests. Added recommendations for TLC circuit and indicator verification conditions.
  - Added new Section 4.2.3, Total harmonic distortion (THD). Added recommendation to verify that the requirements of HEP source characteristics are not exceeded.
  - Added new Section 4.2.4, Electromagnetic compatibility. Added recommendation for compatibility testing with new and existing equipment.
  - Renumbered and renamed former Section 7.3, Vehicle control system, to Section 4.3, Vehicle load test. Revised testing recommendations.
  - Renumbered former Section 7.4, Wayside power commissioning tests, to Section 4.4. Added recommendation to demonstrate fault conditions causing HEP shut down only affect box with fault.



- Renumbered former Section 8, HEP source characteristics, to Section 5.
  - Renumbered former Section 8.1.1, Steady state, to 5.1.1. Added note regarding harmonic content greater than 5% at light load.
  - Renumbered and renamed former Section 8.2, HEP source characteristics: locomotive, power car or wayside with HEP alternator driven by dedicated engine source, to Section 5.2, Locomotive, power car or wayside with HEP alternator driven by dedicated engine source.
  - Renumbered former Section 8.2.1, Steady state, to Section 5.2.1. Added note regarding harmonic content greater than 5% at light load.
  - Renumbered former Section 8.3.1, Steady state, to Section 5.3.1. Added note regarding harmonic content greater than 5% at light load.
  - Renumbered and renamed former Section 8.4, HEP source characteristics: electric locomotive with inverter HEP source, to Section 5.4, Electric locomotive with inverter HEP source.
  - Renumbered former Section 8.4.1, Steady state, to Section 5.4.1. Added note regarding harmonic content greater than 5% at light load.
  - Renumbered and renamed former Section 8.5, HEP source characteristics: wayside with utility source, to Section 5.5, Wayside with utility source.
- Added APTA PR-E-S-010-98, “Development of an Electromagnetic Compatibility Plan,” to Related APTA standards
- Added PRIIA specifications to references.



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## **Introduction**

*This introduction is not part of APTA PR-E-RP-015-99, “Head End Power Source Characteristics.”*

This recommended practice applies to all:

- railroads that operate intercity or commuter passenger train service on the general railroad system of transportation; and
- railroads that provide commuter or other short-haul rail passenger train service in a metropolitan or suburban area, including public authorities operating passenger train service.

This recommended practice does not apply to:

- rapid transit operations in an urban area that are not connected to the general railroad system of transportation;
- tourist, scenic, historic or excursion operations, off the general railroad system of transportation;
- operation of private cars, including business/office cars and circus trains unless otherwise required by other standards or regulations;
- railroads that operate only on track inside an installation that is not part of the general railroad system of transportation; or
- vehicle-to-vehicle interfaces that are permanently or semi-permanently coupled within trainsets; however, the exposed ends are still subject to this recommended practice.

## **Scope and purpose**

This document defines the recommended practices for HEP sources to allow intermixing of cars and locomotives of varying designs. In addition, it defines minimum HEP source construction recommended practices for new equipment. This recommended practice defines the characteristics necessary on new equipment (new locomotives as well as new installation of HEP source on existing units) for head end power sources including diesel-driven alternators, inverters and utility-supplied wayside power. Equipment conforming to this recommended practice should be mutually compatible for HEP operation (with some limitations, as described in Section 1.2).

For a description of the HEP trainline system and the load characteristics, refer to APTA PR-E-RP-016-99, “480 Vac Head End Power System.” For HEP jumper and receptacle hardware, see APTA PR-E-RP-018-99, “480 Vac Head End Power Jumper and Receptacle Hardware.” For procedures to load test HEP power sources, see APTA PR-E-RP-011-98, “Head End Power Load Testing.”

# Head End Power Source Characteristics

## 1. Technical information

### 1.1 General

The HEP system should be composed of the following:

- power source
- switchgear (on-off as well as overload and other protection)
- control system (incorporating trainline complete functions)
- connections to vehicle HEP trainline(s)
- battery charger, powered from the HEP bus

There are four source configurations for HEP:

- alternator driven from locomotive traction prime mover
- alternator driven from exclusive engine
- locomotive inverter
- wayside power (stationary utility)

### 1.2 HEP trainline configurations

Two alternative approaches for the HEP trainline system are detailed in APTA PR-E-RP-016-99, “480 Vac Head End Power System,” and are covered here for convenience: single and split bus.

#### 1.2.1 Single bus

Single bus is used on some commuter equipment and most intercity equipment. The single bus system is recommended, primarily on considerations of lower first cost, less complexity, more widespread usage and increased operational flexibility.

#### 1.2.2 Split bus

Split bus allows the train to be fed from two independent HEP sources simultaneously, which may allow larger consist power demand. Split bus is used on some commuter equipment.

#### 1.2.3 Intermixing

Individual railroad operating practices and rules govern the intermixing of single and split bus equipment. However, for purposes of this document, the alternative approaches are semi-compatible as follows:

- Single bus source can feed single bus, split bus or mixed consist.
- Split bus source can feed only a split bus consist.
- Single bus and split bus equipment can be intermixed within a consist, provided that the HEP source is single bus and both split buses are used throughout the length of the consist.

It is incumbent upon the authority to specify which of the two following configurations the power source should take:

- single bus only
- split bus or single bus (the source is configured to provide power either way, depending upon the setup switch position)

#### **1.2.4 Single bus HEP system attributes**

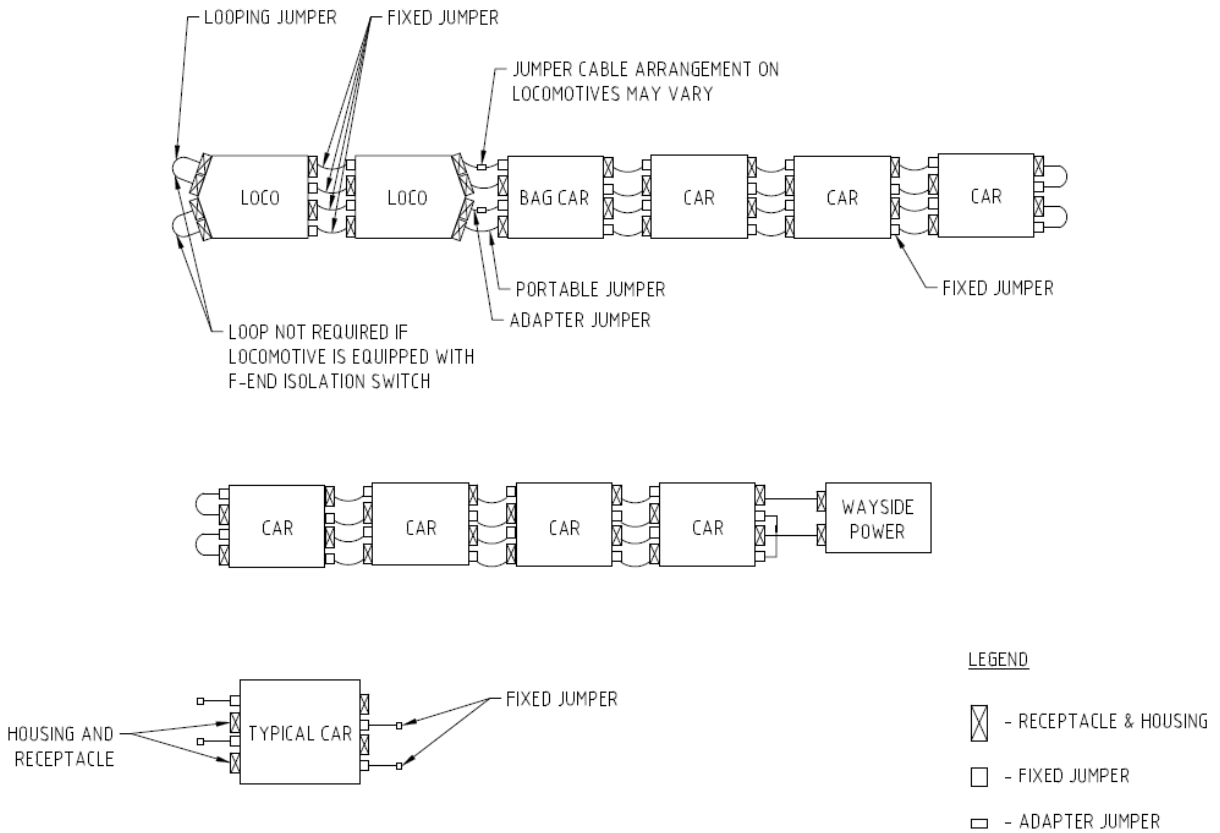
- One HEP bus the length of the train.
- 480 Vac, line-to-line (L-L), 3-phase, 3-wire, 60 Hz operation (the source should have a neutral ground reference, but the distribution system and the load do not).
- 1600 A continuous rating.
- Four jumpers across each car-car-locomotive connection (see [Figure 1](#)).
- All four jumpers in parallel.
- Power schematic per [Figure 2](#).
- Control schematic per [Figure 4](#).

#### **1.2.5 Split bus HEP system attributes**

- Two HEP buses the length of the train, one on each side.
- 480 Vac, line-to-line (L-L), 3-phase, 3-wire, 60 Hz operation (the source should have a neutral ground reference, but the distribution system and the load do not).
- 800 A continuous rating per bus.
- Four jumpers across each car-car-locomotive connection (see [Figure 1](#)).
- Two jumpers in parallel for left bus, two jumpers in parallel for right bus.
- Power schematic per [Figure 3](#).
- Control schematic per [Figure 4](#).

**APTA PR-E-RP-015-99, Rev. 2**  
**Head End Power Source Characteristics**

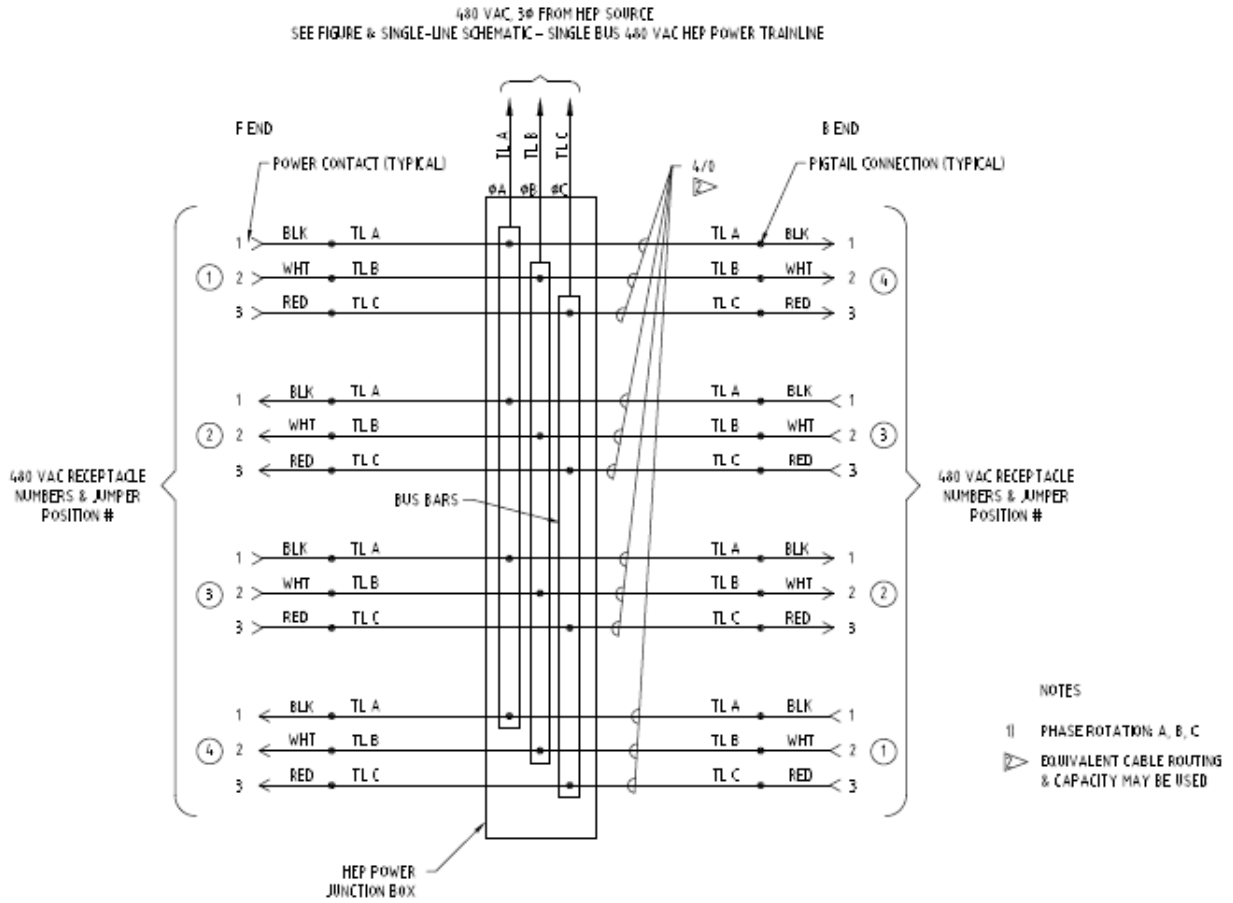
**FIGURE 1**  
**Typical Consist HEP Jumper Cable Arrangement**



**NOTE:** If wayside power for a given track exceeds 800 A capacity, four jumper cables are required between source and consist to not exceed cable rating.

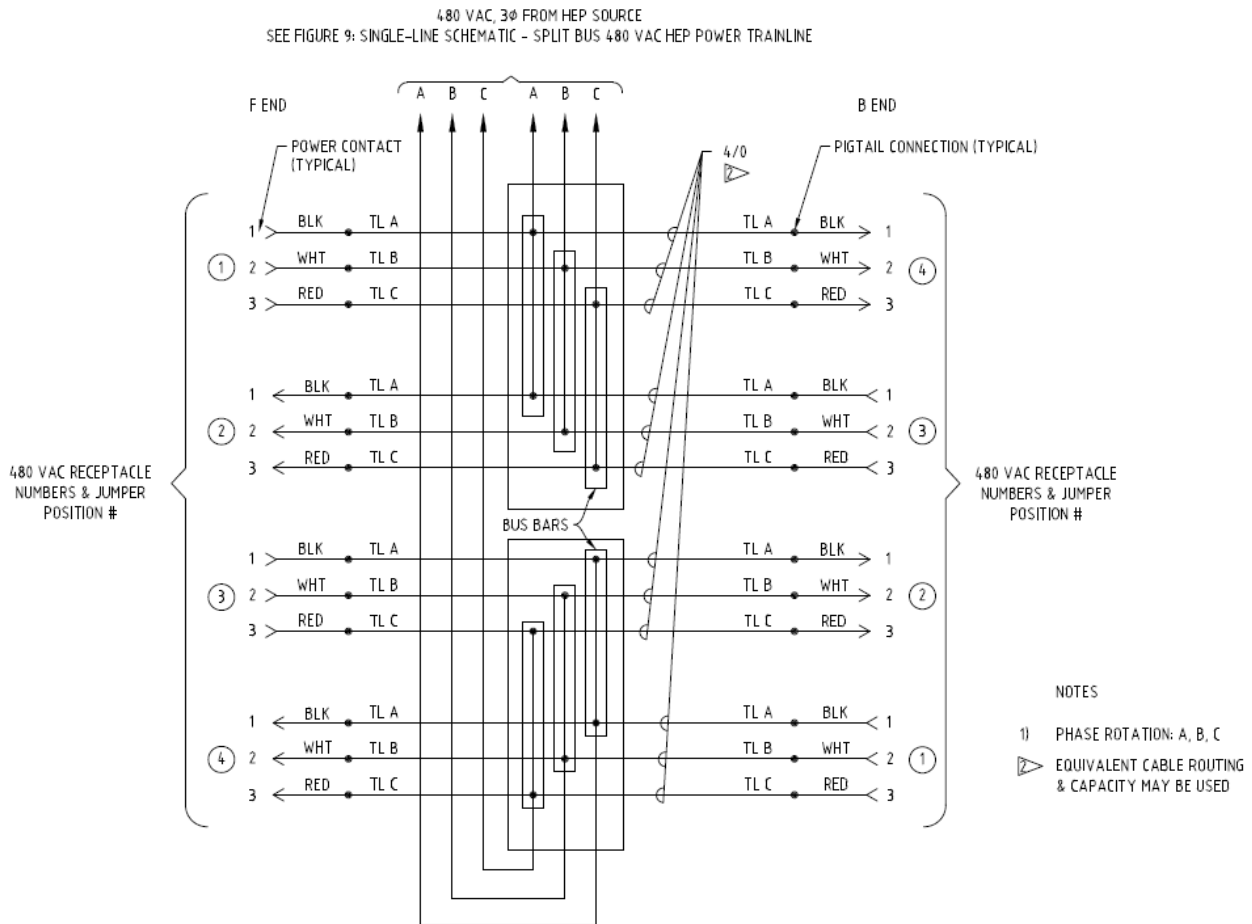
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**FIGURE 2**  
 Locomotive/Power Car/MU 480 V Trainline Power Schematic – Single Bus

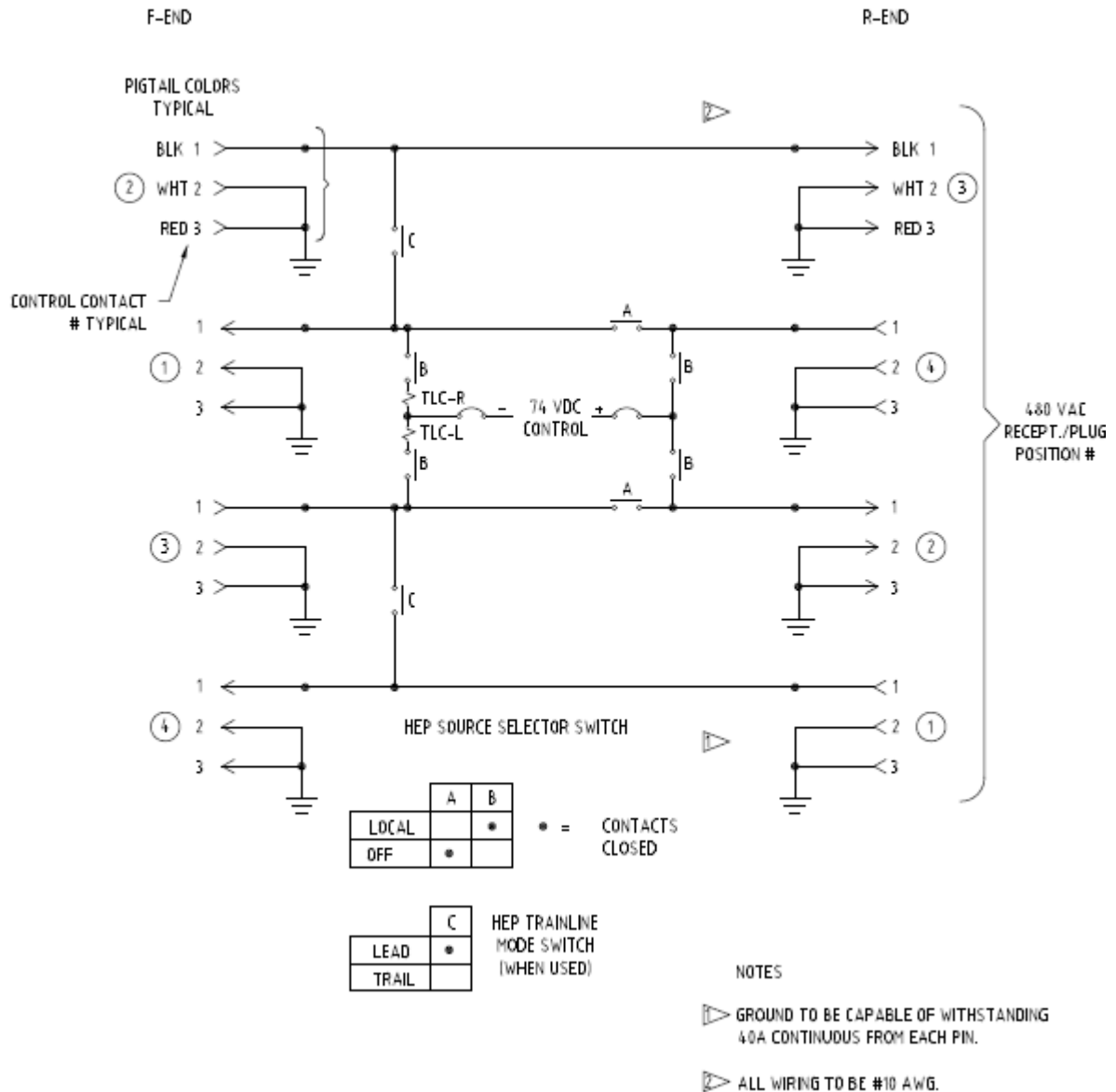


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**FIGURE 3**  
**Locomotive/Power Car/MU 480 V Trainline Power Schematic – Split Bus**



**FIGURE 4**  
 Simplified Locomotive/Power Car/MU 480 V Trainline Control Schematic



### 1.3 Rating

The entire HEP trainline system should be rated for continuous service over the outside ambient temperature of -40 to 110 °F, unless otherwise specified by the authority.

The equipment should be rated, designed and manufactured to operate reliably and without degradation under the following environmental conditions or with any additional requirements specified by the authority. The following are examples of conditions that may occur and should be the subject of such detailed specifications:

- heavy rain, driven by wind or water from a hose
- direct sun
- hail, ice, powdered snow
- blown sand, dust, ballast and rocks

- vehicle speeds to 125 mph (200 km/h)
- wind gusts to 90 mph (145 km/h)
- salt (sea spray or from roads during winter months)
- impact from airborne road debris
- car washing chemicals and wash rack operations
- altitude up to 9200 ft above sea level (engines and cooling systems derate at higher altitudes)

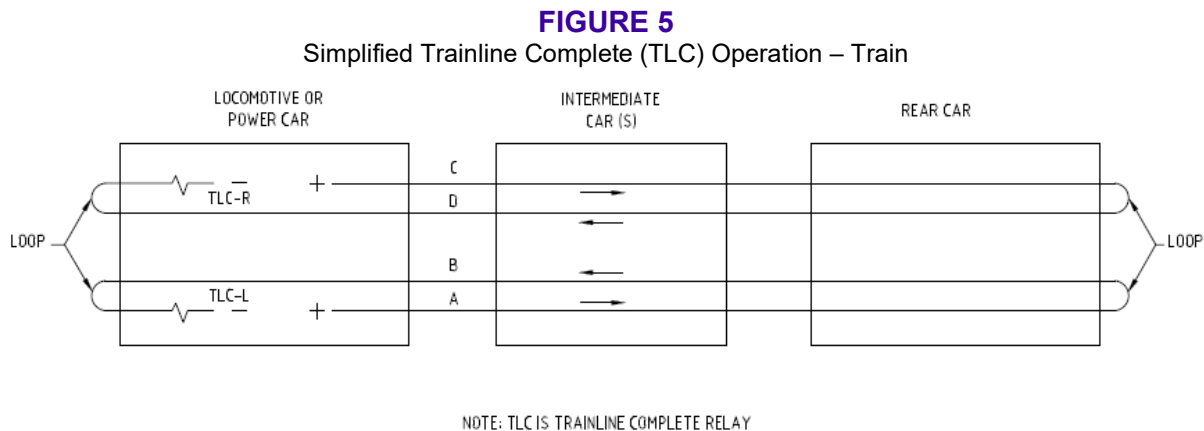
## 1.4 Phase rotation

Phase rotation should be A, B, C, with HEP power pins designated 1 = A, 2 = B, 3 = C.

## 1.5 TLC trainline complete function of a train

### 1.5.1 Operation

The TLC control functions as shown in [Figure 5](#).



The control system of the active HEP source (see Section 1.5.2) applies control voltage to 480 V trainline “A” control contact #1. The resulting current flows rearward along the “A” trainline to the rear of the consist, where the looped jumper connects control contact #1 of trainline “A” to control contact #1 of trainline “B.” The current now travels forward on trainline “B” all the way to the front of the train, where it is similarly looped to trainline “A.” Finally, the current again flows rearward back to the active HEP control system, where it energizes the left-side TLC relay. This relay provides an indication to the operator of consist TLC status and establishes one of the prerequisites for closing the HEP power contactor. (Refer to Section 2.5 for further details.)

An identical circuit on the right side of the consist is established via HEP trainlines “C” and “D,” with a corresponding right-side TLC relay.

Should a locomotive (power car) be turned end-for-end in the train, as in an MU arrangement, the basic TLC function is maintained, though current routing rearward/forward may be altered.

The locomotive/power car should incorporate a 5 mph speed function such that below 5 mph, the TLC circuitry functions normally. However, above 5 mph, TLC should be bypassed so that an open or intermittent TLC does not result in the HEP being de-energized. If the train then slows below 5 mph, the TLC circuits should again become active and de-energize the HEP if TLC is lost. The purpose of this is to prevent loss of HEP when the train is moving along the railroad; with the large number of jumpers and receptacles in a long train, sometimes jumper control contacts become intermittent from train motion.

### **1.5.2 Active sources**

Since several HEP sources (locomotives and/or power cars and/or DMUs) could be present in a consist at the same time, switching is mandatory so only the “active” HEP source (the one actually supplying HEP) is connected to the TLC trainlines. The TLC circuits revert to “pass-through” on inactive HEP source vehicles. Refer to **Figure 4**. This is essential to prevent false TLC indication, which could otherwise result from the interaction of the HEP control systems of two separate HEP sources.

### **1.5.3 Indicator lights**

The separate left and right indicator lights are important to the operator, because if TLC is not established, it identifies which side of the consist has the problem, reducing the sites to inspect by half.

### **1.5.4 Short-looping**

Passenger train short-looping is a practice used by some railroads to avoid train delays due to certain HEP conduction problems. Short-looping is accomplished by a short jumper cable that electronically connects the two adjacent HEP connectors located on one side of a passenger car or locomotive. The following are the consequences of short-looping:

- It removes TLC detection from all intercar jumper cables located downstream from the short loop that are on the same side of the train as the short loop.
- It requires intercar jumper cables downstream from the short loop, but on the opposite side of the train as the short loop, to carry double the current.
- It requires the under car HEP distribution cables of the first car after and before the short loop to carry double the current.

Short-looping causes the intercar jumper connections downstream from and on the same side of the train as the short loop to be electrically energized and not protected by the TLC circuit. This means there is a potential danger of arcing damage and injury in the event of disconnection of a jumper cable at one of these downstream locations with the HEP still online.

For safety reasons, the TLC relay should not be bypassed except under the considerations listed below. FRA views the 74 V control circuit, which includes the TLC relay, as a safety circuit on trains equipped with HEP. If the TLC relay is bypassed, it would be considered a noncomplying condition under 49 CFR 229.7(a) Prohibited Acts, and a violation would be submitted. FRA would accept bypassing the TLC relay en route based only upon the necessity to restore the 480 V circuit for train heating, lighting and/or air conditioning to protect the well-being of passengers until the train reached the next point where repairs could be made.

After extensive discussions with the FRA, the following policy has been evolved to minimize short-looping and to mitigate the potential danger caused by short-looping:

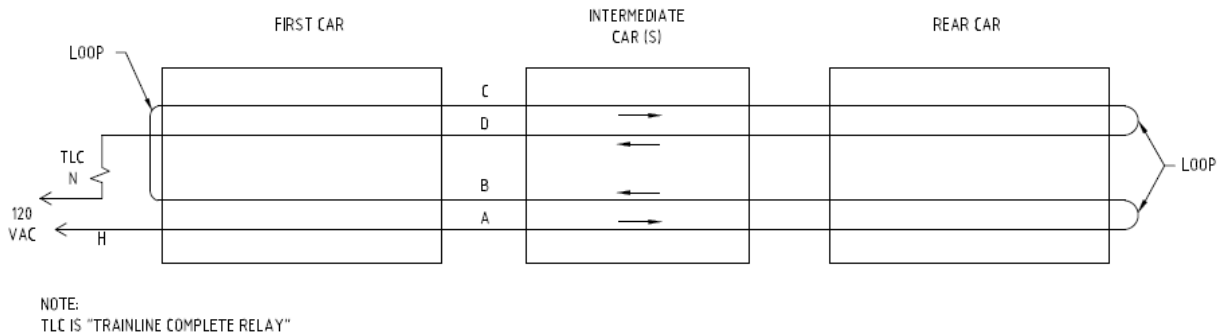
- No work will be done on electrical cables between cars or any portion of the HEP system unless the HEP system is shut down and secured.
- When making up passenger trains in yards, short-looping passenger trains is totally prohibited.
- If the train loses head end power after leaving the yard, attempts will be made to restore the power without resorting to short-looping.
- If the train must be short-looped to avoid a significant delay, the engineer and conductor will be notified in writing.
- If a train is short-looped, the repair points en route will be notified and the problem will be repaired at the train’s destination.

## 1.6 TLC trainline function from wayside

The basic operation of TLC when HEP is fed from a wayside source is similar to that of a train as described in Section 1.5 above, with a few differences (see [Figure 6](#)):

- Only one TLC circuit is provided for both sides of the consist, rather than two.
- The HEP feed end of the consist is also looped, between left and right sides of the consist. This results in the TLC current path through control trainlines “A” to “B” to “C” to “D” and then to the TLC relay.
- No “through” trainline feed switching is provided in the wayside source, since the wayside is always the only active HEP source for the consist.

**FIGURE 6**  
Simplified Trainline Complete (TLC) Operation – Wayside

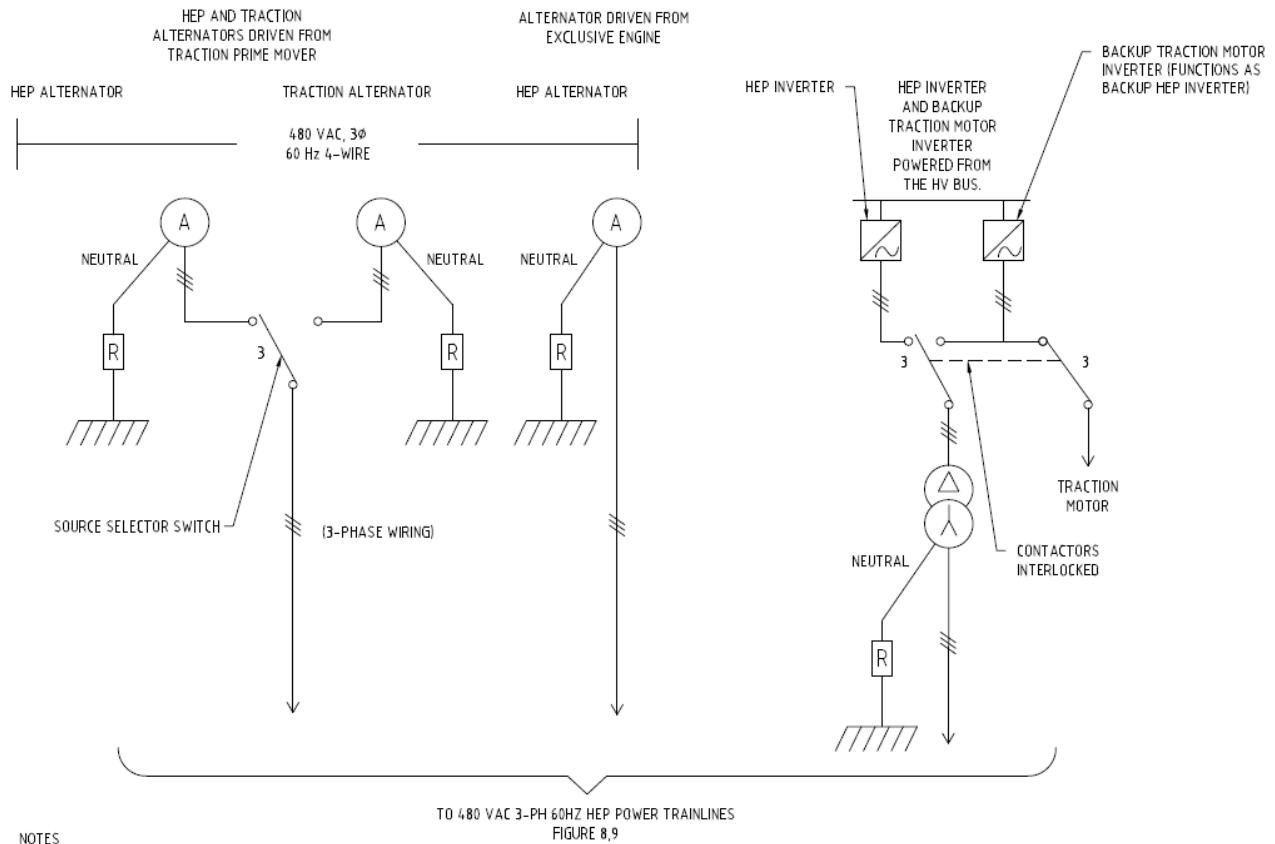


## 2. Vehicle-based HEP sources

The HEP source should be designed to meet the electromagnetic compatibility (EMC) requirements of the authority having jurisdiction in accordance with APTA PR-E-S-010-98, “Development of an Electromagnetic Compatibility Plan.” In addition, while designed to operate with the phase balance load requirements of APTA PR-E-RP-016, the source must be able to operate without difficulty or instability with any phase balance situation, such as a single car whose HVAC system is neither heating nor cooling. At very light loads such as this, phase balance may be poor. The system shall function at all load conditions from full load down to no load without shutdown. For HEP source characteristics, see Section 5.

Refer to [Figure 7](#) for HEP source configurations.

**FIGURE 7**  
 Single-Line Schematics – HEP Sources



NOTES

PHASE ROTATION = A,B,C

THE CIRCLED NUMBERS REFER TO THE RESPECTIVE SECTIONS IN THE DOCUMENT.

## 2.1 Diesel-electric locomotive, alternator driven from traction prime mover

In this arrangement, a single prime mover mechanically drives both a traction and an HEP alternator, providing power for both functions.

### 2.1.1 Engine

The engine should be capable of operating in 3 modes, as determined by the HEP mode switch (see sections 2.5.1 and 2.6.4):

- **HEP Off:** Traditional diesel throttle response for traction.
- **Normal HEP:** Engine operates at a constant speed, regardless of throttle position, and HEP alternator provides HEP to train; traction alternator provides power for traction.
- **Standby HEP:** Engine operates at constant, though reduced speed; traction alternator provides power to HEP loads; no traction power is available.

### 2.1.2 HEP alternator and regulator

The HEP alternator should be rated for continuous operation, as well as overload operation with a service factor, consistent with the authority's specified requirements. The rating should be stated at 480 Vac, 3-phase, 60 Hz with a 0.8 power factor. The machine should be wye-connected, with a high impedance ground

(consistent with the ground fault detection requirements of sections 5.1.2 and 5.2.2) to the locomotive car body.

The alternator should be connected to a suitable voltage regulator, which incorporates a constant voltage-to-frequency ratio feature, over the normal HEP operating speed range of the engine.

### **2.1.3 Traction alternator**

The traction alternator should be rated for continuous HEP operation consistent with the authority's specified requirements. Should the rating be lower than that of the HEP alternator, either electrically or for prime mover restrictions, this should be clearly stated in the builder's documentation; likewise, appropriate overload protection should be provided in the control system.

The alternator should be connected to a suitable voltage regulator, which provides a constant voltage-to-frequency ratio over the normal HEP operating speed range of the engine.

### **2.1.4 Locomotive control system**

The locomotive control system should be configured so that when operating in the normal HEP mode, the requirements for HEP are met first, and the power remaining from the prime mover is available for traction. The majority of the traction engine control, protection and annunciation functionality resides with the locomotive control system.

## **2.2 Locomotive or power car, alternator driven from exclusive engine**

In this arrangement, a dedicated diesel engine (or other type of engine) drives the HEP alternator. This arrangement can also be used in a stationary application to provide wayside power. When used on a locomotive, the entire HEP plant should be completely self-sufficient for continuous operation, not requiring operation of the main engine for any reason whatsoever. This includes, but is not limited to, engine cooling system as well as HEP electrical equipment cooling, control power, etc.

### **2.2.1 Engine**

The engine selected should be well-suited for reliable operation in the railroad environment, consistent with Section 1.3.

It is recommended that the HEP engine be equipped with a layover heat system that keeps the engine warm and allows easy starting and brief warmup times. This system should be powered from the HEP bus, downstream of the line contactor, so it can be fed from an external source, either wayside power or another vehicle.

### **2.2.2 Alternator and regulator**

The HEP alternator should be rated for continuous operation, as well as overload operation with a service factor consistent with the authority's specified requirements. Rating should be stated at 480 Vac, 3-phase, 60 Hz with a 0.8 power factor. The machine should be a wye-connected machine, with a high impedance ground to the locomotive car body.

The alternator should be connected to a suitable voltage regulator, which incorporates a constant voltage-to-frequency ratio feature, over the normal operating speed range of the engine.

### **2.2.3 Engine control system and indicators**

The engine control and protection system should protect the engine from damage, at a minimum including the following indications. Integrated displays, LEDs or lamps may be used; if lamps, they shall be equipped with a lamp-test feature.

- |  |     |
|--|-----|
| • Low lube oil pressure                        | Red |
| • Low coolant level                            | Red |
| • Low lube oil level                           | Red |
| • Hot engine                                   | Red |
| • Overspeed                                    | Red |
| • Crankcase over pressure (diesel engine only) | Red |

An engine start station and control panel should be provided, located near the HEP engine. The enclosure, as well as controls mounted on its exterior, should be specified to be moisture and oil resistant in accordance with applicable NEMA or other standards. Cooling air should be provided when the HEP system is operating to allow the equipment to operate without overheating over the entire vehicle exterior ambient operating range, without regard to the traction engine status. Controls provided at the start station should include the following at a minimum:

- starter fuse with knife switch or circuit breaker (if electric starter)
- air cutout cock (if air starter)
- Start push button
- Stop push button
- Emergency Stop push button
- emergency stop function from MU trainline command (associated with the #3 wire, as described in APTA PR-E-RP-017-99, “27-Point Control and Communication Trainlines for Locomotives and Locomotive-Hauled Equipment”)
- Stop push button, remote mounted in the locomotive cab (locomotive only)

Under normal “Stop” operation, a cooldown period should be provided; however, under “Emergency Stop” no cooldown is allowed.

An HEP engine failure should result in an alarm sounding in the locomotive cab, via energizing the #2 MU trainline circuit, “alarm bell,” as described in APTA PR-E-RP-017-99, “27-Point Control and Communication Trainlines for Locomotives and Locomotive Hauled Equipment.”

Monitor panels, at the engine or other appropriate locations, should include the following gauges at a minimum:

- oil pressure
- engine temperature
- dirty air filter warning
- fuel pressure

### **2.3 Diesel-electric locomotive – inverter HEP**

In this arrangement, a single prime mover drives the main alternator, which usually provides energy for both traction and an HEP inverter via a dc bus.

### **2.3.1 Engine**

The engine should be capable of operating in two modes, as determined by the HEP mode switch (see sections 2.5.1 and 2.6.4):

- **HEP Off:** Traditional diesel throttle response for traction.
- **HEP On:** Engine operates at a throttle-dependent speed; however, traction idle under HEP On condition results in an engine speed higher than normal idle to accommodate large but normal-sized HEP step loads (minimum of 120 kW) without bogging.

### **2.3.2 Inverter**

An isolation transformer with a wye secondary winding should be provided between the HEP inverter and the HEP bus to avoid the risk of inverter DC feed high voltage being applied to the HEP bus in the event of an inverter failure.

The voltage from the HEP inverter shall be suitably filtered to provide a voltage source with appropriate THD as defined in Section 5.

#### **2.3.2.1 HEP inverter**

A solid-state inverter should be provided, rated for continuous operation as well as overload operation with a service factor consistent with the authority's specified requirements. Rating should be stated at 480 Vac, 3-phase, 60 Hz with a 0.8 power factor. The unit should be connected through a high impedance ground to the locomotive car body.

The inverter should be equipped with diagnostic circuitry that provides indication of operating status and defects.

#### **2.3.2.2 Backup inverter**

With the advent of ac traction on many modern locomotives, some locomotives are equipped to allow substituting one of the traction inverters to function in place of the HEP inverter should the latter fail. This approach is recommended, as it allows the train to continue operation at slightly reduced traction performance but still provide power for passenger auxiliaries and safety. The performance characteristics of a traction inverter operating as the HEP source should be essentially equal to those of the HEP inverter described above.

### **2.3.3 Locomotive control system**

The locomotive control system should be configured so that when operating in the HEP mode, the requirements for HEP are met first, and the power remaining from the prime mover is available for traction. The majority of the traction engine control, protection and annunciation functionality should reside with the locomotive control system.

## **2.4 Electric locomotive – inverter HEP**

### **2.4.1 HEP power source**

The main transformer with some form of converter (or third rail) supplies energy to a dc bus. The HEP inverter is fed from this bus. The bus may also provide energy for traction, and if so, regenerative braking should be considered as an energy source for HEP operation.

## **2.4.2 Inverter**

An isolation transformer with a wye secondary winding should be provided between the HEP inverter and the HEP bus to avoid the risk of inverter DC feed high voltage being applied to the HEP bus in the event of an inverter failure.

The voltage from the HEP inverter shall be suitably filtered to provide a voltage source with appropriate THD as defined in Section 5.

### **2.4.2.1 HEP inverter**

A solid-state inverter should be provided, rated for continuous operation and overload operation with a service factor consistent with the authority's specified requirements. Rating should be stated at 480 Vac, 3-phase, 60 Hz with a 0.8 power factor. The unit should be connected through a high impedance ground to the locomotive car body.

The inverter should be equipped with diagnostic circuitry that provides indication of operating status and defects.

### **2.4.2.2 Backup inverter**

With the advent of ac traction on many modern locomotives, some locomotives are equipped to allow substituting one of the traction inverters to function in place of the HEP inverter should the latter fail. This approach is recommended, as it allows the train to continue operation at slightly reduced traction performance, but still providing power for passenger auxiliaries and safety. The performance characteristics of a traction inverter operating as the HEP source should be essentially equal to those of the HEP inverter described above.

## **2.4.3 Locomotive control**

The majority of the dc bus control, protection and annunciation functionality should reside with the locomotive (power car or DMU) control system.

## **2.5 HEP controls**

### **2.5.1 Control panel**

The HEP installation should include one or more control panels to provide the functions described in this section, at a minimum.

#### **2.5.1.1 Controls**

1. Start HEP push button:
  - Commands engine governor to increase engine speed from idle to HEP speed.
  - Initiates inverter operation (when inverter used).
  - Initiates sequence to close line contactor(s).
2. Stop HEP push button:
  - Opens line contactor(s).
  - Commands governor to allow engine to return to idle speed.
  - Shuts off inverter operation (when inverter used).
3. Fault Reset (electrical) push button:
  - Resets electrical faults-overload, etc. It may be combined with Stop HEP button.

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4. HEP Source Selector – locomotive with alternator driven by prime mover:
  - Off position:
    - HEP off on this locomotive.
    - Trainline complete power feed is off.
  - Normal and Standby positions:
    - Configures locomotive to supply HEP in the respective mode (see sections 2.1.1 and 2.6.5).
    - Energizes trainline complete feed and logic.
5. HEP Source Selector – all other applications:
  - Off position:
    - HEP off on this vehicle.
    - Trainline complete power feed is off.
  - Local position:
    - HEP supplied by this vehicle.
    - Energizes trainline complete feed and logic.
6. HEP Trainline Mode Selector – for vehicles equipped with F-end isolation switch:
  - Lead position (long hood trail):
    - F-end receptacles isolated (see Section 2.6.6).
    - Internal loop circuit established for F-end.
  - Trail (short hood trail) and Pass Through positions:
    - F-end receptacles connected to trainline.
    - Internal loop circuit open; F-end now part of TLC circuit.
7. HEP Trainline Mode Selector – for vehicles with split bus only:
  - Left trainline:
    - Trainline complete set up for left trainline bus only.
    - HEP supplied to left trainline bus only.
  - Right trainline:
    - Trainline complete set up for right trainline bus only.
    - HEP supplied to right trainline bus only.
  - Both trainlines:
    - Trainline complete set up for both left and right trainlines (requires both to be satisfied before power applied).
    - HEP supplied to both left and right HEP trainline buses.

**NOTE:** The term “push button” is used in a functional sense; in practice, it may be a physical push button or a touch function on an integrated display unit.

### 2.5.1.2 Indicators

Indicators, or equivalent, equipped with a lamp-test feature, should include the following, at a minimum:

- |   |       |
|---|-------|
| • Trainline complete: left                | green |
| • Trainline complete: right               | green |
| • HEP contactor closed (on this vehicle)* | green |
| • HEP trainline live*                     | amber |
| • HEP fault: over/under voltage           | red   |
| • HEP fault: over/under frequency         | red   |
| • HEP thermal overload trip*              | red   |
| • HEP instantaneous overload trip*        | red   |
| • HEP ground fault                        | amber |

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\*For units with split bus HEP trainline, one indicator should be provided for each trainline.

An HEP system failure (i.e., any abnormal condition resulting in the loss of HEP) should result in an alarm sounding in the locomotive cab, via energizing the #2 MU trainline circuit, “alarm bell,” as described in APTA RP-E-017-99, “27-Point Control and Communication Trainlines for Locomotives and Locomotive Hauled Equipment.”

### **2.5.1.3 Meters**

The following meters and/or screen readouts should be provided to show performance of the HEP system:

- **Voltmeter:** Switchable to each of the 3 phases, reading phase-phase voltage, 2% or better accuracy at 480 Vac.
- **Ammeter:** Switchable to each of the 3 phases, reading phase current, 2% or better accuracy. (For a split bus system, two ammeters and switches are required.)
- **Frequency meter:** Reading the frequency of the HEP source,  $\pm 0.25$  Hz or better accuracy over the range of 55 to 65 Hz.

The meters or screen should be rugged industrial quality, suitable for the operating environment, including but not limited to ambient temperature range as described in Section 1.3. If some form of screen is employed, it is recommended that all 3 phases of voltage and current be displayed simultaneously, rather than having to switch among them.

### **2.5.2 Protection**

Controls for the HEP should include the following protective functions (refer to Section 5 for settings):

- over current: instantaneous and thermal
- over/under voltage
- over/under frequency
- dead bus
- ground fault (indication only, no power shutdown)
- trainline complete (per Section 2.5.3)

### **2.5.3 Trainline complete (TLC)**

A trainline complete function should be incorporated into the HEP control system to ensure that the consist trainline complete is established and maintained in order for the HEP to be on.

There should be a separate TLC trainline for both the left- and right-side trainlines, each provided with its own indicator light to show when continuity has been established.

On single bus systems, safety considerations dictate that both the left and right TLC be complete in order for the line contactor to close.

On split bus systems, the left TLC should control the train left power HEP trainline, while the right TLC should control the train right power HEP bus. For “both” mode, safety considerations dictate that both left and right TLC be established before the line contactors can be closed.

The HEP Source Selector (see Section 2.5.1) should operate so that when the HEP system is not in operation, the electrical feed to the Trainline Complete circuit should be off. The TLC feed should be protected by a circuit breaker, not a fuse.

## 2.6 Switchgear

### 2.6.1 Safety

Safety considerations dictate that HEP electrical equipment be suitably enclosed to protect against accidental contact by personnel. Access doors are required by regulation of both OSHA and FRA (49 CFR 238.303) to have the warning label “Danger 480 volts.”

### 2.6.2 Connections to HEP trainline(s)

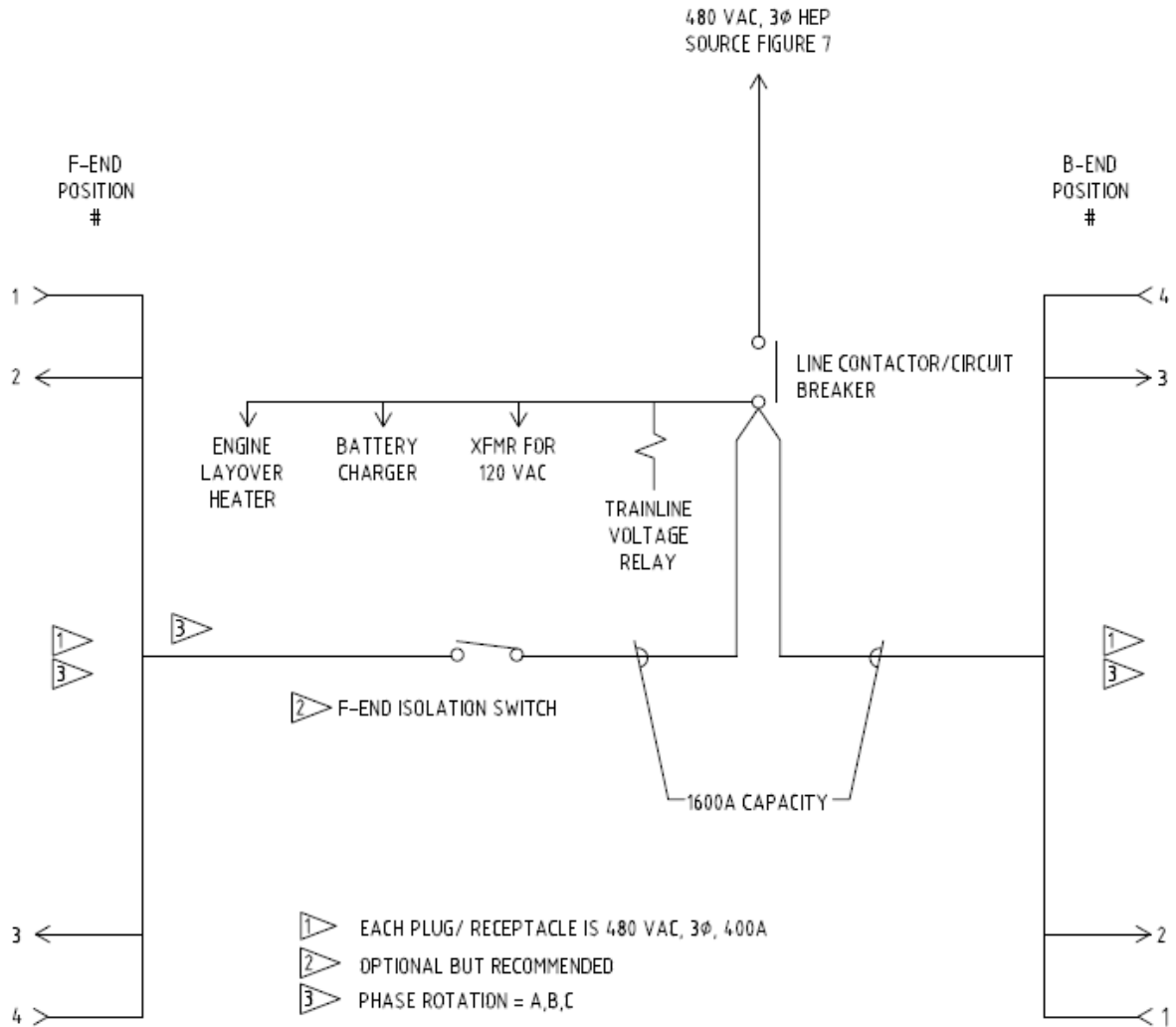
Connections between the HEP source and the HEP trainline should be consistent with Section 1.2 with regard to single or split bus configuration. The connection should take the form of line contactors to isolate the source from the HEP trainlines. The switching device should not take the form of a molded case circuit breaker, as the cycle life is limited. The contactor may also serve as the circuit breaker (provided that the interrupting rating is adequate), or a separate device may be provided.

Trainline connections should be as follows:

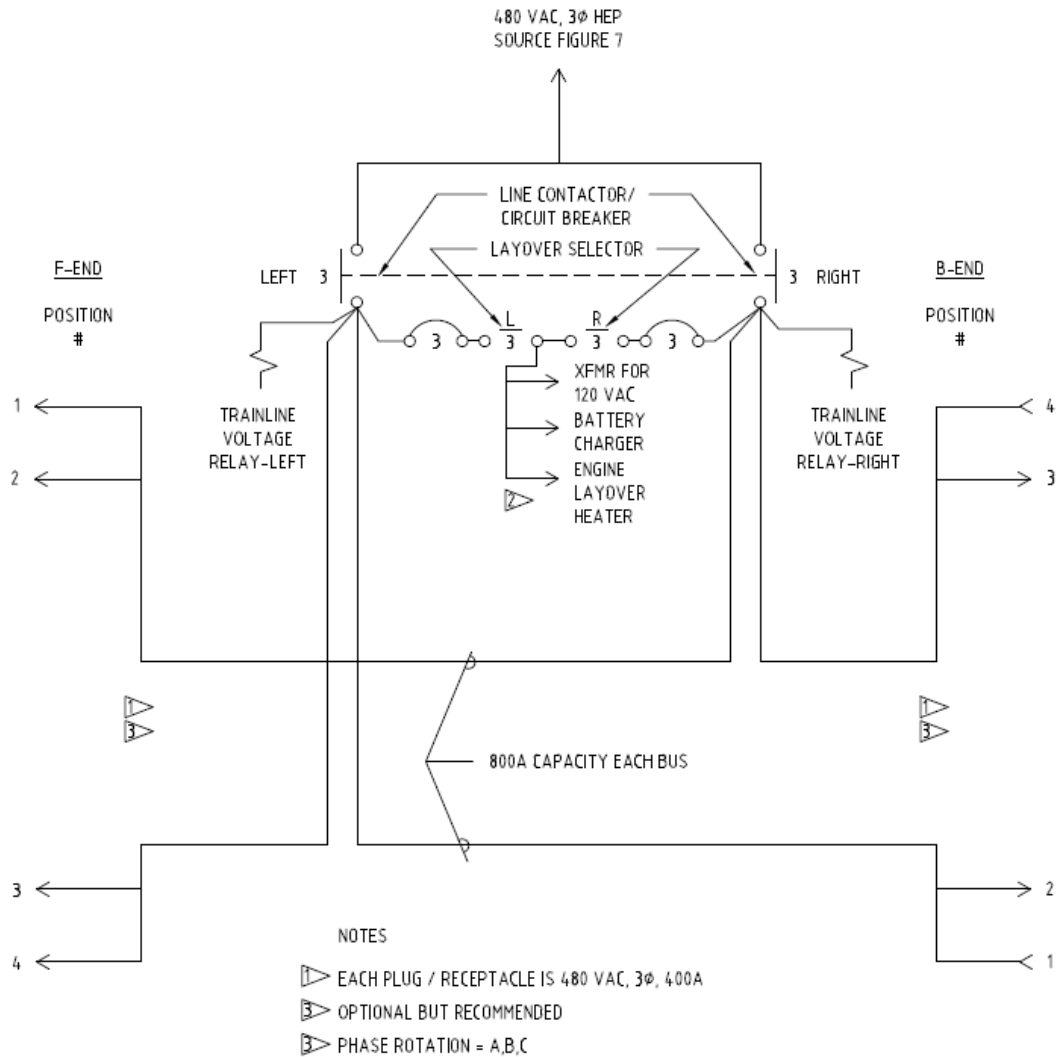
- Single bus configuration: See **Figure 8**.
  - The HEP source should be connected to the trainline through a line contactor.
- Split bus configuration: See **Figure 9**.
  - The HEP source should be connected to the trainlines through separate contactors for the left and right trainlines. The HEP Trainline Mode selector should provide the following options (see Section 2.5.1):
    - left trainline
    - right trainline
    - both trainlines

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**FIGURE 8**  
 Single-Line Schematic – Single Bus 480 V HEP Power Trainline



**FIGURE 9**  
 Single-Line Schematic – Split Bus 480 V HEP Power Trainline



Overload protection should be provided for each contactor separately. The nominal rating of the HEP system should be available from either the left or right trainline, up to the rating of the trainline.

### 2.6.3 Line contactor(s)

The line contactor should be an electromechanical device. It should include thermal and instantaneous overload features to protect the HEP source, or these should be included in a separate circuit breaker.

### 2.6.4 Circuit breaker

If a separate circuit breaker is required beyond the line contactor, it should include suitable overload functions to protect the HEP source.

### 2.6.5 HEP source selector switch

Locomotives equipped with Normal/Standby mode should be equipped with a 480 V switch to determine the source of the HEP, whether HEP alternator or traction alternator. The switch position should be determined by the HEP source selector switch (see [Figure 7](#)).

## **2.6.6 F-end isolation switch**

Locomotives having only a single operating cab and single bus HEP system should be equipped with an HEP F-end isolation switch. This provides improved HEP reliability in the event that F-end HEP receptacles/jumpers suffer impact damage from striking debris (objects on track, such as downed trees, snow/ice berms, grade crossing strikes, etc.). This is especially effective on intercity locomotives.

When installation of the switch is specified by the authority, it should include the following functions:

- Isolation of the F-end receptacles from the locomotive HEP bus.
- A “looping” trainline complete circuit when the switch is in the isolate position. (Thus, the locomotive should not require the jumper cables to be looped on the F-end.)

The switch rating should be 1600 A. This switch should not require control power to maintain it in the closed or open position. Control logic should prevent movement of the switch unless 480 V power is removed. (It is permissible for the switch to require control power for it to change position.)

The position of the switch should be controlled by the HEP Trainline Mode Selector switch on the HEP control panel (see Section 2.5.1). Refer to **Figure 4** and **Figure 8** for schematics.

## **2.7 Trainline connections**

### **2.7.1 Phase rotation**

Phase rotation should be A, B, C with HEP power pins designated 1 = A, 2 = B, 3 = C.

### **2.7.2 Physical connections**

The trainline should be configured to provide continuity between the ends of the vehicle for both power and control (TLC) circuits without regard to whether HEP is being provided by that unit.

The pass-through capacity of the HEP trainline should meet the recommended practices of APTA PR-E-RP-016-99, “480 Vac Head End Power System.”

### **2.7.3 Battery charger**

A battery charger, powered from the HEP bus downstream of the line contactor, should be provided. The charger should provide a redundant method of charging the HEP system battery (which might be the locomotive main battery) such that should the battery be fully discharged, it can be easily recharged by applying external power to the HEP receptacles.

## **3. Wayside power**

### **3.1 General**

Wayside power can take one of two forms:

- utility-supplied energy
- engine-driven supplied energy

In either case, the power should be provided to the rail vehicles from wayside receptacles arranged with a pair of receptacles at each wayside outlet box location. This can be a single site, or multiple outlets, one per track. Each outlet box should be provided with its own control station and switch gear to allow each box to be completely independent of the others, including all fault protections. The purpose is to prevent a fault on one consist from removing HEP power from any outlet box location other than its own.

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For applications requiring more than 800 A of wayside power to a single consist, the installation shall be similar, except four HEP receptacles shall be used, so as to not exceed the rating of the individual jumpers and maintaining 480V HEP bus safety via the trainline complete circuit. As the 480V HEP bus (including the jumper cables) is limited to a per-phase ampacity of 1600 A, the circuit breaker supplying power to that outlet box must not exceed 1600 A to avoid overloading the jumper cables.

For outlet boxes with four receptacles, the control system design shall ensure that the trainline complete (TLC) function requires both sides of the consist to have all jumpers in place before HEP can be supplied. It is recommended that the 480V HEP cabinets have individual left and right side TLC circuit indicating lights to show when TLC is achieved on that side. This is an aid in trouble shooting to make identifying the site when TLC is not achieved easier to find.

### **3.1.1 Fault current interruption**

Due to increasing wayside power loads, larger transformers are being used which can high fault currents. Circuit breaker interrupting capacity and possibly fusing, must be coordinated with available fault current of the transformer feeding the HEP outlet boxes. This includes the car-borne main circuit breakers.

Worst-case / available fault current as calculated at the headend power source's receptacles shall not exceed 35 kA at 480 Vac. This is needed to ensure coordination with the kilo-Ampere Interrupting Capacity (kAIC) ratings of the carborne circuit breakers and other equipment. For more information, see PR-E-RP-016-99."

## **3.2 Power sources**

### **3.2.1 Utility source**

The power source should take the form of a utility-fed step-down transformer, rated for continuous operation consistent with the authority's specified requirements (see **Figure 10**). Recommended capacity is 400 or 800 A per outlet box. Rating should be stated at 480 Vac, 3-phase, 60 Hz with a 0.8 power factor. The transformer should have a grounded, wye-connected secondary. In locations where the railroad employs electric traction on the tracks supplied with HEP, the grounding scheme should be coordinated with that of the traction system to prevent circulating currents occurring from a different potential between rails and HEP source grounds. Suitable transformer primary protection should be provided.

The design of the control system should be such that loss of control power should result in the HEP being shut off to the outlet boxes.

### **3.2.2 Engine-driven source**

The power source should be as described in Section 2.2.

## **3.3 Control panels**

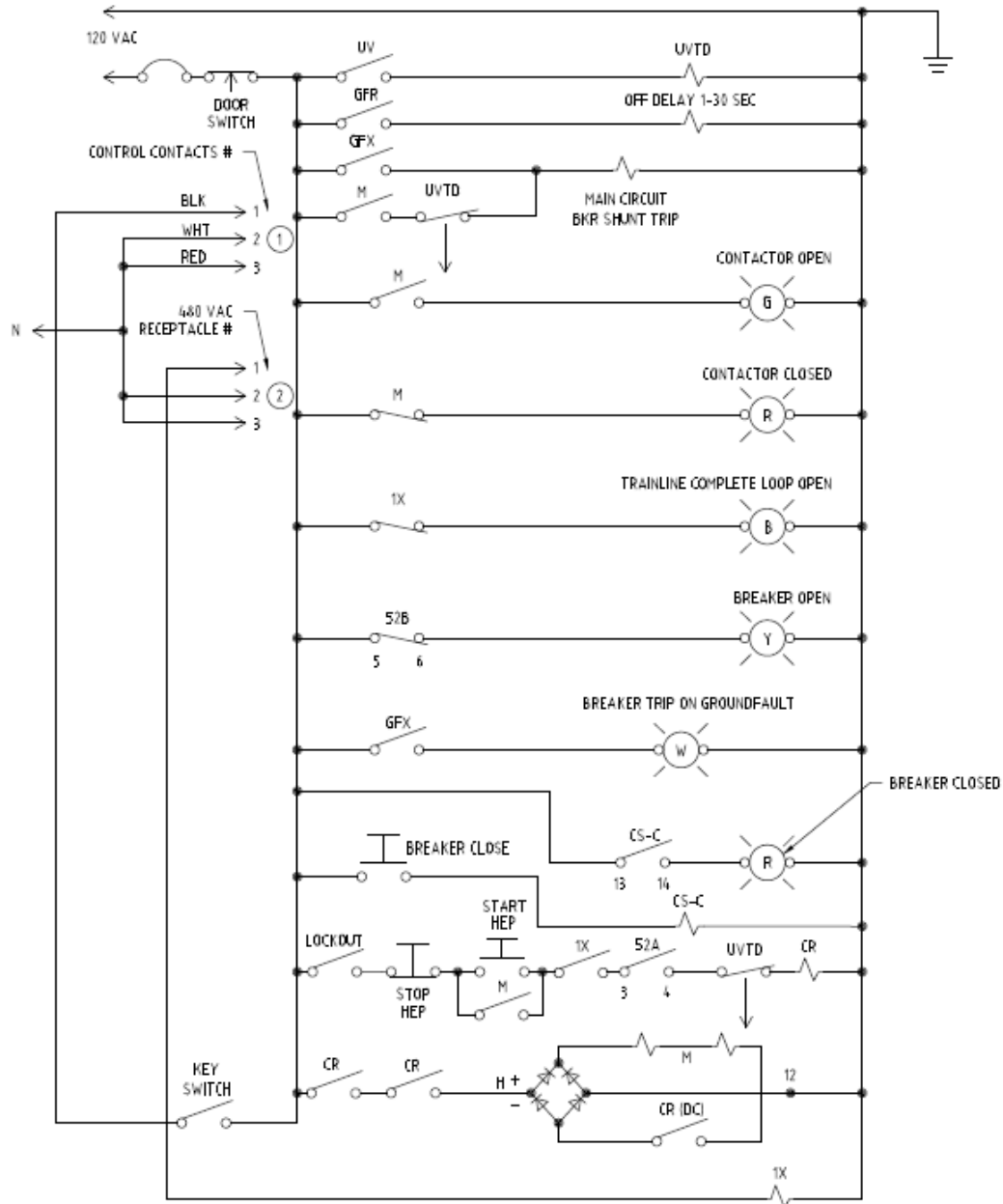
### **3.3.1 Utility-based wayside power**

#### **3.3.1.1 Controls**

Each wayside outlet box should be provided with a trackside control panel, which includes the following controls (see **Figure 10**):

- key switch (to allow only authorized personnel the ability to energize the system)
- Start HEP
- Stop HEP
- lockout control (to disable the control station)

**FIGURE 10**  
 480 V Wayside HEP Control Schematic



**3.3.1.2 Indicators**

Each trackside control panel should include the following indicator lights, equipped with a lamp-test feature:

- Contactor open green
- Contactor closed red
- Trainline complete loop open blue
- Circuit breaker open yellow
- Circuit breaker open from ground fault white
- Circuit breaker closed red

### **3.3.1.3 Meters**

The central control panel should be provided with the following meters to show performance of the overall HEP system:

- **Voltmeter:** Switchable to each of the 3 phases, reading phase-phase voltage, 0.2% or better accuracy at 480 Vac.
- **Ammeter:** Switchable to each of the 3 phases, reading phase current, 2% or better accuracy.

The meters should be rugged industrial quality, suitable for the specified operating environment, including but not limited to the temperature range (which may be in excess of outside ambient temperature). If some form of screen is employed, it is recommended that all 3 phases of voltage and current be displayed simultaneously, rather than having to switch among them.

### **3.3.2 Engine-driven source wayside power**

The trackside control panel should have the controls and indicators as described in Section 3.3.1.

The meters described above should be provided in a location near the engine. In addition, the following industrial quality instrument should be provided:

- Frequency meter: Reading the frequency of the HEP source,  $\pm 0.25$  Hz over the range of 55 to 65 Hz.

### **3.3.3 Protection: Utility source HEP**

Controls for the HEP should include the following protective functions (refer to Section 5.5 for settings):

- over current: instantaneous and thermal
- under voltage
- ground fault
- dead bus (recommended only in situations where there is a likelihood of backfeed from the vehicle source)

### **3.3.4 Protection: Engine-driven source HEP**

Controls for the HEP should include the following protective functions (refer to Section 5.2 for settings):

- over current: instantaneous and thermal
- over/under voltage
- over/under frequency
- ground fault
- dead bus (recommended only in situations where there is a likelihood of backfeed from the vehicle source)

### **3.3.5 Trainline complete**

A trainline complete function should be incorporated into each trackside wayside control system to ensure that the consist trainline complete is established and maintained in order for the HEP to be on. The key switch should operate so that when the HEP system is not in operation, the electrical feed to the trainline complete circuit should be off. The TLC feed should be fused or protected by a circuit breaker, the latter preferred.

### 3.4 Switchgear

The connections between the HEP source and outlet box(es) should include a line contactor and separate circuit breaker for each outlet box.

#### 3.4.1 Line contactor

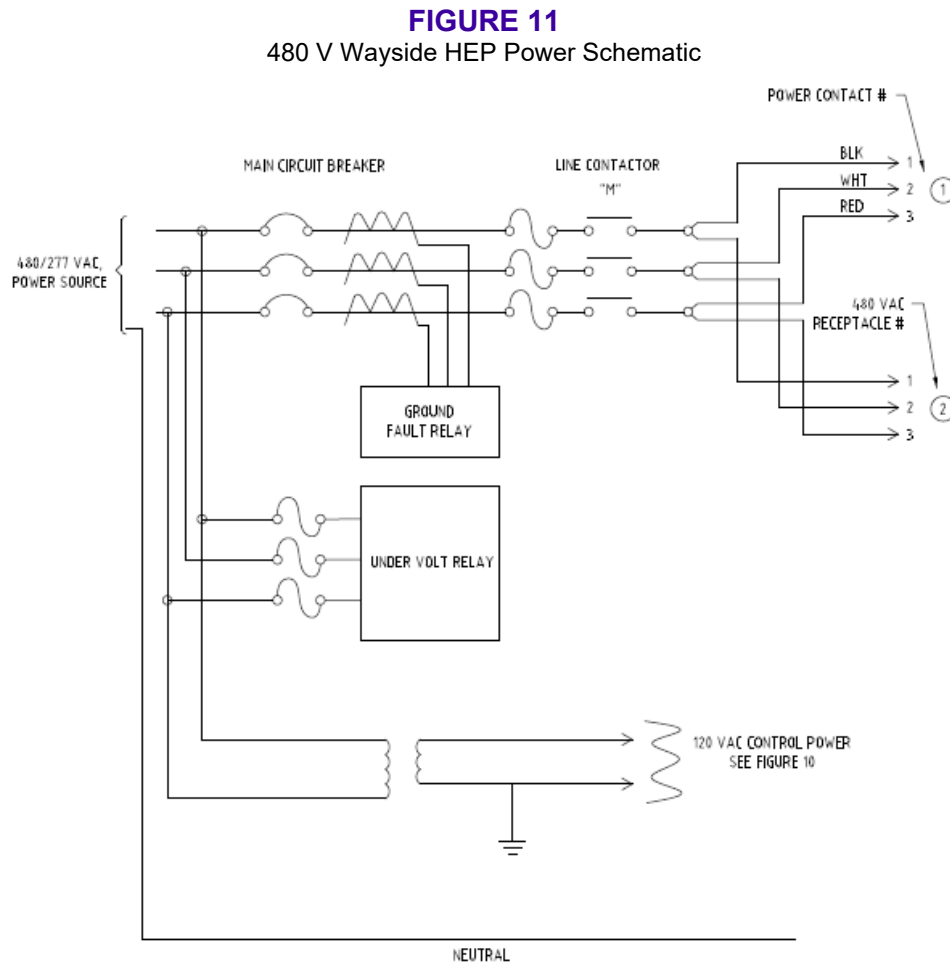
This should be a suitably sized NEMA-rated contactor.

#### 3.4.2 Circuit breaker

A separate circuit breaker should be provided for each outlet box to provide overload and ground fault protection.

### 3.5 Trainline connections

Refer to [Figure 11](#).



#### 3.5.1 Phase rotation

Phase rotation should be A, B, C with HEP power pins designated 1 = A, 2 = B, 3 = C.

### **3.5.2 Wayside outlet box**

The wayside outlet box should consist of a waterproof enclosure in accordance with the authority's specification, equipped with a pair of 480 Vac receptacles and housings, per APTA PR-E-RP-018-99, "480 Vac Head End Power Jumper and Receptacle Hardware."

Warning labels should be provided at the receptacles, which should be painted red.

### **3.5.3 Physical connections**

Suitable cabling should be provided to connect the power source, switchgear and wayside outlet box to allow continuous operation at rated capacity. Wire size should ensure that voltage drop between the source and receptacles does not exceed 0.5%.

### **3.5.4 Battery charger**

A battery charger, powered from the HEP bus downstream of the line contactor, should be provided, except on utility applications. The charger should provide a redundant method of charging the engine-starting battery, such that should the battery be fully discharged it can be easily recharged by applying external power to the HEP receptacles.

## **4. Tests**

### **4.1 Production tests**

Each HEP system should undergo a complete set of tests on the entire system, demonstrating the functions listed in this section.

#### **4.1.1 Insulation**

Insulation resistance and dielectric tests should be conducted in accordance with the requirements of APTA PR-E-S-001-98, "Electrical Insulation Integrity."

#### **4.1.2 Continuity**

Continuity tests should be conducted in accordance with the requirements of APTA PR-E-S-001-98 to ensure the following:

1. Continuity exists between all intended contacts of all receptacles.
2. Continuity exists between trainlines and each vehicle connection to the trainline circuits.
3. No wires are unintentionally grounded.
4. No wires are shorted nor cross-connected to unintended circuits.

#### **4.1.3 Functional tests**

##### **4.1.3.1 Trainline complete**

1. Verify that the TLC functions correctly on both ends and both sides of the locomotive. This includes the following, at a minimum:
  - Each TLC relay (or equivalent) causes HEP lockout.
  - Left- and right-side TLC indications within the locomotive cab coincide with left and right sides of the locomotive relative to the engineer facing forward. This should be done from both ends of the vehicle, since left and right are reversed with orientation.
2. Verify operation of all modes of source selector switch: Off, Normal/Standby.
3. Verify operation of F-end isolation switch: lead/trail on locomotives so equipped.

#### **4.1.3.2 HEP power source**

1. Verify operation of each control, both engine and electrical.
2. Verify operation of each indicator.
3. Verify operation of each meter/screen readout.
4. Verify overcurrent protection, instantaneous and thermal.
5. Verify operation of over-voltage, under-voltage, over-frequency and under-frequency protection.
6. Verify correct phase rotation at one of the 480 V trainline receptacles or jumpers.
7. On locomotives equipped with Normal/Standby modes, verification of proper functioning of all features is required from both HEP alternator and the main alternator, including phase rotation.
8. On inverter-equipped locomotives that also allow traction inverter as a backup verify that the HEP system operates correctly in both modes of operation, including that TLC causes HEP lockout when interrupted from both inverters and including phase rotation.

#### **4.2 Vehicle proof-of-design test**

An engineering proof-of-design type test should be conducted on the new vehicles.

##### **4.2.1 New vehicle tests**

At a minimum, a pair of vehicles should be tested, but should there be more than one vehicle type, all types should be included in the test. This is in addition to compatibility testing with all types of existing vehicles with which the new equipment is to be operated.

##### **4.2.2 Functional tests**

For locomotives (or power cars), tests should verify the correct function of TLC circuits and indications under all the following conditions:

1. Two new locomotives (or power cars), coupled back to back:
  - HEP from lead unit
  - HEP from rear unit
  - pass-through
2. Two new locomotives (or power cars) coupled elephant style (both facing the same direction):
  - HEP from lead unit
  - HEP from rear unit
  - pass-through
3. On inverter-equipped locomotives that also allow traction inverter as a backup, that the HEP system operates correctly in both modes of operation, including all aspects and indications.

Where the new locomotives (or power cars) will be used with a fleet of existing older locomotives, the above tests should be made with all possible permutations of configuration with one each old and new coupled.

##### **4.2.3 Total harmonic distortion (THD)**

Each power source should be tested for total harmonic distortion to verify that it does not exceed the requirements in Section 5. On locomotives with Normal/Standby function, both HEP alternators must be tested. On locomotives with traction inverter backup of the HEP inverter, both inverters must be tested.

Images of the waveform and measurement of the harmonic distortion of the HEP should be taken under different load conditions, ranging from no load in steps up to full rated load with a minimum of 3 steps in between. When more than one power source is available, each should be so recorded.

#### **4.2.4 Electromagnetic compatibility**

Where the new locomotives will be used with a fleet of new and/or existing equipment, electromagnetic compatibility testing should be conducted in accordance with APTA PR-E-S-010-98, “Development of an Electromagnetic Compatibility Plan.”

#### **4.3 Vehicle load test**

Each HEP system should undergo a load box test, in accordance with APTA PR-E-RP-011-98, “Head End Power Load Testing.” On locomotives with Normal/Standby function, both HEP alternators must be tested. On locomotives with traction inverter backup of the HEP inverter, both inverters must be tested. In addition, for situations where the HEP source is new to the customer, a light load test should be conducted to verify acceptable performance with the passenger cars with which it will be used. This should include operation with a single car under minimal load conditions, such as with the HVAC system off. This is to verify source stability and freedom from EMC issues under light load, and/or possibly poor phase balance conditions.

#### **4.4 Wayside power commissioning tests**

The wayside HEP system should undergo a complete set of commissioning tests on the entire system, demonstrating the functions on each wayside outlet box:

1. Verify operation of each control.
2. Verify operation of each indicator.
3. Verify operation of each meter.
4. Verify operation of all trainline complete features, including that opening TLC should result in HEP shutdown.
5. Verify operation of overcurrent protection: instantaneous and thermal.
6. Verify calibration of the ground fault trip setting.
7. Verify operation of under-voltage trip.
8. Verify operation of over-voltage, under-voltage, over-frequency and under-frequency protection (for engine-driven source wayside only).
9. Demonstrate HEP shutdown upon loss of control power.
10. Demonstrate that the HEP system can deliver full rated power to each wayside outlet and full system rated capacity.
11. Demonstrate that the voltage at the receptacles is specification-compliant at full rated load of the system.
12. Demonstrate that when a fault condition causes HEP to shut down, it affects only the outlet box with the fault, not the others.
13. Demonstrate correct phase rotation at each wayside receptacle.
14. For engine-driven source wayside, verify operation of each engine control indicator and gauge.

### **5. HEP source characteristics**

**NOTE:** Guidance on suitable steady-state and transient response characteristics available from sources such as IEEE tends to be based on the performance of utility power supply systems. The values given herein are based on the best information available at the time this document was published. The public-domain ITI (CBEMA) curve listed in the references and included here as Appendix A, while written for information technology equipment, is consistent with IEEE sources, and measured performance of locomotive HEP sources indicates it is applicable as guidance in railroad applications.

## 5.1 Diesel electric locomotive with traction engine driven alternator HEP source

### 5.1.1 Steady state

Parameter	Voltage (max)	Frequency (max)
Regulation	2%	1 Hz
Stability at constant load	±1%	±1 Hz
Dip, full load applied in two equal steps	30%	(n/a)
Recovery, full load applied in two equal steps	To -20% in 0.5 seconds, to regulation in 3 seconds	To regulation in 5 seconds
Total harmonic distortion	5% from 10% to 100% load	(n/a)

**NOTE:** Special attention should be paid to harmonic contents greater than 5% at light load. This is specifically important for short consists, as the consist may draw much less than 10% of the rated HEP load.

### 5.1.2 Shutdown/alarm

Parameter	Low Limit	High Limit	Units
Voltage	440	510	Volts (ac rms)
Frequency	56	64	Hz
Ground fault indication	(n/a)	1.0	Ampere (ac rms)

## 5.2 Locomotive, power car or wayside with HEP alternator driven by dedicated engine source

### 5.2.1 Steady state

Parameter	Voltage (max)	Frequency (max)
Regulation	2%	1 Hz
Stability at constant load	±1%	±1 Hz
Dip, full load applied in two equal steps	-30%	(n/a)
Recovery, full load applied in two equal steps	To -20% in 0.5 seconds, to regulation in 3 seconds	To regulation in 5 seconds
Total harmonic distortion	5% from 10% to 100% load	(n/a)

**NOTE:** Special attention should be paid to harmonic contents greater than 5% at light load. This is specifically important for short consists as the consist may draw much less than 10% of the rated HEP load.

### 5.2.2 Shutdown/alarm

Parameter	Low Limit	High Limit	Units
Voltage	440	510	Volts (ac rms)
Frequency	56	64	Hz
Ground fault indication	(n/a)	1.0	Ampere (ac rms)

### 5.3 Diesel-electric locomotive with inverter HEP source

#### 5.3.1 Steady state

Parameter	Voltage (max)	Frequency (max)
Regulation	2%	1 Hz
Stability at constant load	±1%	±1 Hz
Dip, full load applied in two equal steps	-30%	(n/a)
Recovery, full load applied in two equal steps	To -20% in 0.5 seconds, to regulation in 3 seconds	To regulation in 5 seconds
Total harmonic distortion:	5% from 10% to 100% load	(n/a)

**NOTE:** Special attention should be paid to harmonic contents greater than 5% at light load. This is specifically important for short consists as the consist may draw much less than 10% of the rated HEP load.

#### 5.3.2 Shutdown/alarm

Parameter	Low Limit	High Limit	Units
Voltage	440	510	Volts (ac rms)
Frequency	56	64	Hz
Ground fault indication	(n/a)	1.0	Ampere (ac rms)

### 5.4 Electric locomotive with inverter HEP source

#### 5.4.1 Steady state

Parameter	Voltage (max)	Frequency (max)
Regulation	2%	1 Hz
Stability at constant load	±1%	±1 Hz
Dip, full load applied in two equal steps	-30%	(n/a)
Recovery, full load applied in two equal steps	To -20% in 0.5 seconds, to regulation in 3 seconds	To regulation in 5 seconds
Total harmonic distortion	5% from 10% to 100% load	(n/a)

**NOTE:** Special attention should be paid to harmonic contents greater than 5% at light load. This is specifically important for short consists as the consist may draw much less than 10% of the rated HEP load.

#### 5.4.2 Shutdown/alarm

Parameter	Low Limit	High Limit	Units
Voltage	440	510	Volts (ac rms)
Frequency	56	64	Hz
Ground fault indication	(n/a)	1.0	Ampere (ac rms)

## 5.5 Wayside with utility source

### 5.5.1 Shut down/alarm

Parameter	Low Limit	High Limit	Units
Voltage	440	510	Volts (ac rms)
Ground fault indication	(n/a)	1.0	Ampere (ac rms)

## **Related APTA standards**

**APTA PR-E-S-001-99**, “Electrical Insulation Integrity”

**APTA PR-E-RP-002-98**, “Installation of Wire and Cable on Passenger Rolling Stock”

**APTA PR-E-RP-009-98**, “Ampacities for Wire and Cable Used on Passenger Rolling Stock with Flame, Smoke, and Toxicity Considerations”

**APTA PR-E-S-010-98**, “Development of an Electromagnetic Compatibility Plan”

**APTA PR-E-RP-011-98**, “Head End Power Load Testing”

**APTA PR-E-RP-016-99**, “480 Vac Head End Power System”

**APTA PR-E-RP-017-99**, “27-Point Control and Communication Trainlines for Locomotives and Locomotive Hauled Equipment”

**APTA PR-E-RP-018-99**, “480 Vac Head End Power Jumper and Receptacle Hardware”

## **References**

Code of Federal Regulations, 49 CFR §229, Railroad Locomotive Safety Standards, Section 7(a), Prohibited Acts, July 2019

Information Technology Industry Council, Application Note and Curve, Voltage versus Duration.

PRIIA specifications:

305-005: Specification for Diesel-Electric Passenger Locomotives

305-007: Specification for Trainset

305-009: Specification for Diesel Multiple Units (DMUs)

305-011: Specification for Dual Mode (DC 3rd Rail) Passenger Locomotives

## **Definitions**

**dead bus protection:** A control system feature that confirms that the HEP bus is not energized (dead bus) before allowing the local output contactor to close. This prevents inadvertently connecting two HEP sources to the same bus.

**fixed jumper:** A variation of an HEP jumper cable in which only one end is provided with a plug, while the remaining end is provided with a flange for mounting on a vehicle. This approach is taken to permanently affix the jumper to the vehicle and reduce the number of contacts, since they are present on only one end rather than two.

**head end power (HEP):** A system by which 480 Vac 3-phase electrical power, to operate auxiliaries, is provided to railroad vehicles from a central source via a trainline system. The power source can be locomotive (hence “head end”), power car or wayside source.

**HEP jumper cable:** A cable assembly having the necessary power and control conductors and equipped with a plug on one or both ends, which is used to provide a flexible electrical connection between two cars and/or locomotives or wayside equipment.

**HEP receptacles:** The receptacles mounted on the ends of rail vehicles and wayside equipment into which the HEP jumper cables mate.

**HEP source:** A source of head end power, contained in a locomotive, power car or from a wayside power connection.

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**HEP switchgear:** The contactors, circuit breakers, power switches, overload protection and associated control components used to connect the HEP power source to the trainline system.

**HEP system, single bus:** A form of HEP transmission system in which there is a single electrical bus running the length of the train. All four jumpers connecting adjacent vehicles are wired in parallel.

**HEP system, split bus:** A form of HEP transmission system in which there are two independent electrical buses running the length of the train, a train left and train right (relative to the forward direction of the train). The buses may be fed HEP independently from separate sources, such as two locomotives. Two of the jumpers connecting vehicles are wired in parallel to the left bus, and two to the right bus. Vehicle loads may be divided so as to take some power from each bus.

**HEP trainline:** An electrical cable system that allows HEP to be transmitted over the entire length of a train. It includes both power and control conductors. The trainline may provide power to equipment in each vehicle or may simply pass straight through, providing a power path between vehicles on opposite ends of that vehicle.

**load box:** A piece of wayside equipment used to provide a test load for an HEP source to allow its performance to be measured. The equipment consists of a variable resistance load, cooling fan, load control switching, control panel and instrumentation.

**looping:** The process of connecting a jumper cable between two adjacent receptacles (or a fixed jumper and adjacent receptacle) on the same vehicle. This is normally done on the exposed end of the first and last vehicles of a train and establishes the trainline complete circuit. Locomotives having the F-end HEP receptacles disconnected through the use of an isolation switch use an internal loop circuit and do not require an F-end loop.

**NOTE:** When wayside power is applied via the end of the consist, the far end of the train is looped in the normal fashion, the wayside feed end is looped between left and right sides of the train, and the wayside power is connected with one jumper on each side of the train.

**Normal mode:** On a locomotive where the prime mover drives both the traction alternator and the HEP alternator, the operating mode in which HEP is supplied by the HEP alternator.

**portable jumper:** A form of an HEP jumper cable in which both ends are provided with plugs. This approach is taken to allow the jumper cable to be easily removed from the vehicle and moved elsewhere.

**power car:** For purposes of this document, a power car is a rail vehicle, other than a locomotive, containing an HEP source and control system. This generally takes the form of a baggage car or a car converted from a locomotive that has had the traction system removed.

**short-looping:** The process of looping the HEP jumpers at points other than the ends of the train. This is used in an emergency situation such as a damaged jumper on the road to bypass an open trainline complete circuit on one side of the train.

**CAUTION:** When short-looped, vehicles behind the short-loop site do not have the TLC indication or control interlock at the HEP controls, even though the 480 Vac circuits may be live.

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**Standby mode:** On a locomotive where the prime mover drives both the traction alternator and the HEP alternator, the operating mode in which HEP is supplied by the traction alternator. In this mode, the locomotive cannot supply traction power. This mode is used primarily in terminals since the engine should consume less fuel and generate less noise when operating in this mode, as it operates at a lower speed than in Normal mode.

**trainline complete (TLC):** A series continuity check circuit, originating at the HEP control system, used to determine that all HEP trainline jumper cables throughout the entire length of the consist are plugged in correctly. The circuit provides an indication at the HEP control panel and is interlocked with the HEP main contactor/circuit breaker to allow the trainlines to be energized only when the TLC is established.

**CAUTION:** The practice of short-looping will negate the TLC protection and is generally prohibited except when absolutely necessary to protect the health and well-being of passengers.

**wayside power:** An installation that provides HEP from a ground-based source, used to provide power to the consist when the onboard source is unavailable, such as in a yard. Generally, utility power is used, though sometimes a diesel generator is provided.

## **Abbreviations and acronyms**

<b>A</b>	amperes
<b>ac</b>	alternating current
<b>CBEMA</b>	Computer and Business Equipment Manufacturers Association
<b>CFR</b>	Code of Federal Regulations
<b>dc</b>	direct current
<b>DMU</b>	diesel multiple unit
<b>EMC</b>	electromagnetic compatibility
<b>FRA</b>	Federal Railroad Administration
<b>HEP</b>	head end power
<b>HVAC</b>	heating, ventilation and air conditioning
<b>Hz</b>	hertz
<b>IEEE</b>	Institute of Electrical and Electronics Engineers
<b>ITI</b>	Information Technology Industry Council
<b>kW</b>	kilowatts
<b>LED</b>	light-emitting diode
<b>MU</b>	multiple unit
<b>NEMA</b>	National Electrical Manufacturers Association
<b>OSHA</b>	Occupational Safety and Health Administration
<b>PRIIA</b>	Passenger Rail Investment and Improvement Act of 2008
<b>rms</b>	root mean squared
<b>TLC</b>	trainline complete
<b>V</b>	volts
<b>Vac</b>	volts alternating current

**APTA PR-E-RP-015-99, Rev. 2**  
**Head End Power Source Characteristics**

**Document history**

Document Version	Working Group Vote	Public Comment/ Technical Oversight	CEO Approval	Policy & Planning Approval	Publish Date
First published	—	—	—	—	Aug. 28, 1999
First revision	—	—	—	—	March 22, 2004
Second revision	Nov. 16, 2025	Jan. 30, 2026	April 19, 2026	May 5, 2026	May 13, 2026

The passenger rail industry phased this recommended practice into practice over the six-month period from July 1 to December 31, 1999. The recommended practice took effect January 1, 2000.

**Figure sources**

Figure	Illustration Name	Source	Comments
1	Typical Consist HEP Jumper Cable Arrangement	PR-E-RP-016, Figure 1	
2	Locomotive/Power Car/MU 480 V Trainline Power Schematic – Single Bus	Modified from -016, Figure 3	Reference note at top is different
3	Locomotive/Power Car/MU 480 V Trainline Power Schematic – Split Bus	Modified from -016, Figure 5	Reference note at top is different
4	Simplified Locomotive/Power Car/MU 480 V Trainline Control Schematic	PR-E-RP-016, Figure 7	
5	Simplified Trainline Complete (TLC) Operation – Train	PR-E-RP-016, Figure 8	
6	Simplified Trainline Complete (TLC) Operation – Wayside	PR-E-RP-016, Figure 9	

## Appendix A (informative): ITI (CBEMA) Application Note and Curve

### ITI (CBEMA) CURVE APPLICATION NOTE

The ITI (CBEMA) Curve, included within this Application Note, is published by Technical Committee 3 (TC3) of the Information Technology Industry Council (ITI, formerly known as the Computer & Business Equipment Manufacturers Association). It is available at <http://www.itic.org/technical/iticurv.pdf>.

#### 1) SCOPE

The ITI (CBEMA) Curve and this Application Note describe an AC input voltage envelope which typically can be tolerated (no interruption in function) by most Information Technology Equipment (ITE). The Curve and this Application Note comprise a single document and are not to be considered separately from each other. They are not intended to serve as a design specification for products or AC distribution systems. The Curve and this Application Note describe both steady-state and transitory conditions.

#### 2) APPLICABILITY

The Curve and this Application Note are applicable to 120V nominal voltages obtained from 120V, 208Y/120V, and 120/240V 60Hz systems. Other nominal voltages and frequencies are not specifically considered and it is the responsibility of the user to determine the applicability of these documents for such conditions.

#### 3) DISCUSSION

This section provides a brief description of the individual conditions which are considered in the Curve. For all conditions, the term "nominal voltage" implies an ideal condition of 120V RMS, 60Hz.

Seven types of events are described in this composite envelope. Each event is briefly described in the following sections, with two similar line voltage sags being described under a single heading. Two regions outside the envelope are also noted. All conditions are assumed to be mutually exclusive at any point in time, and with the exception of steady-state tolerances, are assumed to commence from the nominal voltage. The timing between transients is assumed to be such that the ITE returns to equilibrium (electrical, mechanical, and thermal) prior to commencement of the next transient.

##### 3.1) Steady-State Tolerances

The steady-state range describes an RMS voltage which is either very slowly varying or is constant. The subject range is

+/- 10% from the nominal voltage. Any voltages in this range may be present for an indefinite period, and are a function of normal loadings and losses in the distribution system.

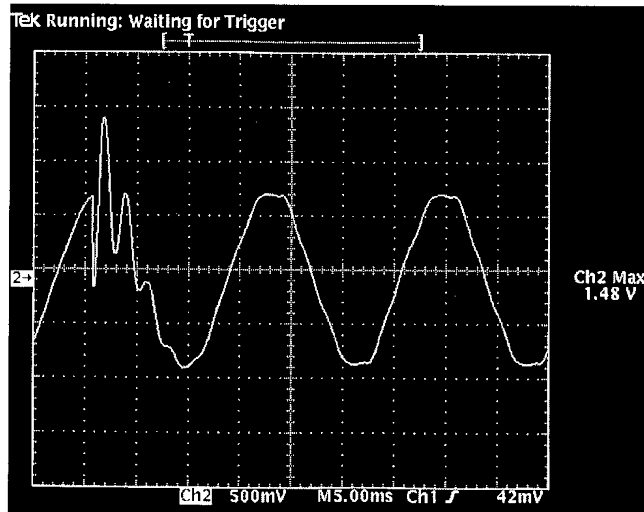
##### 3.2) Line Voltage Swell

This region describes a voltage swell having an RMS amplitude of up to 120% of the RMS nominal voltage, with a duration of up to 0.5 seconds. This transient may occur when large loads are removed from the system or when voltage is supplied from sources other than the electric utility.

##### 3.3) Low-Frequency Decaying Ringwave

This region describes a decaying ringwave transient which typically results from the connection of power-factor-correction capacitors to an AC distribution system. The frequency of this transient may range from 200Hz to 5KHz, depending upon the resonant frequency of the AC distribution system. The magnitude of the transient is expressed as a percentage of the peak 60Hz nominal voltage (not the RMS value). The transient is assumed to be completely decayed by the end of the half-cycle in which it occurs. The transient is assumed to occur near the peak of the nominal voltage waveform. The amplitude of the transient varies from 140% for 200Hz ringwaves to 200% for 5KHz ringwaves, with a linear increase in amplitude with increasing frequency. Refer to Figure 1 for an example of a typical waveform.

FIGURE 1



TYPICAL LOW FREQUENCY DECAYING RINGWAVE

3.4) High-Frequency Impulse and Ringwave

This region describes the transients which typically occur as a result of lightning strikes. Wave shapes applicable to this transient and general test conditions are described in ANSI/IEEE C62.41-1991. This region of the curve deals with both amplitude and duration (energy), rather than RMS amplitude. The intent is to provide an 80 Joule minimum transient immunity.

3.5) Voltage Sags

Two different RMS voltage sags are described. Generally, these transients result from application of heavy loads, as well as fault conditions, at various points in the AC distribution system. Sags to 80% of nominal (maximum deviation of 20%) are assumed to have a typical duration of up to 10 seconds, and sags to 70% of nominal (maximum deviation of 30%) are assumed to have a duration of up to 0.5 seconds.

3.6) Dropout

A voltage dropout includes both severe RMS voltage sags and complete interruptions of the applied voltage, followed by immediate re-application of the nominal voltage. The interruption may last up to 20 milliseconds. This transient typically results from the occurrence and subsequent clearing of faults in the AC distribution system.

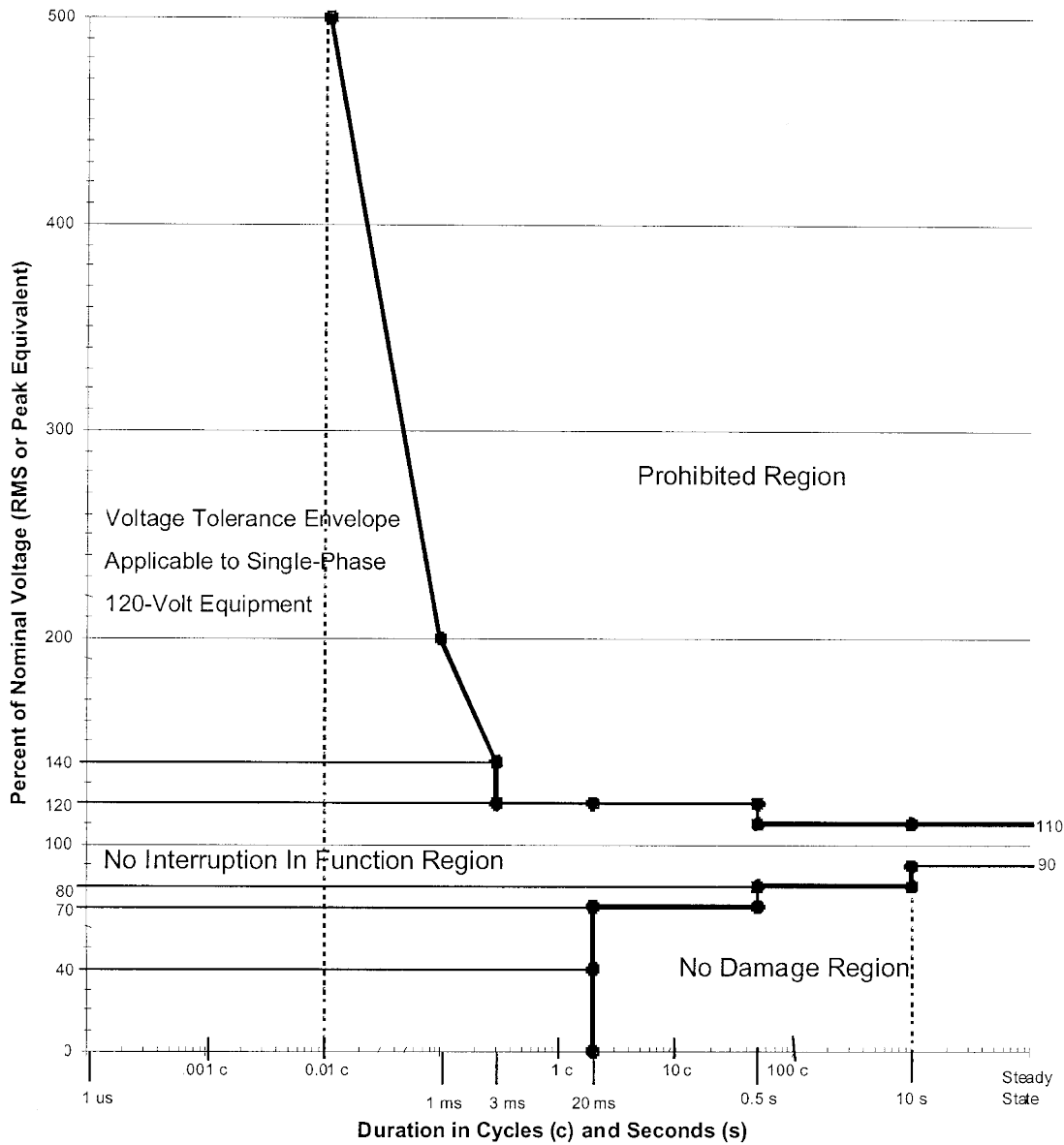
3.7) No Damage Region

Events in this region include sags and dropouts which are more severe than those specified in the preceding paragraphs, and continuously applied voltages which are less than the lower limit of the steady-state tolerance range. The normal functional state of the ITE is not typically expected during these conditions, but no damage to the ITE should result.

3.8) Prohibited Region

This region includes any surge or swell which exceeds the upper limit of the envelope. If ITE is subjected to such conditions, damage to the ITE may result.

ITI (CBEMA) Curve  
 (Revised 2000)



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