Inrush Current Analysis

Electric Power Load Analysis (EPLA)

Revision of 12 July 2026

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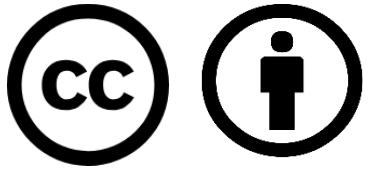


Essential Questions

What are the characteristics of inrush current for different types of equipment?	Understand
What are system implications of inrush current on ac systems powered by generators? Powered by transformers?	Understand
What are system implications of inrush current on systems powered by power electronic converters?	Understand
What can be done to mitigate the impact of in-rush current on system performance?	Understand
How is in-rush current analysis performed?	Apply

Introduction

- Large inrush currents may occur when energizing loads
  - Depends on the design of the loads
  - Depends on what inrush current mitigation features have been incorporated.
  - Can last from milliseconds to seconds (15 ms to 35 ms is typical)
- Inrush currents interact with sources and power system impedances to cause voltage to transiently dip.
  - Voltage transient should stay within voltage transient tolerance limits (typically within 20% of nominal system voltage)
  - Excessive inrush current may cause other loads to experience a service interruption.
- Circuit protection equipment (circuit breakers and fuses) should be selected and configured to not respond to inrush current.
- If many loads experience inrush current at the same time, their impacts are additive and can quickly lead to the voltage transients exceeding limits.

Inrush current: Resistive Loads

- Inrush current usually only an issue if the temperature of the load changes significantly between the off state and the on state
  - Resistance is usually a positive function of temperature
  - Current draw when cold can be many times greater than when hot.
- Typical equipment where inrush current is of concern
  - Incandescent lights
  - Electric Heaters

Electric Heater onboard BB-64

Inrush Current: Motors

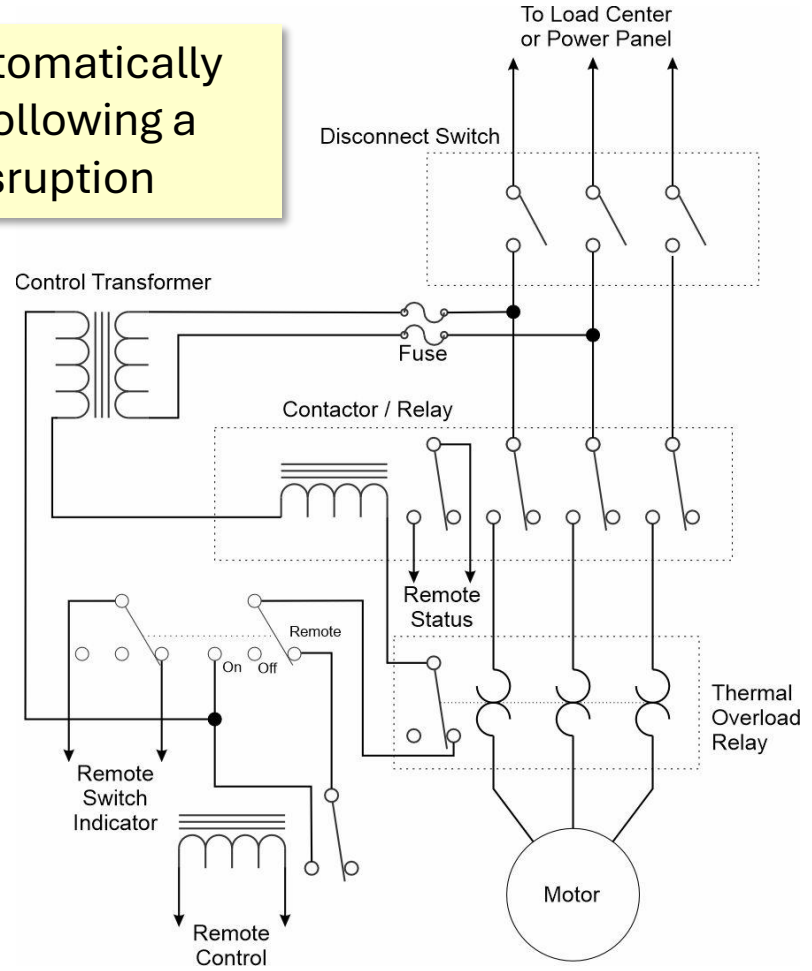
- Inrush current can be significant
  - May be 5 to 10 times the full load amps
  - Estimate peak with the Locked Rotor Amps (LRA)
    - On the label plate
    - Alternately, the label plate may have a code letter indicating range of kVA per horsepower (see NEC)
- Motor controller Types
  - Low Voltage Release (LVR): Automatic restart following a power disruption
  - Low Voltage Protection (LVP): Must be manually (or remotely) restarted following a power disruption

Ventilation Fan Motor

Low Voltage Release (LVR) motor controller

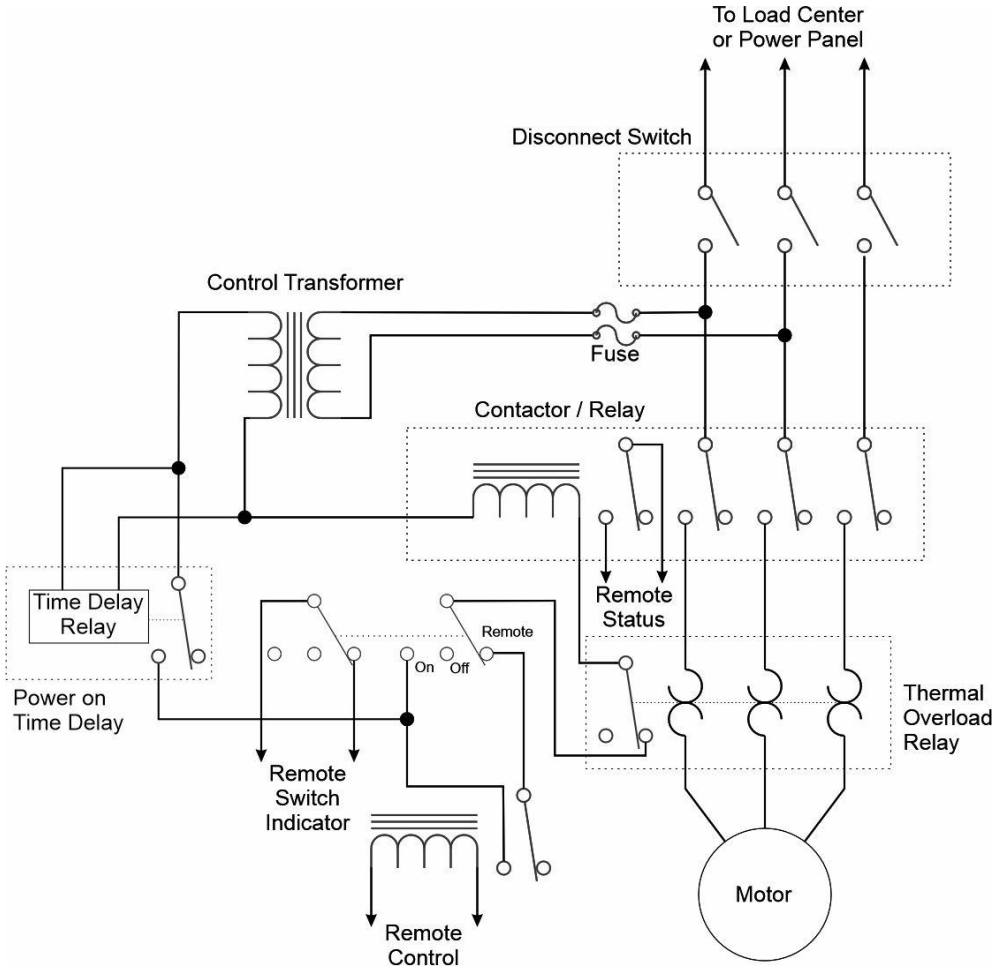
- Disconnect Switch
  - Enables maintenance on motor and rest of motor controller
- Contactor Relay
  - Allows for low voltage to control turning the motor on or off
- Thermal Overload Relay
  - Turns the motor on if the current is too big for two long
- Control transformer
  - Provides low voltage control power
- On-Off-Remote Switch
  - Controls whether the motor is on, off or controlled remotely

Motor automatically restarts following a power disruption



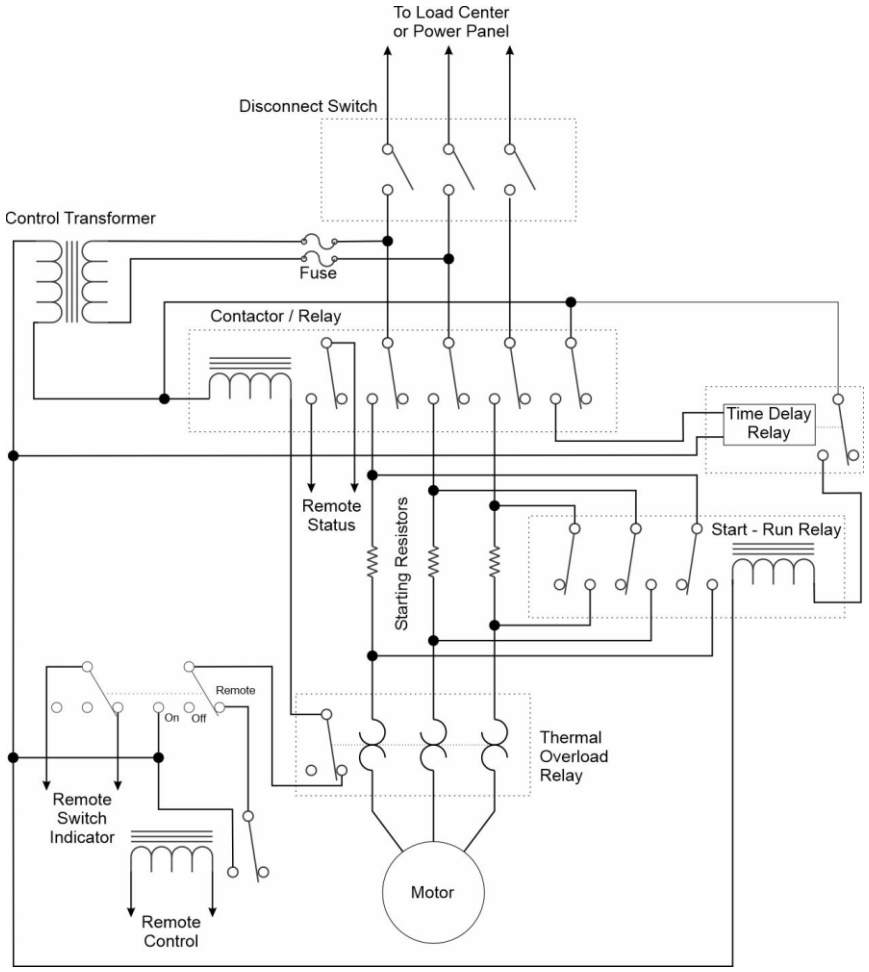
LVR with time delay relay

- Time Delay Relay used to delay starting the motor for a short time after power is restored
  - Typically 50 ms to several seconds.
- Spreads out the inrush current over time to reduce the peak inrush current experienced by sources.



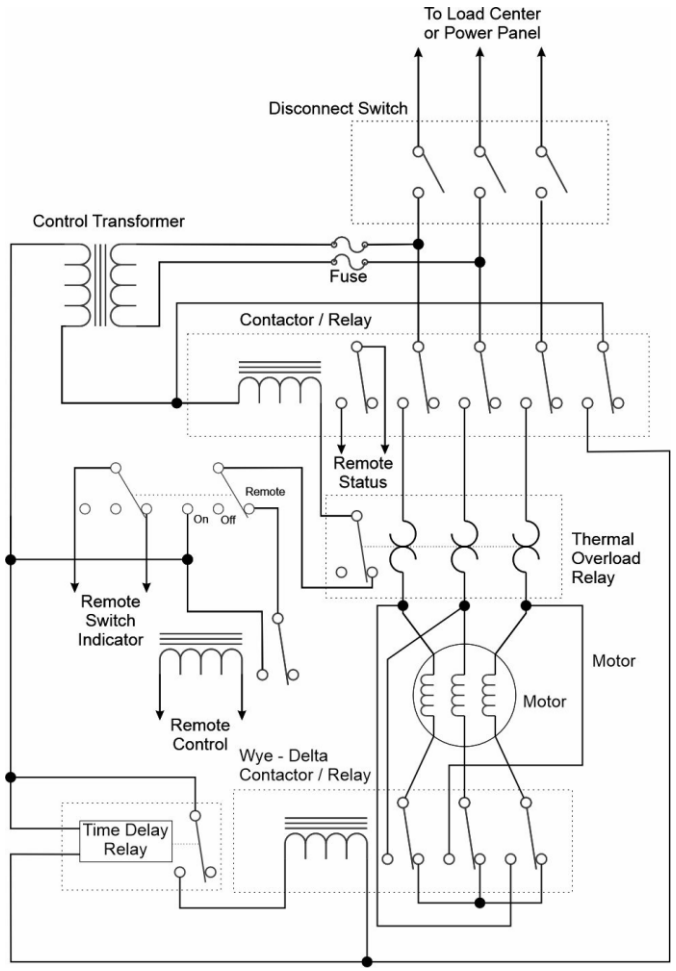
LVR with starting resistors

- Starting resistors limit the inrush current when the motor starts
- Starting resistors shorted out after the initial inrush current
  - Fixed time based on time delay relay (shown)
  - Minimum speed attained based on speed sensor



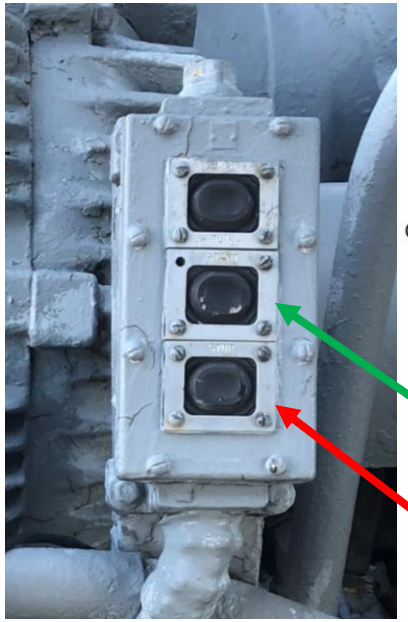
LVR with wye-delta Starting

- Wye-delta starting reduces the voltage on the motor windings when starting (wye) before switching to the run configuration (delta)
- Winding configuration switched from wye to delta after the initial inrush current
  - Fixed time based on time delay relay (shown)
  - Minimum speed attained based on speed sensor

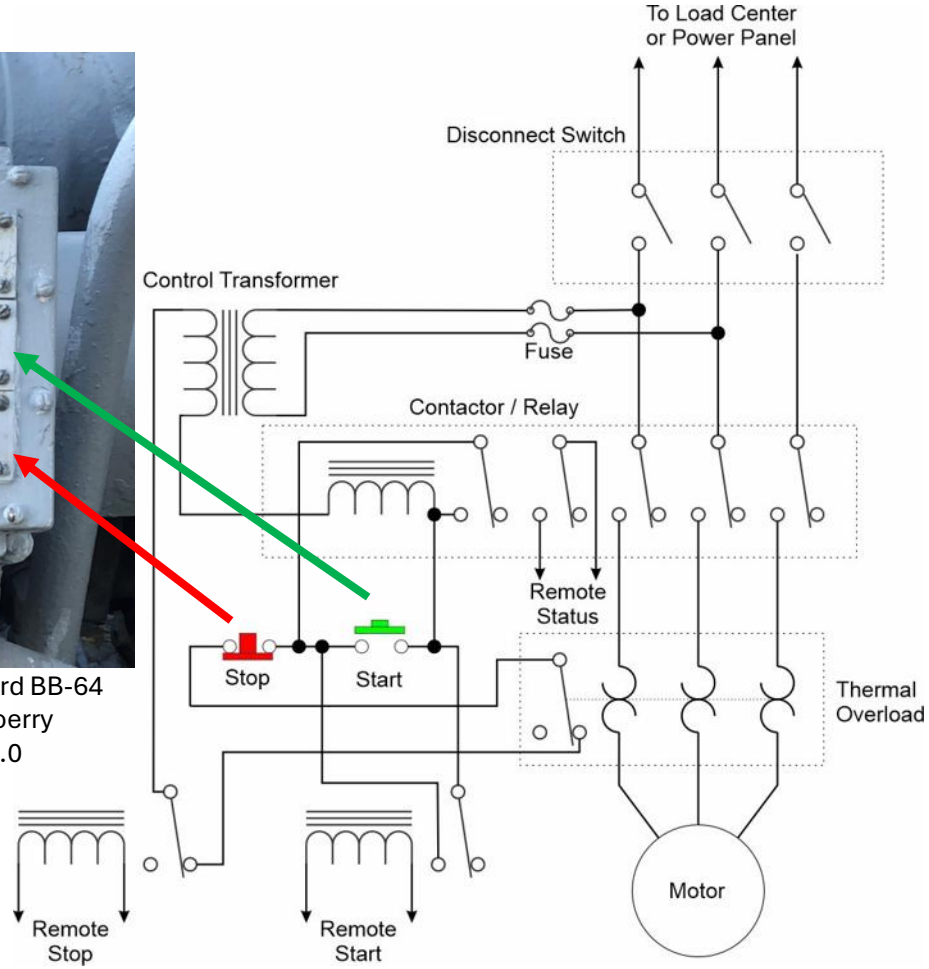


Low Voltage Protection motor controller

- Start button energizes the contactor / relay
- Contacts on the contactor / relay short out the start button to keep the motor powered when the start button is released.
  - Remote start signal can also start the motor
- Motor turns off when:
  - Stop button pressed
  - Power is lost
  - Thermal overload trips
  - Remote stop signal is received



LVP controller onboard BB-64



Inrush Current: Transformers

- When a transformer is initially energized, inrush current may be between 5 and 12 times the rated current
  - During first half cycle, the flux may achieve twice its steady-state value resulting in core saturating
  - Core saturation leads to high inrush current
- Inrush current can be managed by
  - Pre-magnetization circuits
  - Starting resistors
- Medium voltage (> 1 kV) to low voltage (< 1 kV) transformers almost always require some method of reducing inrush current

Transformer bank onboard CV-41

Inrush Current: Capacitive filters

- Without mitigation, the inrush current into an input filter capacitor is often limited by just the internal resistance of the capacitor
- Large electronic equipment typically employ a method to “soft” charge the capacitor slowly to avoid a large inrush current.
- Consult equipment data sheets to determine the inrush current.

Impact of Inrush current on Generators

- Reaction time of voltage regulator to a disturbance limited by the field current time constant (typically on order of seconds)
- Inrush current results in voltage drop at the generator terminals
  - In-rush current times the sub-transient reactance
- Inrush current capability limited by the transient voltage tolerance (~20%)
  - Typically can only support an inrush current of between 1.4 to 2.5 times the rated current.

Col. James M. Schoonmaker Diesel Generator

Impact of Inrush current on Transformers

- Voltage dip at the secondary terminals due to supplying inrush current function of
  - Voltage dip on the primary
  - Transformer impedance
- Transformer impedance should be calculated at the voltage transient frequency (usually around 1 kHz)
- Inrush current supplying capability could be as low as 20% of the full load current.

Transformer bank onboard CV-41

Impact of Inrush current on Power Electronics

- Inrush current capability a function of
  - Thermal limits of the semiconductors
  - Amount of energy stored in the dc link
- Manufacturer's data sheets should be consulted.
- A typical inverter may supply inrush current on the order of the rated current for a maximum of 3 seconds.
  - If magnitude or duration is exceeded inverter may self-protect and shut down.

Impact of Inrush current on Switchboards, Load Centers and Power Panels

- Voltage transient at a switchboard load center or power panel a function of:
  - Voltage drops due to the generator / power electronic converter and power transformers (if applicable)
  - Voltage drop in the feeder cables to the load centers and power panels
- Feeder cable voltage drop calculated based on cable impedance and fault current magnitude
  - Feeder cable impedance should be calculated at the voltage transient frequency (about 1 kHz)
- Circuit analysis may be used to determine the maximum inrush current that can be provided without exceeding transient voltage requirements.

U.S. Navy Photo: 2017 load center on USS Cole (DDG 67)

Inrush Current Analysis

- Developing Load List
  - Collect information on loads with respect to inrush current properties
- Estimating Feeder cable impedance
- Determining Switchboard, Load Center, and Power Panel Capability
  - Use circuit analysis
- Developing Scenarios
  - Identify the conditions under which the worst-case voltage transients are experienced.
  - Detail initial state, and the loads that are simultaneously energized to produce the inrush current.
- Calculating total inrush current
- Identifying inrush current issues

Inrush current mitigation

- Install soft starters or variable speed drives on induction motors.
- Install a pre-magnetization system for initializing the magnetic field on large transformers.
- Install starting resistors or current limiters on equipment with large inrush currents.
- Use wye-delta starting on motors.
- Incorporate energy storage to provide the inrush current.
- Increase the rating of power electronic converters so they can provide more inrush current.
- Employ control systems, time delay relays, interlocks, or Low Voltage Protection (LVP) controllers to prevent multiple loads with high inrush current from starting at the same time.
- Replace loads with functional equivalents that have a lower inrush current.