APPLICATION NOTE

Techniques to Mitigate Inrush Current Using NTC Thermistors and RC Circuits

Bourns® POWrTherm™
Negative Temperature Coefficient (NTC)
Thermistors

Introduction

Inrush current is a current surge that occurs during the initial power-up of a system. This initial power up typically lasts from a few milliseconds to a few hundred milliseconds, and primarily arises from the presence of inductive and capacitive components within a circuit. These surges are the cause of potentially harmful effects within a system. Unfortunately, the common techniques to mitigate inrush currents can negatively impact efficiency and power dissipation.

This paper analyzes the cause of inrush current and examines passive component-based strategies for mitigation. A real-world application showcasing the effectiveness of NTC thermistors and RC circuits is presented.

Inrush Current from Components

Below are the reasons why inrush current surges occur from various loads:

1. **Inductive Loads**
   - **Motors:** When a motor starts, it draws a high current to establish its magnetic field.
   - **Transformers:** Similar to motors, transformers require a significant initial current to magnetize their cores.
   - **Inductors:** Any component with inductance, such as chokes and filters, will oppose sudden changes in current, leading to a temporary surge.

2. **Capacitive Loads**
   - **Capacitors:** When initially connected to a voltage source, a capacitor acts like a short circuit, drawing a high current to charge-up. This current gradually decreases as the capacitor reaches its full charge.

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Potential Inrush Current Effects

High inrush currents can cause various issues, including:

- **Damage to components:** Excessive current can stress components like switches, fuses, and power supplies.
- **Tripping of circuit breakers:** Inrush currents are able to trigger circuit breakers, leading to unexpected interruptions.
- **Electromagnetic interference (EMI):** High current surges have the ability to generate electromagnetic noise, affecting nearby devices.

Common Inrush Current Mitigation Techniques

Several techniques to alleviate surges are commonly employed:

1. **Passive Components**
   - **Resistors:** Adding a series resistor can limit the initial current surge. However, this method dissipates power and reduces efficiency.
   - **Inductors:** Using an inductor in series can limit the rate of current rise, but it can also introduce voltage spikes.
   - **Negative Temperature Coefficient (NTC) Thermistor:** An NTC thermistor, connected in series, can limit the initial current surge. Initially, the NTC thermistor has a higher resistance. As it heats up due to current flow, its resistance decreases, gradually allowing more current to pass through. This method can minimize the power dissipation and efficiency loss due to NTC characteristics.

2. **Active Components**
   - **Electronic Soft-Start Circuits:** These circuits gradually increase the voltage applied to a load, limiting the inrush current.
   - **Power Factor Correction (PFC) Circuits:** PFC circuits can reduce inrush current by controlling the power factor of the load.

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Common Inrush Current Mitigation Techniques (Continued)

There are many ways to mitigate the inrush current. The more complex the circuit, the more chances of potential failure. The example below outlines a simple solution that can be achieved with a few passive components. The parameters of the devices used are presented first.

Circuit

- Operating Voltage: 24 VDC.
- Nominal Operating Current: 3 A.
- NTC Thermistor: Initial Resistance = 3 Ohms, Final Resistance (heated) = 0.5 Ohms.

Analysis

- Given a 3 A load, the equivalent load resistance is approximately 8 Ohms (Ohm's Law: R = V/I).

Initial Inrush Current Limitation

- With the NTC thermistor at its initial resistance of 3 Ohms, the total circuit resistance becomes 11 Ohms (8 Ohms + 3 Ohms).
- This limits the initial current to approximately 2.18 A (Ohm's Law: I = V/R).

Steady-State Operation

- As the NTC thermistor heats up, its resistance decreases to 0.5 Ohms.
- The total circuit resistance reduces to 8.5 Ohms.
- This allows the current to increase to approximately 2.82 A.

NTC Thermistor Power Dissipation

- With the NTC thermistor at 0.5 Ohms and a current of 2.82 A, the power dissipated by the NTC thermistor can be calculated using the formula $P = I^2 * R$.
- This results in a power dissipation of approximately **3.98 Watts.**

Note:

This is a quick-and-dirty estimation. The power dissipation of the NTC thermistor should be carefully considered when selecting a suitable component. The device must be rated for at least this power dissipation to avoid overheating and potential failure. Additionally, the physical size and mounting of the NTC thermistor should be appropriate to ensure adequate heat dissipation. Bourns recommends using its POWrTherm™ NTC thermistors for this application, and has developed a helpful selection guide.

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Relay and RC Circuit Integration

- A relay and RC circuit can be added to the circuit to further reduce power dissipation and improve efficiency.
- The RC circuit, consisting of a resistor and capacitor, can be used to delay the activation of the relay.
- The relay, once activated, can bypass the NTC thermistor, reducing its power dissipation.

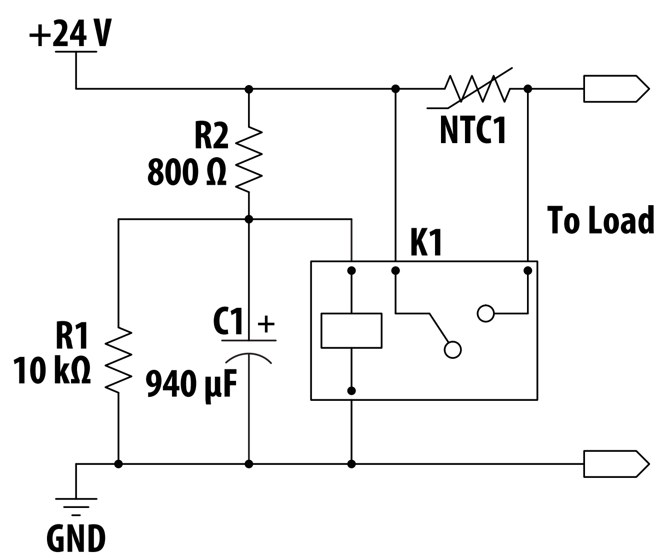

Figure 1. | *Relay and RC Circuit*

Benefits of this Approach

- **Reduced power dissipation:** By bypassing the NTC thermistor after a certain time, the overall power dissipation of the circuit can be significantly reduced.
- **Improved efficiency:** The reduced power dissipation leads to improved efficiency.
- **Enhanced reliability:** By reducing the power dissipation of the NTC thermistor, its lifespan can be extended.

R1 functions as a **bleeding resistor**, controlling the capacitor C1's discharge rate when the circuit is powered down.

C1 requires approximately 650 milliseconds (see figure 2) to reach 8 volts (the relay's activation threshold) due to the charging current limited by R2. Once C1 reaches this voltage, the relay engages, bypassing the NTC1.

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Relay and RC Circuit Integration (Continued)

Considering the 500 Ohm relay coil resistance and 800 Ohm R2 resistor, the maximum voltage across the capacitor is limited to 9 volts. By adjusting the values of R2, the relay's coil resistance, the relay's activation voltage, and the capacitor's capacitance, you can precisely fine-tune the timing for NTC1 bypass.

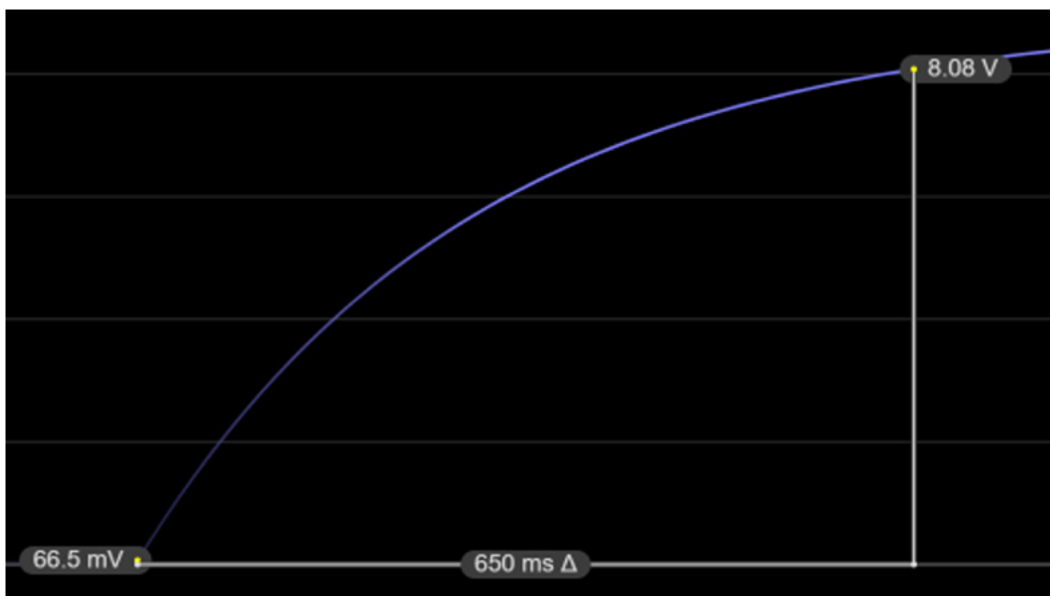

Figure 2. | *Capacitor Charging Time*

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Conclusion

This paper has shown that implementing the combination of an NTC thermistor, relay and RC circuit provides an effective and efficient solution for mitigating inrush current. By carefully selecting the components and optimizing the circuit design, the power dissipation and efficiency of the system can be significantly improved.

Additional Resources

- Bourns® POWrTherm™ NTC Thermistors
- Bourns Parametric Search
- Bourns® POWrTherm™ NTC Thermistors for ICL Product Guide

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