The Impact of Output Capacitor Aging under Constant and Cycled Temperature Conditions on LED Driver Lifetime

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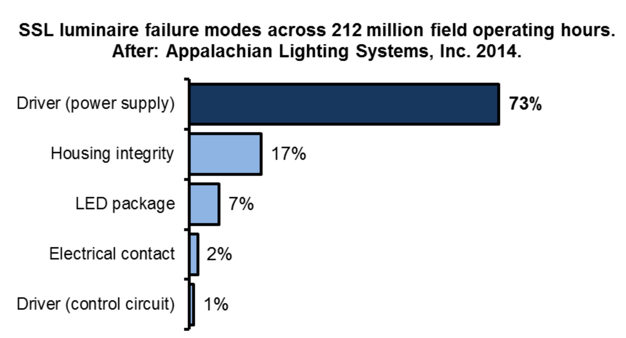
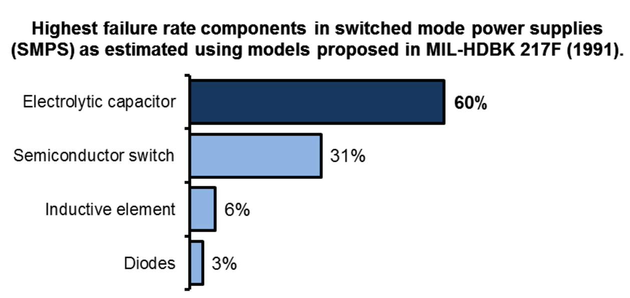
Background

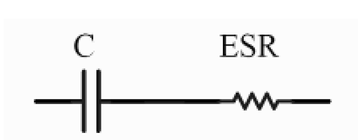
- LED system life is mostly determined by failures in solder joints and driver components.
  - NGLIA, 2014
- Most LED drivers are switch mode power supplies (SMPS) that include components such as electrolytic capacitors, power MOSFETs, and diodes.
- Past studies have reported that the electrolytic capacitor is one of the main failure components in LED outdoor light fixtures.
  - Gupta A. et al., 2018
- LED driver failure can be catastrophic or parametric.
  - Han, L. et al., 2011; Sun, B et al., 2016



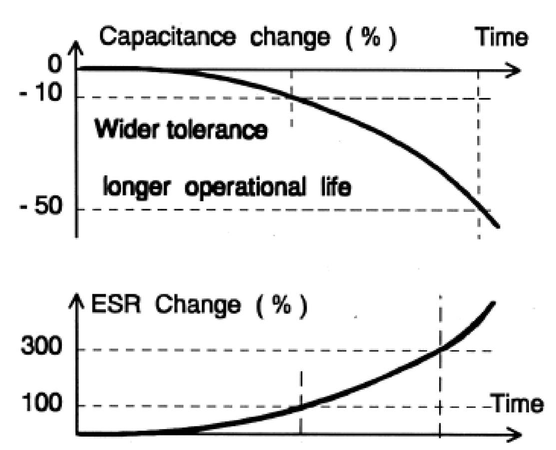


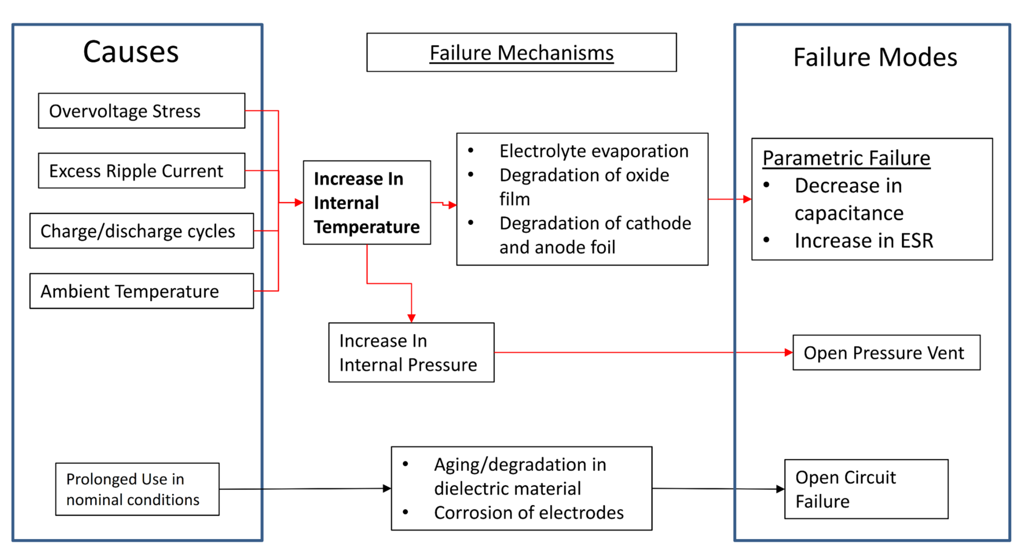
Failure Mechanisms of Electrolytic Capacitors

- Electrolytic capacitors degrade due to evaporation of electrolyte.
  - Capacitance (C) decreases,
  - ESR (Equivalent Series Resistance) increases.



Equivalent Model of an Electrolytic capacitor





Past Studies on LED Driver Life

- Changes in LED driver electrical parameters due to capacitor degradation under constant temperature have been studied extensively in the past.
  - Han, L. et al., 2011; Zhai, G. et al., 2012; Pradeep, L. et al., 2014; Sun, B. et al., 2016; Bin, Y. et al., 2017.
- In 2016, Narendran et al. showed that switching LED lamps on and off accelerated catastrophic failure rates
  - Most failures were due to LED board solder joints and driver components
  - The driver component that failed the most was a rectifying diode

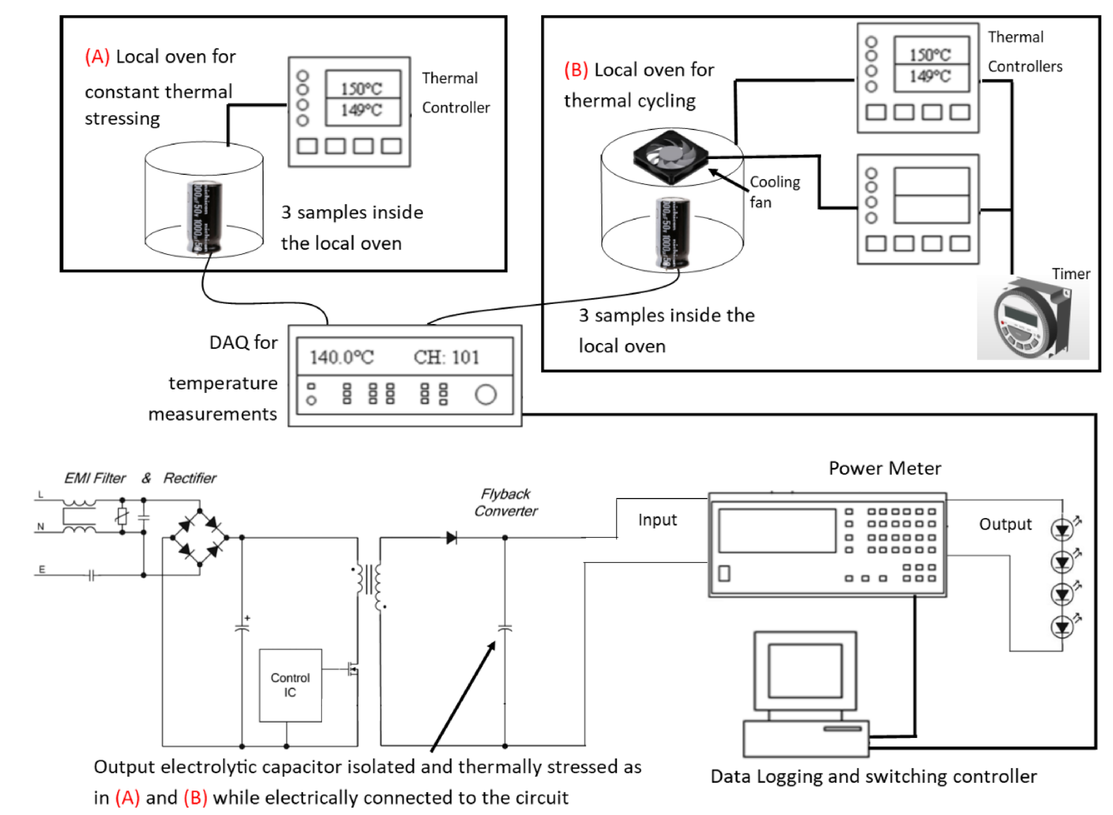
Knowledge Gap

- The authors were not able to find any past studies that have investigated the effect of switching on and off on the electrolytic capacitors at the output stage of LED drivers.

Study Objectives

- To understand the effects of temperature & power cycling on electrolytic capacitors at the output stage of LED drivers.
  - By comparing changes in electrical parameters under continuous accelerated aging operation to changes under temperature & power cycling conditions
- To understand electrolytic capacitor degradation mechanisms under continuous and cycling operating conditions

Experiment Setup



Experiment 1: Continuous Operation vs. Thermal Cycling

- Experimental design
  - 6 samples, 330 µF aluminum electrolytic capacitors
    - Continuous operation: Samples 1,2,3
      - Temperature maintained at 150˚C
    - Cycling operation: Samples 7,8,9
      - 3 hours ON – 1 hour OFF
      - Time average temperature maintained at 150˚C
      - Average temperature during the ON period: 170˚C
- Results
  - LED drivers with capacitors under cycled conditions showed accelerated parametric failure (change in output current ripple) compared to drivers under constant operation.
    - Criterion: time for current ripple change by 200%
      - 1300 h ± 52 h vs. 2866 ±66 h

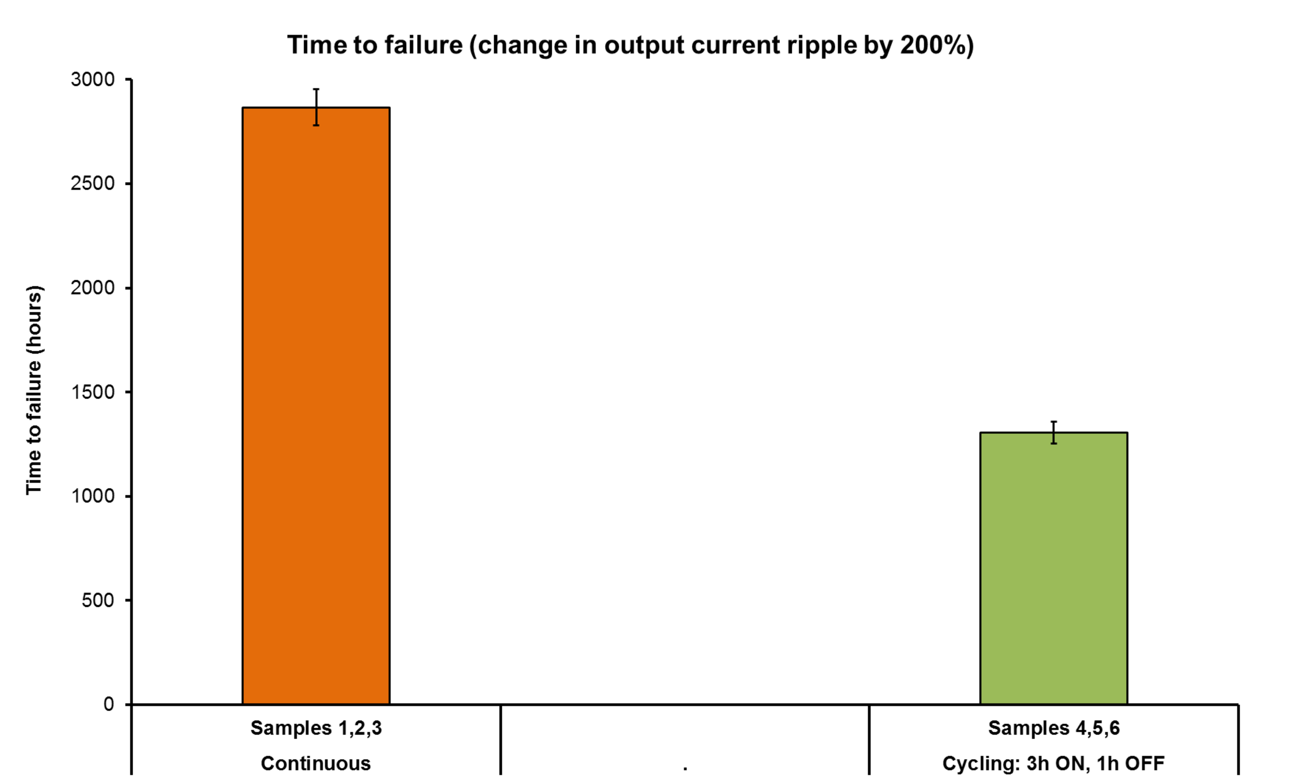


Fig. 1. Driver output current ripple change over time for samples under continuous (Samples 1,2,3) and cycling (Samples 4,5,6) operating conditions. The time average temperature was maintained at 150˚C in both instances.

Experiment 2: Thermal Cycling @ Different ON/OFF Durations

- Experimental design
  - 9 samples, 330 µF aluminum electrolytic capacitors
    - Continuous operation: Samples 7,8,9 (for comparison)
      - Temperature maintained at 170°C
    - Cycling operation
      - Average temperature during the ON period: 170˚C
      - ON duration 1 (3 hours ON, 1 hour OFF): Samples 4,5,6
      - ON duration 2 (4 hours ON, 1 hour OFF): Sample 10
- Results
  - LED drivers with capacitors thermally stressed under higher ON periods within the cycles showed accelerated parametric failure (change in output current ripple) compared to drivers stressed under lower ON periods.
    - Criterion: time for current ripple change by 200%
      - 603 h ± 39 h (Samples 7.8.9) vs. 859 h (sample 10)

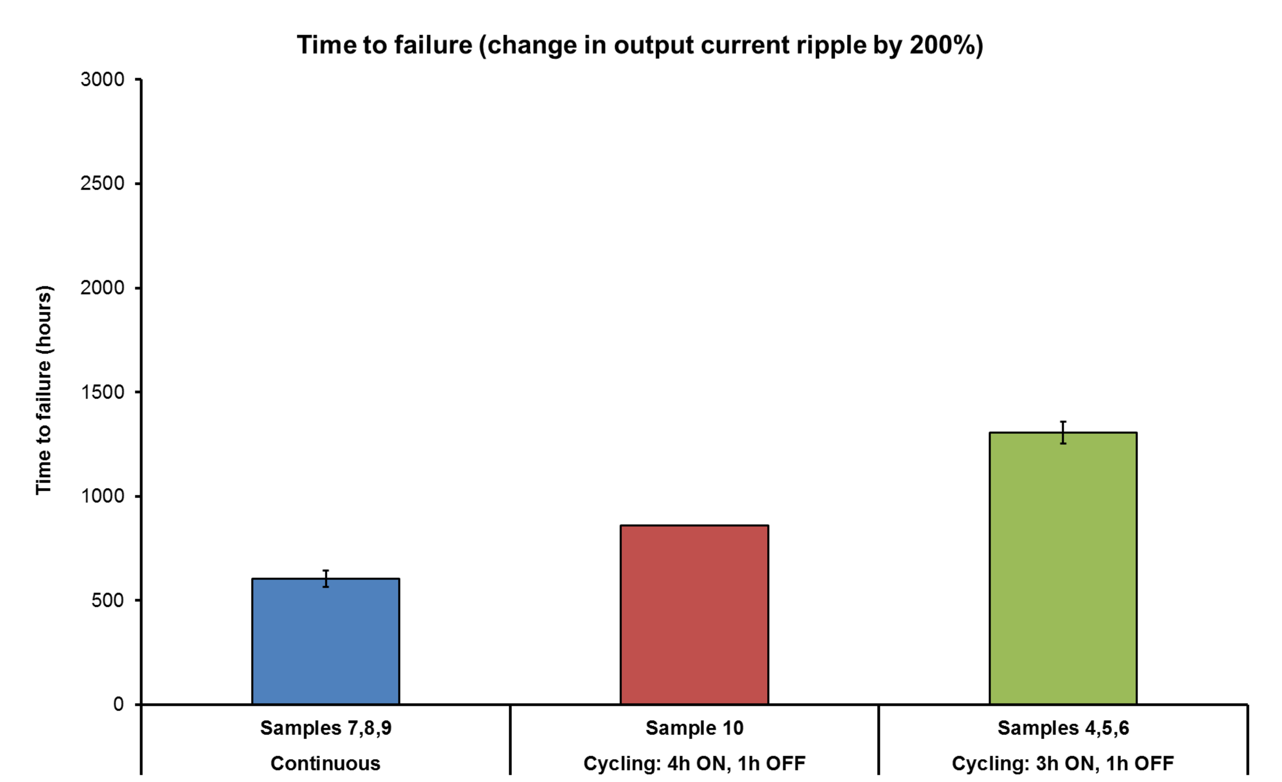
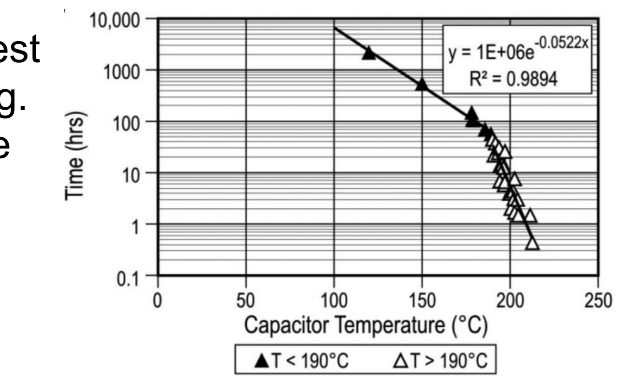


Fig. 2. Driver output current ripple change over time for samples under continuous stressing at 170˚C (Samples 7,8,9) and cycled stressing with average ON temperature at 170˚C (Samples 4,5,6).

Discussion

Continuous Operation vs. Thermal Cycling

- In Experiment 1, the time average temperature was kept at 150°C for both test conditions, continuous and thermal cycling. However the maximum temperature in the thermal cycling condition 170°C and minimum was 40°C.
- Past studies have shown that the time to failure of LED drivers due to capacitor degradation reduces exponentially at higher temperatures.
  - Han, L. and N. Narendran, 2011
- The higher temperatures experienced in the thermal cycling condition, compared to the continuous condition, may have influenced the shorter time to failure.



Han, L. and N. Narendran, 2011.

Capacitor Thermal Cycling

- When capacitors are thermally cycled, degradation above the average temperature is much higher than that of below the average due to the logarithmic relationship between temperature and lifetime.
- Therefore, when capacitors are thermally cycled, both the maximum temperature of the cycling profile and the ON time determine the overall time to failure of the driver.
- Predictions of useful LED driver lifetime based on capacitor degradation can be based on
  – Driver usage pattern (on, off cycles)
  – Temperature profile of the driver in its operating environment

Acknowledgements

The authors would like to thank Jean Paul Freyssinier, Indika Perera, Akila Udage, Dinusha Thotagamuwa, Martin Overington and Howard Ohlhous of Rensselaer's Lighting Research Center for their valuable contributions.

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