Nadler & Associates

Antares Precharger Failure Analysis and ECO

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Overview

The propulsion motor controller's precharge circuit ballast resistor has burned in multiple Antares (including Dave's), disabling the propulsion system. This document analyzes the problem and provides an ECO to fix it.

This analysis was delayed as while Dave's glider had this failure in May 2018, it was not repaired until December 2019, and analysis from the burned component's manufacturer was delayed due to COVID-19.

Document Change Log

Revision	Notes
Version 1, 28-Dec-2020	Dave Nadler write-up (consolidated engineering notes).

Background

All high-voltage high-current motor controllers include a large capacitor close to the commutating switches driving the motor. This capacitor is required to avoid demanding massive current fluctuations from the supply while the motor commutates and motor windings are sequentially switched on and off. When powering on the motor controller, the capacitor cannot be directly connected to the supply, otherwise excessive current would flow to charge the capacitor (exceeding the limits of cabling, connectors, supply, etc.). Thus all such systems have a ***precharger*** circuit to charge the capacitor slowly and with manageable current. Only after the capacitor is fully charged is it directly connected to the supply via a high-current switch.

In Antares, the motor controller capacitor is 4400uF at 300V.

Types of Precharger

Cheap-And-Cheerful Ballast Resistor Precharger

The simplest precharger is a resistor between the supply and capacitor. The resistor (often called a ballast resistor) acts as a current limiter. This is often used because it is extremely simple, though as we see below Lange has managed to get this wrong not just once but twice! Drawbacks with this approach include:

- When power is connected, the current through the resistor will be high, so the resistor must dissipate a lot of power. Thus an expensive power resistor is required mounted on an ample heat-sink; expensive parts and expensive assembly.
- With an RC circuit like this, the capacitor approaches the supply voltage asymptotically, so it is slow to reach full charge.

Constant-Current Precharger

A constant-current circuit is used to feed power from the supply to the capacitor. A transistor is placed between the supply and capacitor. The transistor is continually adjusted to maintain the desired charge current. While it finishes precharge much faster than a simple ballast resistor, drawbacks with this approach include:

- When power is initially connected, the voltage drop across the transistor high, so the transistor must dissipate a lot of power. Thus an expensive power transistor is required mounted on an ample heat-sink; expensive parts and expensive assembly.
- It requires some power engineering skill to design.

Switching-Supply Precharger

A switched inductor can be used to precharge the capacitor. Design of a switcher requires more serious engineering skill, but has these advantages:

- No high-power components or heat sinks are required.
- Cost is therefore lower than above approaches (parts and assembly).
- Precharge can be completed faster than with a simple ballast resistor (under 5 seconds in example circuit Dave designed).

Resistive Power Dissipation

A precharger that limits current by resistance (whether resistor or transistor) must dissipate the same energy in the resistive element as stored in the capacitor; use this for sizing heat-sink: Energy loss in R is equal to final energy stored in capacitor = ½ C V^2 = 198 joules.

Lange Ballast-Resistor Engineering Errors

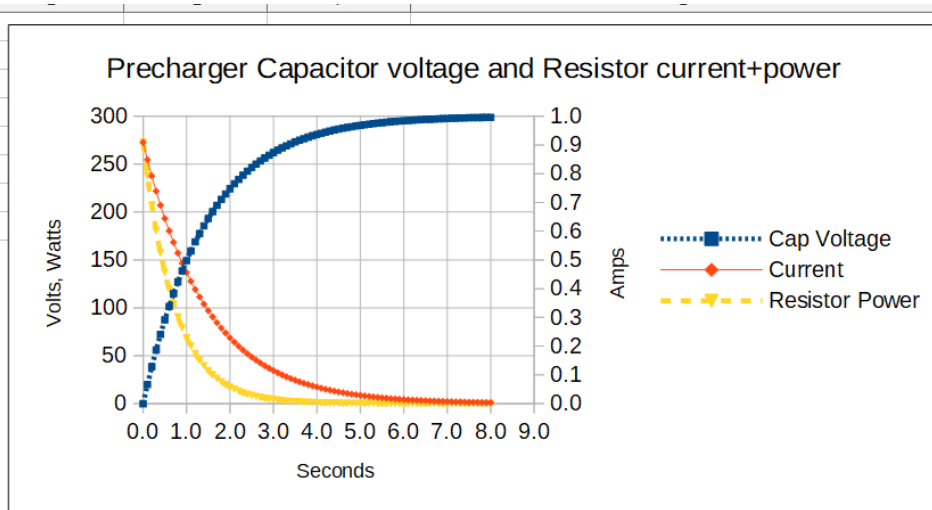
Antares precharger uses a simple ballast-resistor connected to the battery via a relay.

The original Antares precharger ballast resistor was:
Vishay RCH50S330 Chassis Mount 50W 330Ω 5%

When my precharger failed, Lange advised a known problem with undersized ballast resistor. Initial power dissipation V^2/R =300v^2/330Ω= 275W, but this Vishay resistor is only 50 Watt! Plot shows power dissipation is over 50W for ~1.3 seconds:

Capacitor	4400	uF
Resistor	330	Ohm
Tau = R*C	1.452	seconds
Vb	300	volts

V(t) = (1-e^(-t/Tau))*Vb
I(t) = (Vb/Resistor)*e^(-t/Tau)
Power = V*I = (I*R)*I = V*(V/R)



I disassembled my Antares expecting to find the above Vishay resistor. Instead I was amazed to find a burned TE Connectivity BDS2A100330RK 330Ω 10% 100W (in SOT-227 package). Only 100W resistor, still much less than required 275W!

TE Electronics Analysis of Burned Resistor

I sent the burned resistor to manufacturer TE for analysis and reviewed the design with TE engineers. TE analyzed the burned part in their laboratory and provided a detailed report (in August 2020, delayed by COVID-19). Major points from TE:

- TE would not approve use of this resistor in this application; a higher power rating is required for acceptable lifetime, and
- The resistor was well burned though the fire was mostly contained inside the housing with only some charring on the outside. Full TE report

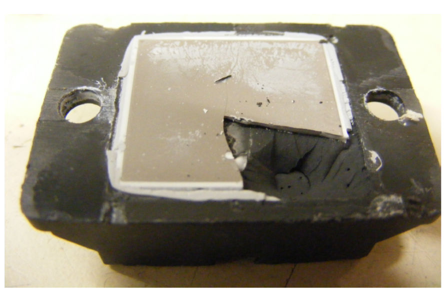


Image 6: bottom view ceramic substrate; substrate has cracked through centreline of ceramic. Resistor is open circuit. Heat damage on potting material located above resistor tile.

Is Short Over-Power OK for Ballast Resistor?

Some manufacturer specifications permit short-term power overload. However, this seriously affects the lifetime of the parts. A qualified engineer will de-rate parts like these to achieve acceptable life. The TE resistor used here is only specified to endure 2000 cycles if used at rated power, and exceeding the rated power will shorten part life – thus de-rating is absolutely required for acceptable lifetime. **In simple terms: For acceptable life, the power rating of the resistor must be substantially greater than peak power required.**

Some manufacturer overload specifications summarized from datasheets:

Vishay	OK to exceed nominal power rating with a very brief pulse, but in this case ~165 joules dissipated in first 1.3 seconds greatly exceeds the Vishay part's specified limits.
TE	Short Term Overload: 3 x P_{Rated} (10s) Only 2000 cycles lifetime if used at P_{Rated} (less with overloads). Only manufacturer to specify such a large overload and such a short lifetime.
Reidon	Permits very short pulse overload but not the overload duration above.
Ohmite	No overload permitted

This TE ballast resistor failed after ~300 flights in Antares serial 35E33.

How Did This Happen?

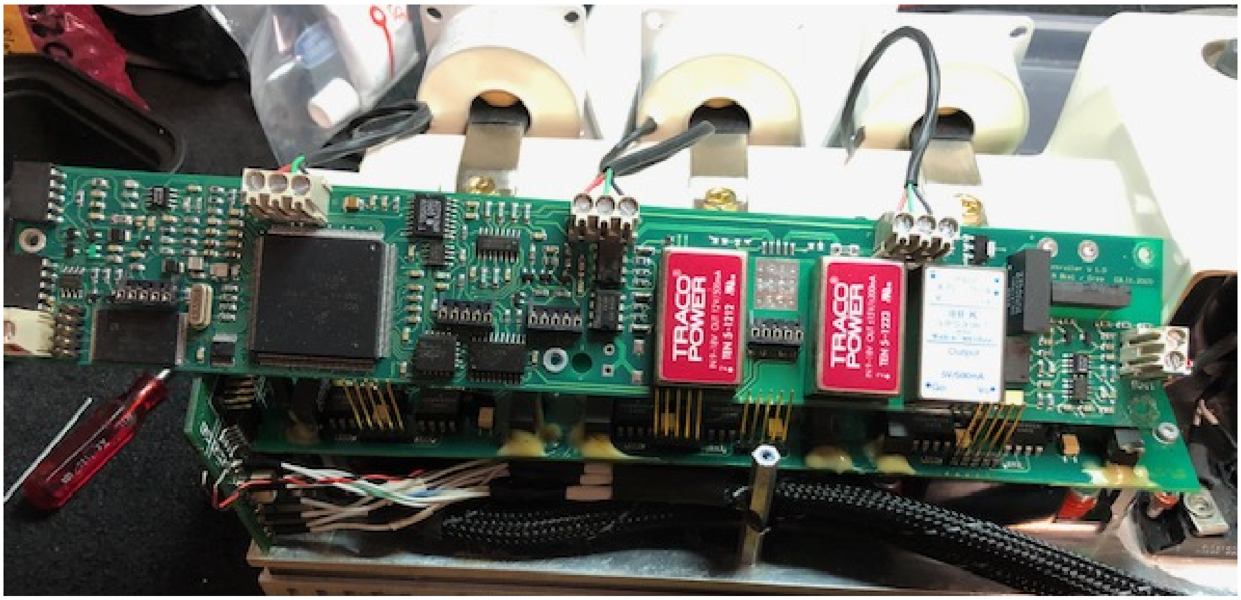
After the initial mistake was discovered (Vishay resistor failures), it appears someone at Lange just chose the next larger-power resistor and did not do any power calculations (certainly not taking into account part lifetime).

This appears to be yet another case of Lange using unqualified personnel on electronics issues, as this is not a mistake a qualified engineer would make once, and certainly not twice!

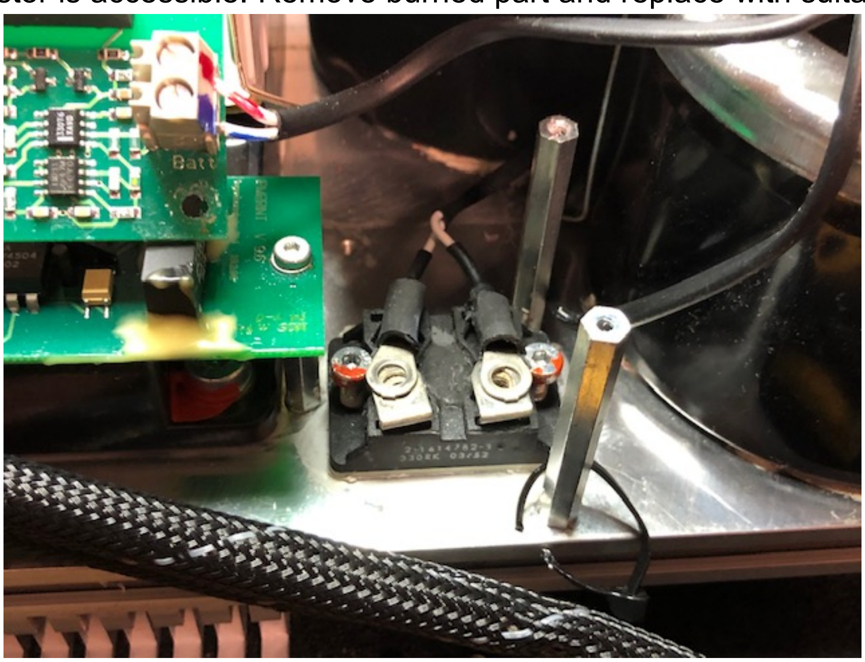
ECO

This ECO was tested in Dave's glider and flown through 2020: Replace TE ballast resistor with any SOT-227 resistor of appropriate power rating (available from several vendors).

Remove motor controller (~35 shop hours).
Using anti-static workstation, remove cover then carefully loosen controller main board (on top in picture below) and slide to the left.
Precharger ballast resistor now visible and accessible at lower right of picture.
Remove tie-wraps and pull back cables to allow access to ballast resistor.



Now ballast resistor is accessible. Remove burned part and replace with suitable new part:



Reinstall all parts, inspect, and test (~35 shop hours).