Evaluation of Electrolytic Capacitor Application in Enphase Microinverters

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Summary

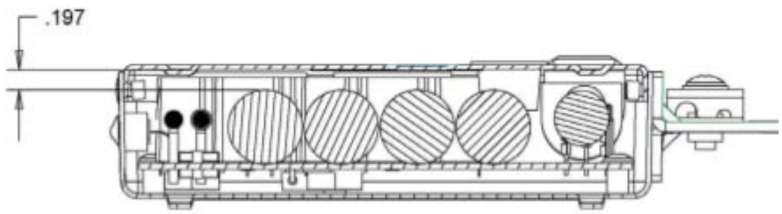
This report was initiated via a commission by potential investors for the last round of venture funding for Enphase Energy, Inc. As part of the due diligence by the VC's, the author was hired to audit the results of the testing of the electrolytic capacitors (e-caps) used in the Enphase Microinverter design. The reason for the interest in the e-caps was because they have been known to be a weak link in other inverter designs. The tests and audit focused on the following two areas:

Life Expectancy: The first area examined was the life expectancy of the e-caps used in the Enphase Microinverter. The audit determined that the calculations and results of the tests support a 50-year life expectancy for the electrolytic capacitors used in the Enphase Microinverters. A further stress test involving an even more cautious approach with further limitations supports a 30-year life expectancy prediction for these capacitors.

Corrosion: The second area examined was the possibility of catastrophic failure due to corrosion. The audit focused on corrosion from the possibility of halides escaping from the potting compound used to encapsulate the entire inverter. One device exposed to this material during temperature cycling was opened and inspected. No indication of corrosion was detected.

Background

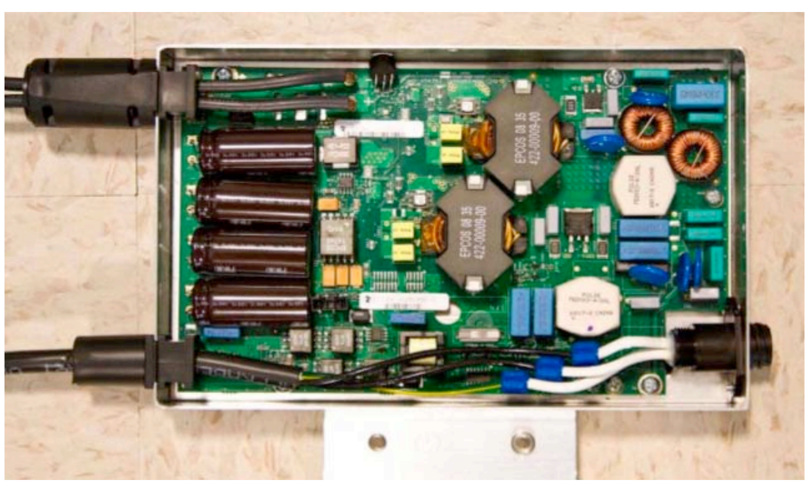
The Enphase Microinverter design includes four parallel Nichicon electrolytic capacitors for energy storage. The device chosen by Enphase is a PW series Nichicon UPW1J222MHD 2200 μF, 63V rated device. This capacitor has a life expectancy of 8000 hours while operating continuously at 105^{o}C core temperature.



RAPTOR END VIEW
THRU CAPACITORS
SECTION Z-Z

The core is the geometric center and normally the hottest spot in the device. This means that the ambient temperature plus the added internal temperature due to power dissipated by the equivalent series resistance (esr) of the capacitor should not exceed 105^{o}C during the course of the life test.

If the core temperature is reduced in any way, e.g. lower ambient or lower ripple current, the life expectancy can be further increased under the assumption that the deteriorations of the device are temperature activated and follow the usual Arrhenius relationship. That is, the rate of deterioration is reduced by a factor of two for every 10^{o}C reduction in temperature.



Enphase has made some measurements external to the capacitor during actual application that indicated the surface temperature to be a maximum of 65^{o}C. Life expectancy based on this measurement would indicate a 40^{o}C lower temperature that is used in the manufacturer life test. Enphase literature used a calculation that resulted in a 50-year lifetime. This is based on actual temperature taken during application of the inverter in Palm Springs, CA.

To audit these results, and to present an even more conservative evaluation, a stress test was applied to the calculations. $5^{o}C$ was added to the surface temperature, indicating a $70^{o}C$ core temperature for life calculations. The resulting delta temperature from the life test temperature is then $35^{o}C$. Expected life then becomes 8000hr * $2^{(105-70)/10}$. Applying this equation results in an expected ~ 90,000 hr continuous life expectancy at that elevated temperature. Doubling that value assuming 12 hours per day of full power operation, even a 20-year warranty could be easily supported. In real life, it is expected that these inverters will operate at an equivalent of 6 to 8 hours per day at full power. With this assumption, a 30-year life expectancy is reasonable.

Peak Voltage

Another area of concern is the peak voltage expected across the capacitor. Formation voltage of the foil used by Enphase is assumed to be ~ 100 volts. As the voltage applied to the devices approaches this value, current starts to flow between the anode and cathode plates producing heat and potential catastrophic failure. The value of 40 volts as tested by Enphase as the typical maximum value is an added safety factor that should eliminate any path to this failure mode.

Catastrophic Failure

Of more concern in this application is the possibility of catastrophic failure. For electrolytic capacitors there are two major potential areas for unpredicted failures: shorts caused by contact between the metal electrodes and corrosion caused by contaminates (usually halides) which deteriorate the internal connections of the device. The manufacturer of the e-caps, Nichicon, indicated they have had no failures of these types during life testing of these units. This leaves only potential problems from the actual application.

In application, these capacitors are potted in a polybutadiene urethane compound that completely surrounds the device, even at the interface of the rubber bung and the metal feed-throughs. Further inquiry of the Enphase urethane supplier indicates the potential of “a few ppm chloride” residual in the material. In application, the cycling of the temperature of years of operation may cause breathing of the device during which a small amount of vapor would be expelled during high temperatures and a small amount of ambient atmosphere could be drawn in during cold temperatures.

<u>Lab Work</u>

To investigate the corrosion concern, one unit that had undergone a temperature cycling test was opened and inspected for incipient corrosion.

Sectioned Capacitor

The unit had undergone the IEC61215 test identified as "Thermal cycling test (IEC 61215 para. 10.11)". The unit was brought to 25^{o}C and measured 1885 μF, 0.048 ohms at 120 Hz and 0.038 ohms at 1kHz using a GenRad 1489 RLC Digibridge. Enphase had used the 100kHz esr value of 0.028 ohm for some of their dissipated power calculations versus the 120 Hz esr value. Leakage current at 63 volts was good indicating <5uA after 5 minutes.

Terminations

Unwound Device

The unit was opened and inspected. It was still very moist indicating little or no loss of electrolyte during the ~880 hours of the elevated temperature cycle test. There was no sign of electrolyte leakage around the rubber bung/rubber interface areas. The tab area was inspected with 20x microscope and no trace of corrosion was detected. Any halide attack will first appear at these areas as microscopic corrosion pits. The unit was unwound and both anode and cathode were inspected with no trace of pitting corrosion attack. However, a small area of discoloration was visible without aid. These are usually caused during anode etching and/or formation and pose no threat to capacitor performance. The cathode was also inspected with no visible defects.

Conclusion

The conclusion of the audit is that the two areas of interest for the electrolytic capacitors – life expectancy and corrosion – do not pose a concern and the results of the testing performed are valid. It is my determination that, a further stress test involving an even more cautious approach with further limitations supports a 30-year life expectancy prediction for these capacitors used in the Enphase Microinverter design.

About the Author

Dr. J.S. (Steve) Shaffer

ELECTROLYTIC CAPACITORS AND FOILS

EDUCATION	B.S. Physics	Univ. of SC	1965
	Ph.D. Physics (Solid State)	Univ of S.C.	1975
PROFESSIONAL EXPERIENCE	Development Physicist	General Electric	1975 – 1978
	Director of R and D	Mepco Electra	1978 – 1985
	Senior Scientist	N.V.Philips (Europe)	1985 – 1988
	Innovation Manager	Philips Components	1988 – 1998
	Technical Advisor	BC Components	1998 – 2003
	Consultant	Shaffer Consulting	2003 - Present

EXPERTISE

Etching Aluminum Foil
Oxide Formation of Aluminum Foil
Control for Electrochemical Processing
Electrolytes for Capacitors
Application of Electrolytic Capacitors
Thermal modeling for both ac and dc Capacitors

MILITARY	Active Duty US Navy, Line Officer		1965 - 1970
	US Navy Reserve	retired as Captain (06)	1970 - 1992

PATENTS AND PUBLICATIONS	1. 4,437,955	Combined ac and dc etching ….
	2. 4,546,415	Heat Dissipation in Capacitors …..
	3. 4,609,971	Capacitor with Polymer Conductor
	4. 4,761,713	Glycol-based Mid-Volt Electrolyte
	5. 5,143,591	Method for Producing Ultra Stable Oxide
	Pending	Electrolyte for High Reliability ……

MEMBERSHIPS

Advisory Council USC College of Science and Mathematics
Treasurer, Rotary Club of St. Andrews
USC NROTC Alumni Association
American Association for the Advancement of Science
American Physical Society
Explorer's Club

Dr. J.S. (Steve) Shaffer

Background PhD in Solid State Physics. 27 years experience in the field of electrolytic capacitors with General Electric, N.V. Philips and BC Components.

Areas of Expertise

Etching Aluminum Foil
Foil cleaning methods
Core or porous etching.
Methods using ac, dc and pulsed waveforms.
Aluminum metallurgy and processing necessary for successful etching

Oxide Formation of Aluminum Foil
Amorphous and crystalline oxide preparation
Techniques for improved foil stability
Analysis of tunnel and other structural effects

Control for Electrochemical Processing
Process parameter control in large electrolytic baths.
Acid recovery systems.. High current application. Using FEA techniques

Electrolytes for Capacitors
Formulation and evaluation of filling electrolytes using various solvent systems
Interaction of electrolytes with anode, cathode, covers and papers.
Corrosion potential evaluation

Application of Electrolytic Capacitors
Thermal modeling of capacitors for both ac and dc application
Capacitor response to various waveforms
Life time calculations

Failure Analysis
Foil Analysis
Analysis of construction details

Specialty Capacitors
Super capacitors
Polymer conductor electrolytes
Prismatic Construction devices

Papers and Publications
J. S. Shaffer

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DEFECTS IN CRYSTALLINE ANODIC ALUMINA. CORRELATION OF REFORMATION CURVES AND ELECTRONOPTICAL DATA
STEVENS JL, SHAFFER JS , J. of Electrochemical Society 133 (1982) p. 1160

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J. S. Shaffer, H.A. Farach and C.P. Poole Physical Review B, 13, (1976) p.1869