InfluxGreen Energy Pte Ltd
1 Goldhill Plaza • #03-35/37 Podium Block
Singapore 308899
Tel: +65 3151 5993 • Fax: +65 3151 5893
www.influxgreen.com
sales.singapore@influxgreen.com

IGSM series micro inverters – Reliability Analysis Report

Summary

In the current PV industry, photovoltaic string inverters and central inverters have typical design life and warranty of about 5-10 years. However, in a solar system using photovoltaic panels, the typical design life and warranty of the photovoltaic panel is usually up to 25 years. Therefore, there has always been a mismatch in such an implementation that brought about the beginning of the micro inverters – whereby the product is designed to match the operational lifetime of the photovoltaic panels.

Component Design, Selection and Analysis of the Electrolytic Capacitors

One of the key component that is indispensible in the design of power conversion products is the capacitor. The capacitors component are required for energy storage and filtering in the electrical circuit design of the power conversion products and they come in various form – electrolytic capacitors, ceramic capacitors and metallized film capacitors. Each of these families of capacitors is unique in its own way and the design and reliability engineers will assess each typical operational mode and mechanism of failures with the objective to select the most suitable component technology to meet the specifications, cost, safety and reliability expectations of the power conversion product.

Electrolytic capacitors are used in the power conversion design due to its relatively high capacitance in volume ratio as compared to ceramic or film capacitors. The design uses a liquid electrolyte in the electrolytic and its volume will decrease over time due to evaporation and diffusion. The reduction of the liquid is also accelerated through different temperature environment. Typical failure modes are discussed below:-

1) Over-Voltage Failure
   Electrolytic capacitors are usually rated at different voltages – 63V, 100V, 315V, 450V etc. This is the upper limit and breaching (or nearing) this limit will cause current flow between the anode and cathode, producing heat and potential catastrophic failure.

2) Design life
   Capacitors have a finite design life. During normal working operation, the capacitors are subjected to charge and discharge cycles, and the drying out phenomena of the electrolytic is accelerated through temperatures.

3) High Ripple Current
   In the power conversion products, there will be continuous charge and discharge cycles. High ripple current will result in higher temperatures, thus leading to quicker losses of the electrolyte and failure.

4) Temperature Failure
   As highlighted from above, temperature is a very important parameter to all failures. The high temperature phenomena may be due to incorrect design or component used.

Therefore, in order for the InfluxGreen micro inverter to attain similar design lifetime objectives of the photovoltaic panels in a solar system implementation, the design and reliability engineers will ensure a design architecture that utilises the most reliable component available in the market, balancing the needs of the specifications, cost, safety and reliability.

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In the selection process of the electrolytic capacitors, the specifications of the capacitor, repute of the manufacturer as well as product standing in the industry are key considerations.

- EKY-630ELL222M (previous P/N: EKY-630ELL182MM40S) from Nippon Chemi-Con Corporation

The EKY-630ELL222M electrolytic capacitor from Nippon Chemi-Con Corporation is rated at 63V/2200uF. The capacitor has a life expectancy of 10,000 hours at an upper limit operating core temperature of 105^{o}C. It is designed with very low ESR (Equivalent Series Resistant) which helps to reduce heat dissipation exacerbated by high ripple current, a phenomena that accelerates ageing.

The design takes into consideration the tolerance and the parameters, such that when the IGSM-220 is at full output load, the ripple current is at 1.0A. This is only about 30% of the rated 3.5A of the capacitor specifications. This results in a heat energy generation of 0.07W. Such design architecture ensures that the capacitor does not generate excessive heat dissipation, which reduces the overall lifetime.

In regards to temperature, the accepted theoretical practice is that for every 10^{o}C reduction of working temperature, the working life is doubled. This is thus used to assess the maximum life of the capacitors designed in the micro inverters, and the data which will be supported by the actual unit working in a realistic environment.

At a continuous maximum ambient operating temperature of 50^{o}C, our engineers measured and determined that the aluminium capacitors used has a case temperature of not more than 65^{o}C. We understood that the internal core temperature of the aluminium electrolytic capacitor is typical rated at 5^{o}C above the case temperature, and with this, we can deduce the working life of the capacitor based on the core temperature of 70^{o}C (at ambient of 50^{o}C, with a case temperature of 65^{o}C and a typical deduced core temperature of 70^{o}C). Using the formula, working life of the aluminium electrolytic capacitor = 10,000 hr x $2^{(105-70)/10}$ = 113,137 hrs.

This implies an expected working life of up to 12.9 years (24-hr day). However, the micro inverter does not operate > 12 hours per day and this effectively double the number of years of operation to 25.8 years. In actual operation, the micro inverter only works about 6-8 hours per day on average and therefore, we can safely conclude that the aluminium electrolytic capacitor can achieve an expected working life in excess of 30 years based on the above working parameters.

Managing Risks and other key tests for Reliability

Electrolytic capacitors are just but one of the many key component that affects the overall operating life of the micro inverter. Even the range of low-risk capacitor such as the film and ceramic capacitors are subjected to voltage, power and temperature stresses, and these can also lead to premature failure if design considerations are not done extensively. Therefore, there is a need for electrical and thermal de-rating to manage such risks.

Some other materials such as solder and printed circuit boards (PCBs) will always be present in the power conversion products, and they also exhibit their own unique wear-out mechanisms. Other component such as the Magnetics and FETs, also have their specific design considerations to be taken care of.

Although it is important that the design process has to ensure that component selection and the various technical design architecture employed are fitting to meet the specifications as well as lifetime objectives, there is also a need to include a variety of accelerated tests at the assembly level to confirm that failure mechanisms were not missed during the design review process.

Reliability engineers also used the bathtub curves, which describe the hazard functions of the product life cycle, to ensure lone term reliability of the product life cycle.

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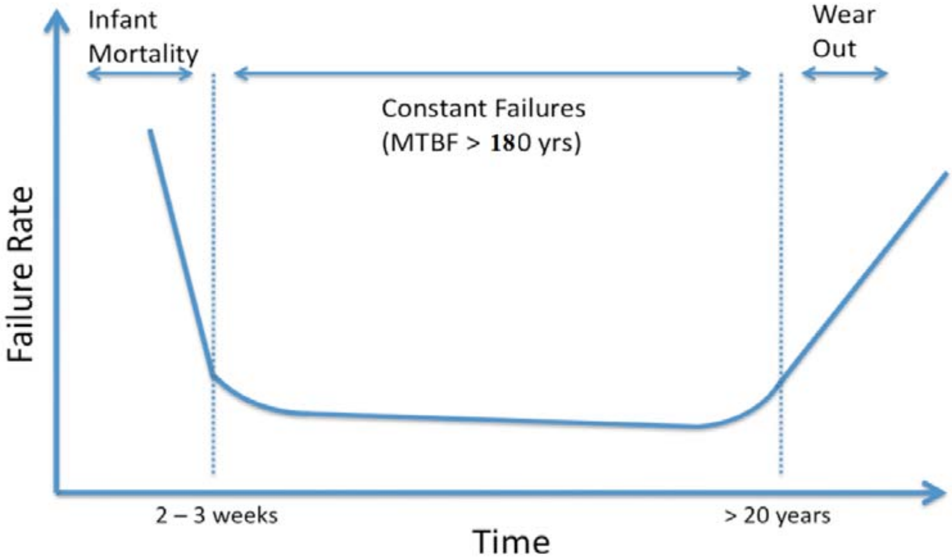

Figure 1: Bathtub curve of the IGSM series micro inverter

The first part of the curve is the "Early Infant Mortality Rate", followed by the "Constant Failure Rate" and the "Wear-out Failure Rate".

Every single InfluxGreen micro inverter that is manufactured out from the production line will be subjected to a high temperature ageing with the objective to filter out the units that have not complied with the required specifications. At the same time, the defective products are identified and analyzed with the objective to prevent potential failure.

As highlighted earlier, the selection of component, circuit topologies and types of technology architecture are conducted with due diligence to ensure the correct specifications and operating lifetime objectives. The key steps are detailed below:-

1) Electrolytic capacitors – choice of electrolytic capacitors from reputed manufacturer(s) where the typical design life and specifications are suited to meet the working conditions and life of the micro inverters.
2) In the selection of other core component and Magnetics, high insulation resistant and high temperature resistant are key considerations.
3) Power FETs shall be selected according to repute of manufacturer(s), and the critical specifications such as voltage and current, both in normal and extreme working conditions.
4) Similarly to the electrolytic capacitors, ceramic capacitors are selected based on the design life, and its electrical specifications, especially the effect of temperature.
5) The entire PCBs are encapsulated to provide complete insulation in order to couple the good electrical properties with excellent mechanical protection. This level of protection that is achieved through the mass of the resin surrounding the PCB unit shall effectively protect the unit against environmental conditions such as humidity, dust and vibration.

Reliability tests form a final vital piece of puzzle to the overall product design cycle. Although such tests cannot be based on the actual real-world electrical and environmental parameters, they form a key aspect in the overall product design cycle. Accelerated tests and simulations are made against expected electrical and environmental parameters in order to make it as real-life as possible.

1) Accelerated life test – Units are subjected to simulated working operation of a high temperature to determine the theoretical extended life of the micro inverters.
2) Operating temperature tests – To ensure that the units work within the specifications as per technical requirements.
3) Ingress Protection tests – To ensure that the rated IP65 units operate within the specifications, which allows for full outdoor applications.
4) Endurance life test – Units are subjected to a set temperature in a controlled environment to simulate actual working ambient temperature. For this test, there are currently 3 units of micro inverters installed within the controlled temperature environment of 50^{o}C and they have been in continuous full load operation since Oct 2012. This temperature reliability tests will continue indefinitely and the data are recorded accordingly.
5) Real-world life test – At present, a total of 9kW solar system using the micro inverters (c/w 44 PV modules) has been set up in the rooftop of the factory to simulate real-world operation. The initial 1.6kW has been in operation since Oct 2012, and this is followed by a subsequent 1.2kW in Jan 2013. The remaining 6.2kW will be implemented before end of Feb 2013. All data recorded (including temperature and energy harvesting capacity) shall provide important feedback on the units' design specifications against actual working environment as well as the long term reliability of the products. Issues that surfaced can also be quickly reviewed and resolved accordingly.
6) Field feedback mechanism – Actual feedback from customers will be recorded and form part of the reliability database that help to ensure continuous improvement of the product and process.

InfluxGreen also advocates long term stability and quality assurance, both in the management of the logistics and manufacturing systems. These shall include, but not limited to the following:-

1) Vendor management and control mechanism
2) Incoming quality mechanism
3) Stringent product process control
4) Various stages of tests for semi-finished products during assembly
5) 100% ageing tests of finished products
6) 100% final inspection

Conclusion

The potential for photovoltaic system solutions to greatly expand the energy market is compelling but they must still be balanced by an understanding of the reliability issues at stake. To realize the full advantages of photovoltaic modules, micro inverters must be designed for its reliability in order to pair and match the working life. Component selection, circuit topologies and design architecture must be complemented such that the product designed can withstand the harsh environmental operations.

The design and reliability engineers have taken all necessary considerations, evaluating the hardware design, component selection, simulated and real-world reliability testing, production quality process and control and other aspects of analysis (including field feedback), and all these are aim at producing a micro inverter that is able to meet the lifetime objectives.

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Appendix

A study of the electrolytic capacitor used our InfluxGreen micro inverter as compared to the electrolytic capacitor used in a string PV inverter of a reputable manufacturer.

	IGSM-220	String PV inverter
Capacitor model	EKY-630ELL222M	EKMQ3B1VSN102M
Manufacturer	NCC	NCC
Rated Maximum Voltage (V)	333	315V
Rated Capacitance (uF)	2200	1000
Rated Highest Temperature (^{o}C)	105	105
Rated Ripple Current (A)	3.5	2.3
Rated Design Life (hrs)	10,000	2,000
Loss Angle Tangent	0.11	0.15

NCC (Black diamond) electrolytic capacitor are used in both products. Due to the topological structure, the capacitance will probably be different. It is also observed that the ripple current, voltage, specified life and the loss impedance angle are more superior for the EKY-630ELL222M capacitor.

Ripple Current Calculation
IGSM-220 has a rated input voltage of 36V and power of 220W. With 4 electrolytic capacitor used, each EKY-630ELL222M is subjected to a ripple current @ 220/36/1.414/4=1.08A. This is 31% of rated value.

Stirng inverter as an input voltage of 300Vand power of 2700W. Based on calcuation, each EKMQ3B1VSN102M is subjected to a ripple current @ 2700/300/1.414/5=1.27A. This is about 55% of rated value.

ESR and Power Consumption Calculation

IGSM-200: EKY-630ELL222M ESR @ 0.11/(2*3.14*120*2200*0.000001) = 0.066 Ohm
Power consumption @ 0.066*1.08*1.08=0.076 W

SB2500: EKMQ3B1VSN102M ESR @ 0.15/(2*3.14*120*1000*0.000001）= 0.199 Ohm
Power consumption @ 0.199*1.27*1.27=0.32 W

Mechanical Protection
For IGSM-220, the PCB adopts silicon plotting for complete encapsulation, whereas the string PV inverter uses apron and waterproof protection technique.

Data Evaluation and Conclusion
EKY-630ELL222M is subjected to a lower ripple current as compared to EKMQ3B1VSN102M. This also results in lower power consumption.

In addition, just by comparing the rated design life of the capacitors within the rated operating conditions, EKY-630ELL222M capacitor is rated at 5 times more than EKMQ3B1VSN102M capacitor. Coupled this observation with the lower ripple current and power consumption, we can safely infer that the working life is at least 5 times higher.

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