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Realistic climatic profiles and their effect on condensation in encapsulated test structures representing power modules

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ABSTRACT

During the last years applications for power modules with harsh environmental conditions have gained increasing importance. Extreme combinations of environmental conditions especially at weak load conditions have to be understood to avoid risks induced by humidity condensation. The present work investigates the influence of different cycling profiles on condensation phenomena. The phase within the cycling profile that is liable for condensation can be identified and the risk for long term build-up of humidity inside a package is studied in outdoor measurements.

1. Motivation

Applications for power electronic modules with harsh environmental conditions are gaining increasing importance. Extreme combinations of environmental conditions especially at weak load conditions can lead to agglomeration of humidity inside inverters that may even cause condensation. Examples are found in applications during long term off the grid mode or under rapidly changing ambient conditions. In wind turbine applications power electronic modules may suffer stronger from environmental impact compared to thermomechanical loading [1]. It is necessary to understand the physical processes inside power modules including the direct chip environment to apply life time modelling for these conditions. Furthermore an empirical study is needed to check the applicability of hygro-thermal simulations of complex converter designs such as mentioned by [2].

Cycles with high ambient temperature gradients were already investigated by the authors [3]. The step functions of the temperature leading to high spatial gradients are suspected to be the reasons for the occurring condensation effects which are observed only on those surfaces that cool down fastest when ambient temperature T_a steps down or heat up retarded when T_a steps up. In the present work the influence of the temperature gradient up to conditions that are comparable to realistic day/night cycles is investigated.

2. Repetitive cycling with day/night frequency and effect on condensation phenomena

2.1. Natural boundary conditions for T/RH-profile generation

To find a general profile representing an environment that is typical for warm damp equable climate according to IEC 60721-2-1 [4], temperature and humidity data of 3 specific locations (2 of the location representing central and east china, 1 representing south India) are statistically evaluated. For this purpose climatic data with a resolution 1/h for at least 3 consecutive years are used. All profiles show similar behaviour allowing to extract a typical model profile. Fig. 1 shows a characteristic variation of temperature (T), relative humidity (RH) and absolute humidity (cabs): cabs over a one day cycle is roughly constant but T and RH are varying.

To identify conditions that are most promising to trigger condensation the absolute humidity level and the corresponding daily temperature change ΔT are further analysed. The correlation of both parameters for two locations (East China and India coastal region) is shown in Fig. 2. The data is clustered by seasons. One obvious conclusion is that for the chosen region c_{abs} is limited at ~29 g/m^3 (99% limit).

Temperature changes ΔT/day above 12 K only occur in combination with lower c_{abs} which can be explained by assuming that a high amount of humidity acts as heat capacity and dampens the possible temperature change. The dashed straight line in the right half of Fig. 2 indicates this correlation and encompasses 99% of the data points.

The worst case combination regarding both high absolute humidity and high temperature change is given by the edge of the

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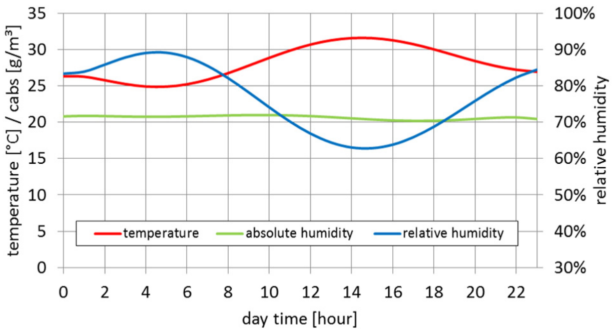

Fig. 1. Typical T, RH and c_{abs} profiles for a location characteristic for warm damp equable climate.

aforementioned 99%-limits in Fig. 2 (point E), resulting in c_{abs} ~29 g/m^3 and ΔT/d = 11,5 K/d. These boundary conditions are used for designing the following experiments.

2.2. Test setup and measurement configuration

Fig. 3 shows the schematic of the used test setup. The sensor positions for measurement of (RH, T) and condensation is shown. Additionally a sensor below the enclosure is placed inside the chamber (RH_{ch}, T_{ch}: not shown). A metal enclosure is used to suppress disturbances of the RH-profile of the climatic chamber occurring during steep temperature gradients due to the control mechanism of the chamber. Furthermore the enclosure represents the converter housing including the power semiconductor module. Sensors for the measurement of RH, T as well as for condensation are mounted as depicted schematically. Details of the test methodology are described in [3].

2.3. Results for simulated worst case day/night profiles

Special care is taken at designing the test profiles (T_{ch}; RH_{ch}) as functions of time. As starting point for repetitive cycling the upper temperature limit is calculated to reach c_{abs} = 29 g/m^3 to meet the worst case condition described in Fig. 2. RH = 85% is used to ensure that the test chamber stays in a regime of good controllability of (RH, T). Hence the desired c_{abs} is reached at a temperature $T_{ch} = T_{ch.max}$ = 32,5 °C. From this condition onward the cycling by ΔT = 11,5 K/day is performed. The exact slope of T = f(t) is deduced by approximating the realistic profiles for typical conditions shown in Fig. 1. Under these conditions the dew point is reached at 29,4 °C.

A precondition phase of 48 h duration with T_{ch} = 32,5 °C and RH = 85% is applied until all sensors are in equilibrium. By this procedure a

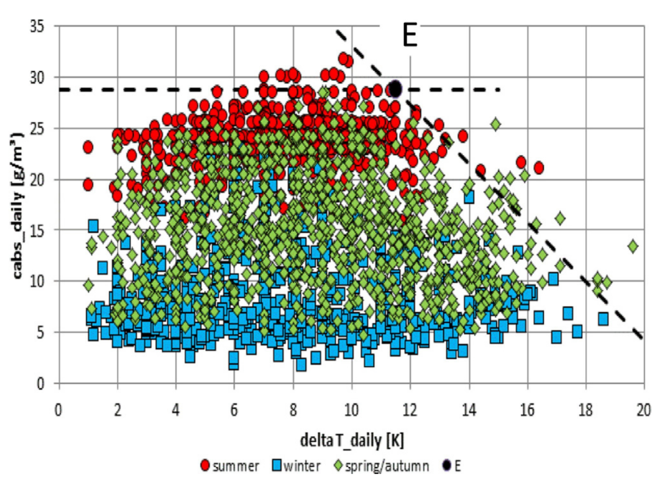

Fig. 2. $Cabs_{max,daily}$ = f ($deltaT_{daily}$).

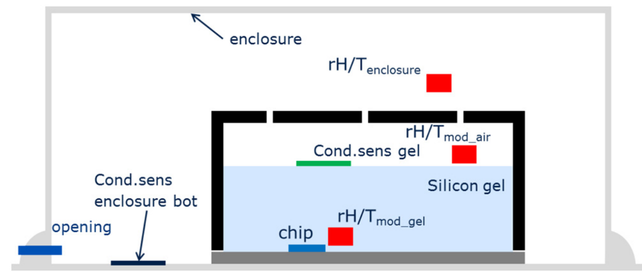

Fig. 3. Schematic of test setup inside the enclosure.

continuous absolute humidity increase driven by balancing of c_{abs} between inside and outside the enclosure as observed in [6] is avoided. Thereafter five cycles are applied each with 24 h period.

The RH/T-response inside of the enclosure is displayed in Fig. 5 showing the cyclic behaviour of temperature and humidity for the different measurement points outlined in Fig. 3. The measured temperatures show fairly synchronous variation with no systematic shift between all measurement points inside the enclosure. On the other hand RH is behaving quite differently: RH_{ch} shows small (~2%) and decreasing fluctuations around the target value RH = 85% which indicates that the control mechanism is too slow to keep it completely stable. The RH sensors inside the enclosure exhibit a far stronger excursion by ~±9% which proofs that the absolute humidity is captured inside the enclosure and RH oscillates in a complementary way compared to T. But RH = 100% is not reached although the dew point at 29,4 °C is underrun and the calculated absolute humidity c_{abs} inside of the enclosure is not constant but decreases during the cooling phases. This phenomenon can be explained by condensation at the enclosure walls transferring humidity from vapour into liquid phase.

Indeed the condensation sensor at the enclosure wall is indicating condensation during the temperature fall proving that water molecules are adsorbed at the cooled inner walls of the enclosure. The fact that the absolute humidity inside of the enclosure c_{abs_encl} drops down and never reaches the starting value (indicated by the dashed blue line of Fig. 5) confirms this observation.

On the other hand the condensation sensor inside of the module doesn't exhibit condensation which can be explained by assuming a retarded cooling of the gel surface compared to the metal enclosure walls. Basically the same mechanism as described in [3] for step like cycles also acts in favour of the gel surface for realistic cycles.

Compared to the phenomena observed for 24 h cycling, the step like temperature change investigated in [3] leads to a stronger condensation at the enclosure wall and in addition to condensation on the Si gel during warm-up of the climatic chamber (Fig. 4). Therefore in the next step the speed of the temperature transient is raised by performing cycling within 6 h. The results for the cycles with reduced cycling time to 6 h are shown in Fig. 6.

A comparison against the data recorded in Fig. 5 for 24 h cycling leads to the following conclusions: Both temperature and absolute humidity for the measurement points inside of the enclosure and also

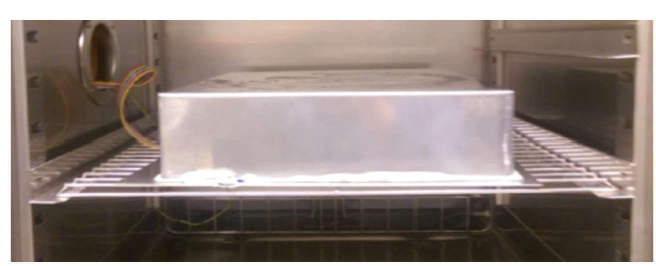

Fig. 4. Enclosure setup inside the climatic chamber.

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