Mission Profile of NH – Fuses for PV Inverter Applications

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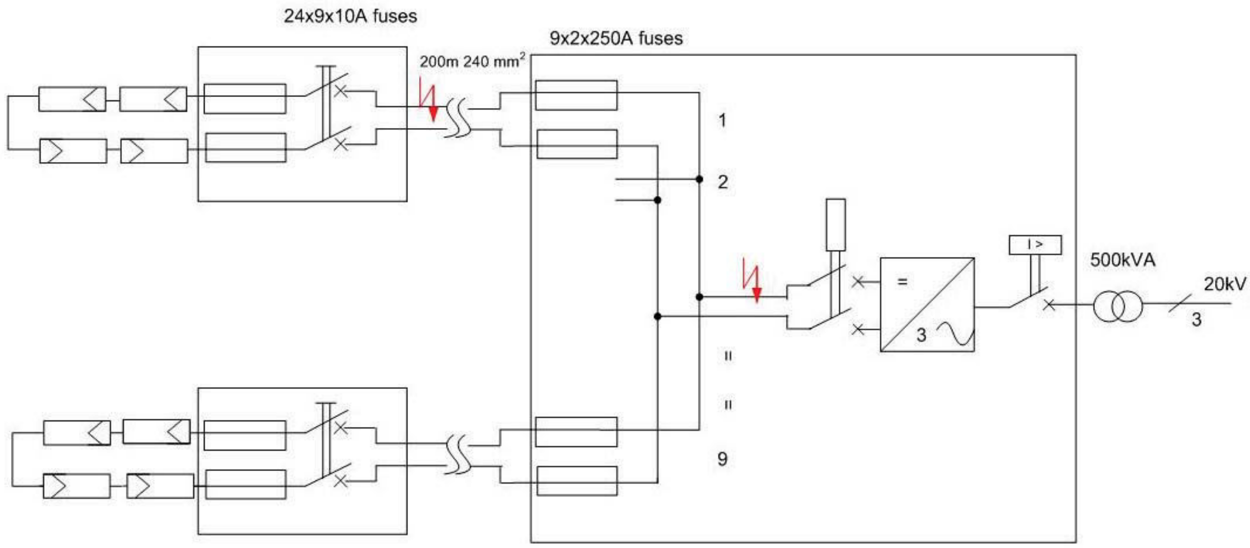
Keywords: fuse coordination, photovoltaic fuses

The Purpose of the NH – Fuse
The NH fuse protects the feeding cable against overcurrent.

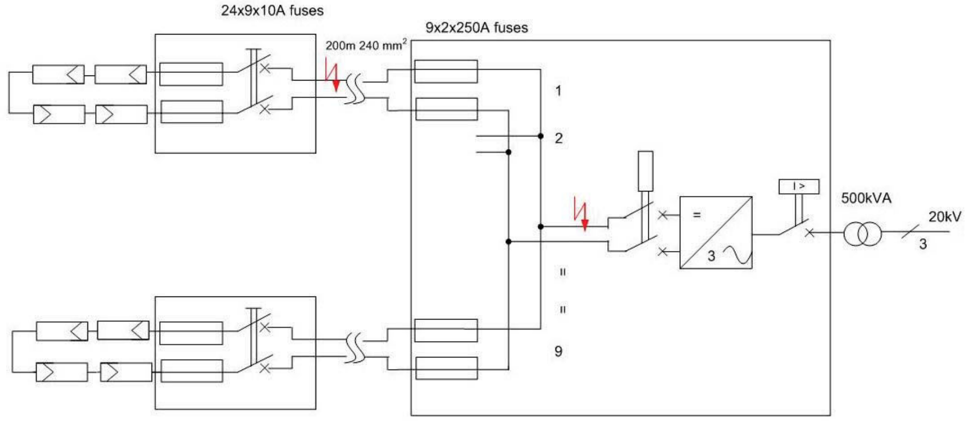


Engineering Standard Requirements

- Design guidelines and recommendations for photovoltaic arrays „IEC/TS 62548“.
- This standard defines:
  Current and short-circuit current Cable cross-section protection requirements
- This standard does not distinguish between PV module protection and feeding cable protection.
- This standard refers to IEC 60269-6. This describes the fuse.
- The NEC2014 article 690.9 (C) describes more or less the same way.
- IEC or NEC does not distinguish between PV module protection and feeding cable protection. The result is a very fast and nervous NH fuse to protect a cable.

Protection Limits of Fuse

The fuse is no arc protection.



For understanding:

A short circuit in the Inverter is possible. Stop the Inverter, generate a hart short. The Standard IEC/TS 62548 give 20% thermal reserve for the cable.

The Market

- A 500 MW solar power station needs approx. 1,000 inverter.
- Every inverter has between 6 … 18 NH3 fuses.
- SMA has delivered approx.150,000 NH3 PV fuses in inverters.
- This is approx. 30% of the market.

Picture from google earth position 35°23‘40“N 120°3‘25“W

The Cost

- This typical solar installation needs an area of 150 m x 170m around the converter in the desert.
- The collected DC – current in this area is 1,200A.
- The converter in the center collects the PV current via nine feeder cables.
- Every cable is protected by 250 A fuses in the + and – line.
- This provides133 A in every 250 A fuse.
- The 250 A fuse must be reduced by 53% to achieve 133A.
- The wire cross-section is designed for 250A.
- A better reduction factor, like 70%, reduces the cable cost.

Cost – Reduction Factor – Temperature

- PV systems and their fuses are designed for 20 years lifetime.
- The maximum temperature at the tin point should never exceed 140°C.
- Details are under construction rules.
- The fuse standards do not specify how to achieve a good temperature reduction factor.

$$\vartheta_{fuse\ element} = R_{thermal} * I^2 * R + \vartheta_{ambient}$$

$$\frac{\vartheta_{fuse\ element} - \vartheta_{1ambient}}{I_1^2 * R} = R_{thermal} = \frac{\vartheta_{fuse\ element} - \vartheta_{2ambient}}{I_2^2 * R}$$

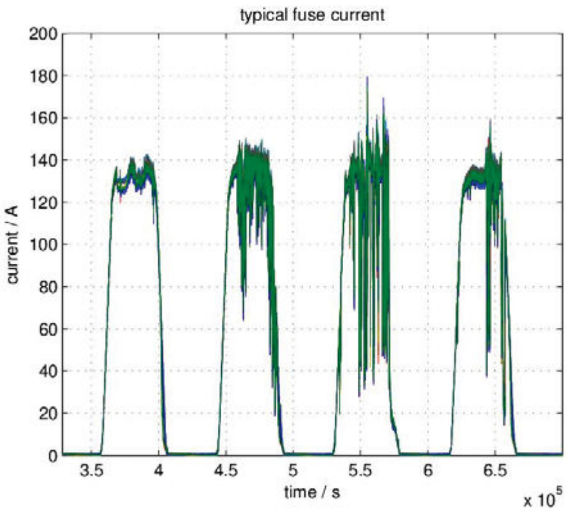
$$I_2 = \sqrt{\frac{\vartheta_{fuse\ element} - \vartheta_{2ambient}}{\vartheta_{fuse\ element} - \vartheta_{1ambient}}} * I_1$$

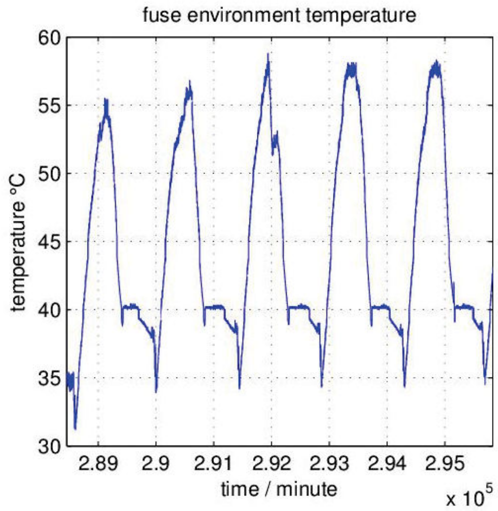
$\vartheta_{fuse\ element} = 140\ °C$
$\vartheta_{2\ ambient} = 60°\text{C}\ ambient$ temperature
$\vartheta_{1\ ambient} = 20°\text{C}\ test\ condition\ of\ gPV - norm$

For this example, the temperature reduction factor is approx. 0.8.

Cost – Reduction Factor – Alternating Load

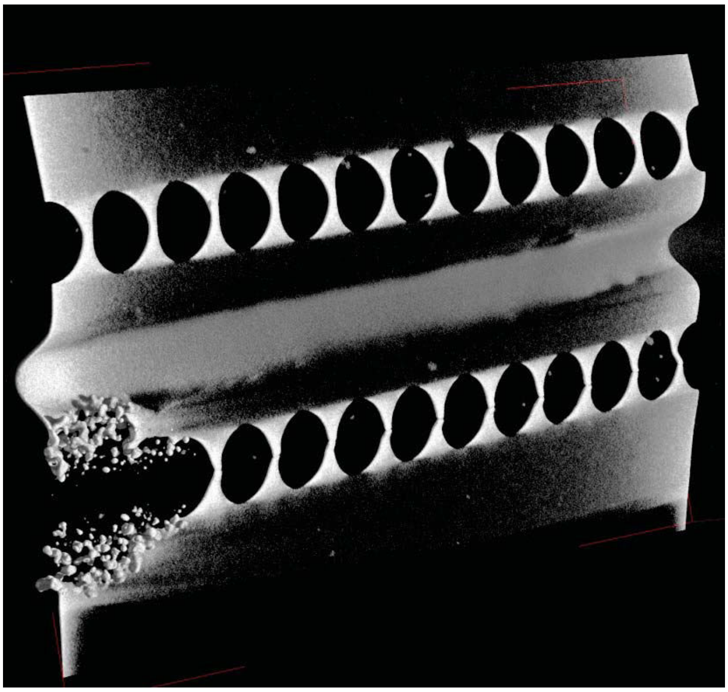
- The alternating load is a result of moving clouds and environmental temperature changes.
- This results in mechanical stress / alternating load cracks at the fuse element.
- Typical for a alternating load failure is, when the fuse trigger at the morning during the sunrise.
- Some vendors need a reduction factor of 0.7 to 0.8 for an alternating load.





Cost – Reduction Factor – Alternating Load

- Example: alternating load cracks.
- Ten bottlenecks are broken.
- The remaining ones destroyed by an arc.

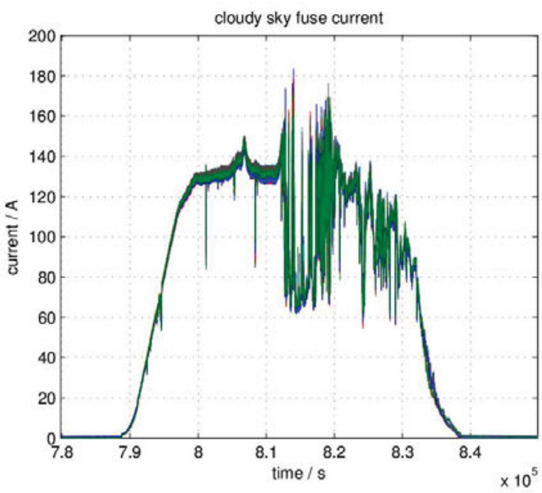


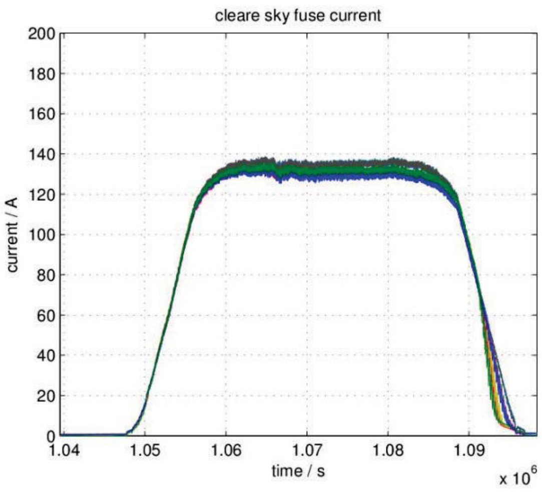
Cost – Reduction Factor – Alternating Load

- The day and night cycles and moving clouds change the fuse current.
- This results in mechanical stress to the fuse element.
- This stress during 20 years lifetime can be described as follows:
  150,000 cycles with 10% nominal current
  75,000 cycles with 10 to 40% nominal current
  25,000 cycles with more than 40% nominal current
  The cycle time is in a range > 15 minutes
- These values are the result of one-year current recording with one measurement per second at 10 converter and nine fuses each.
- The Standard 60269-6 describes a test with 3,000 cycles with10 second cycle time.

Cost – Reduction Factor – Current Peak

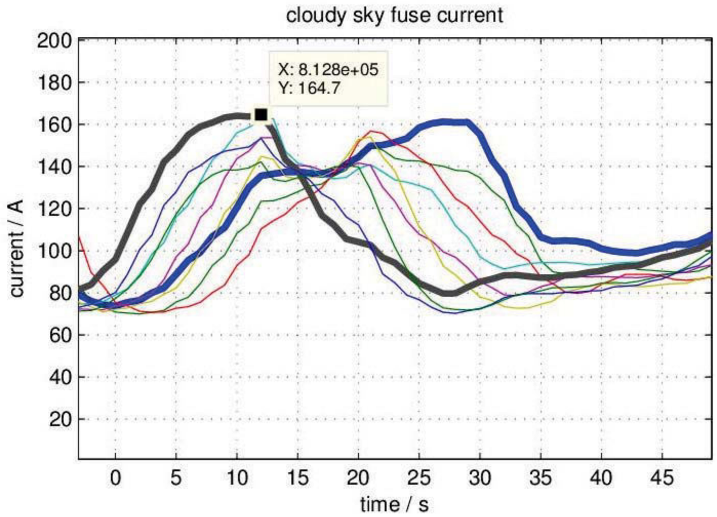
A cloud is like a mirror. It reflects the sun light and increases fuse current to up to 150%.
A shaded PV module is colder by 30… 50°C, resulting in a higher module voltage.





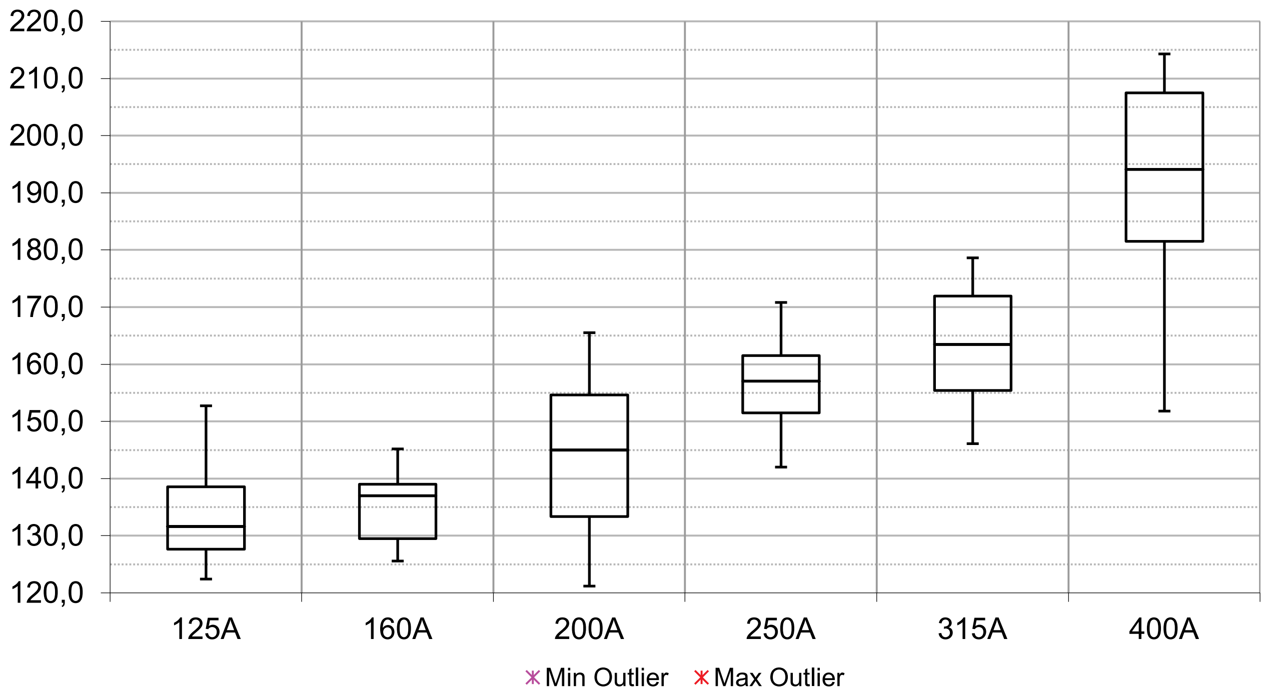
Cost – Reduction Factor – Current Peak

- The current peak time depends on the cloud speed.
- The time of a peak ranges from a few seconds to several minutes.



Cost – Reduction Factor – Production Variance

- Medium fuse element temperature at 90% nominal current.
- The coldest 400A fuse tolerates 350A.
- The hot 400A fuse with 215°C tolerates 280A.
- The reference point for this current is 140°C at the tin depot.
- This variation of fuse element temperature needs a reduction factor of 0.7.
- The standard IEC 60269-6 does not consider a variation of the production or the fuse element temperature.



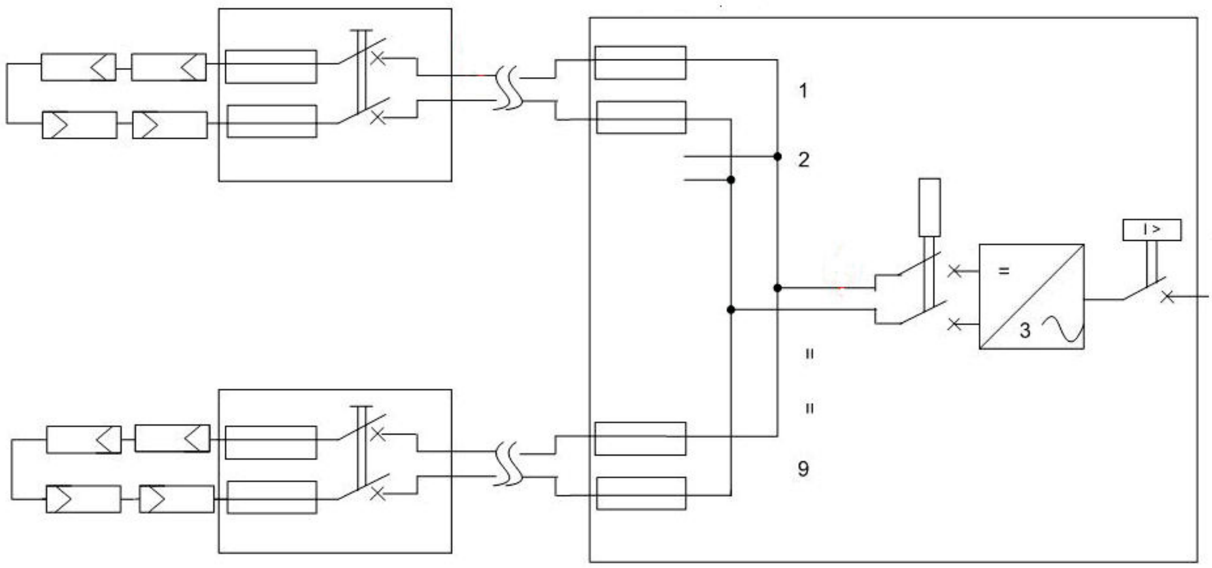
Cost – A Total Reduction Factor

- Reduction factor – temperature = 0.8
- Reduction factor – alternating load = 0.7
- Reduction factor – current peak = 0.7
- Reduction factor – production variance = 0.7
- This results in a total reduction factor of 0.3.
  A nominal current of 110 A need a 400A fuse with a 400A cable.

A total reduction factor of 0.7 is the target for a profitable PV installation

Reliability – Indicator / Flap

- As much as 5% of fuses die / year without a short circuit. (depend of fuse construction).
- A broken NH fuse results in 100 to 200 $ / day loss.
- The operator identifies at a clear day a defective fuse with a reduced power generation.
- The indicator flap is needed to identify the defective fuse within the inverter.
- The indicator flap has to work with a low-voltage difference over a tripped fuse.
- The voltage difference between open circuit voltage and working circuit voltage is sometimes in a range of 20V.



Rules of Construction – Diffusion

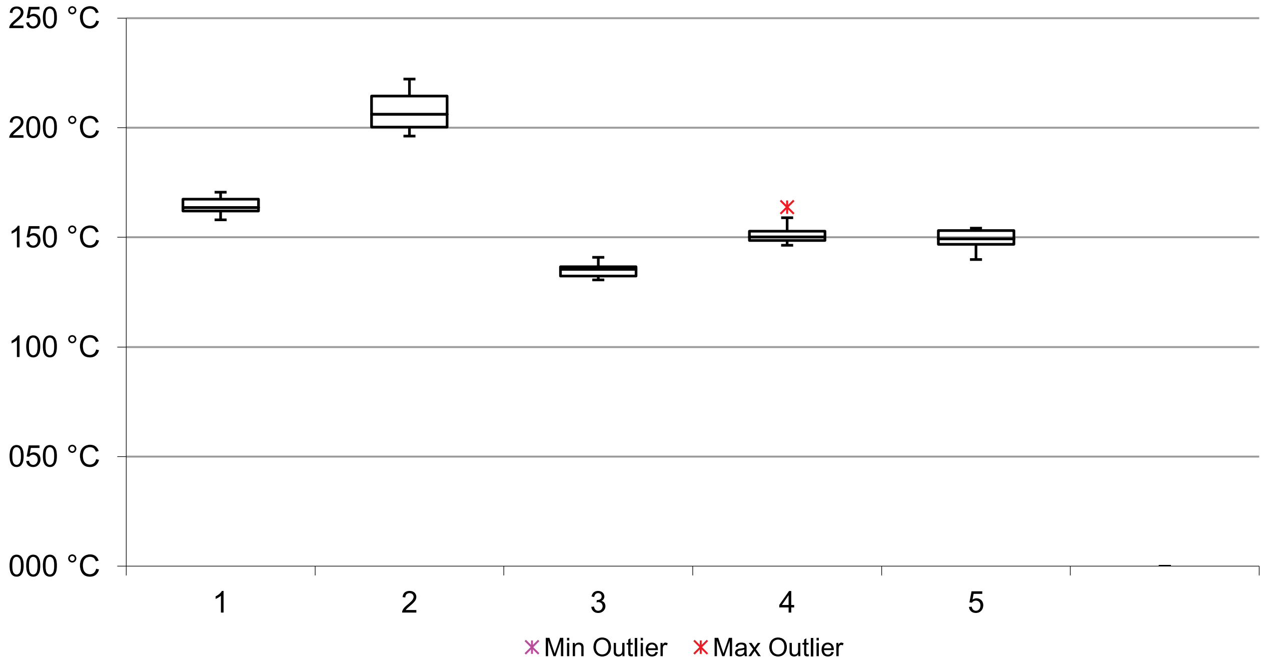
- When analyzing open fuses from the field. We mostly saw the picture below.
- The tin has dissolved the silver.

- The table below is from J.E. Daalder Eindhoven University of Technology.
- The fuse element is 200 µm thick.
- More then 20 % diffusion change the time current characteristic.
  40 µm diffusion during 20 years lifetime is tolerable.
- The temperature at the tin should stay under 140°C.
- For a detailed description see: "Reactive Diffusion between Ag and Sn at Solid State Temperature"
  Japan Institute of Metals 2005 Material Transactions, Volume 46, No 5 pp.969 to 973

Table 1. Times for transformation of 50/100 µm thick silver ribbons into Ag_3Sn.

Temperature [°C]	Transformation times 50 µm	100 µm
250	5 hrs	20 hrs
225	2.8 days	11 days
210	100 days	1.1 years
170	4.3 years	17 years
140	9.9 years	39 years
100	23.8 years	

Rules of Construction – Temperature
400A fuse from five vendors around the world.
This isn't the temperature in the tin depot. This is the medium temperature of the fuse element.



Conclusion
- The PV industry needs a lot of NH fuses.
- The cost of PV field cabling depends on the fuse.
- The cost of ownership depends on the fuse.
- The PV industry needs a fuse with the precision of a microcontroller.
- The mission of a NH – PV fuse isn't the mission of a string fuse.
  The string fuse protects the module.
  The NH-PV fuse protects the cable.

References

- [1] J.E. Daalder Eindhoven University of Technology
- SMA internal test results

Conference: 10th International Conference on Electric Fuses and their Applications

Organized by: Dresden University of Technology
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September, 2015